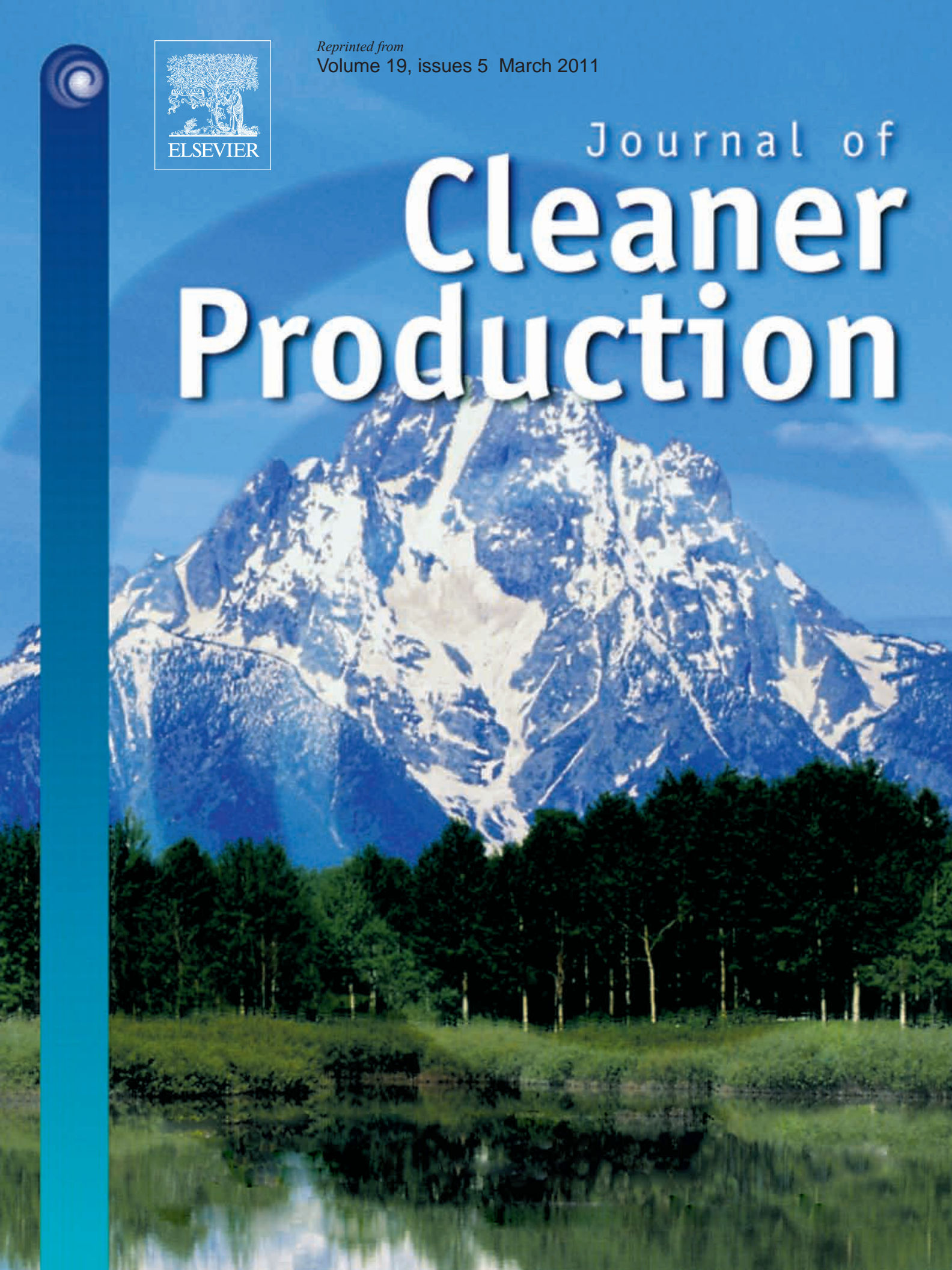


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SPECIAL ISSUE

**Improving the Health of the Public, Workers and the Environment:
Twenty Years of Toxics Use Reduction**

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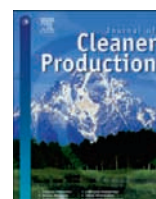
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At the source: the origins of the Massachusetts toxics use reduction program and an overview of this special issue

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ABSTRACT

This special edition of the Journal of Cleaner Production celebrates the twentieth anniversary of a piece of legislation that has special significance to the environmental movement – the Massachusetts Toxics Use Reduction Act of 1989 (TURA). Most of the papers in this issue were presented at a symposium to commemorate the twentieth anniversary that was held on November 4, 2009.

Much has been written about the Massachusetts Toxics Use Reduction Program. It has been heralded as a major pollution prevention success story. It has been lauded as a premier American example of the precautionary principle in action. It has been condemned by the American chemical industry trade association as “bad for the chemical industry”. And it has been praised by the Ford Foundation and Harvard’s Kennedy School of Government as an award-receiving example of innovation in government (Harvard Kennedy School, 2005).

Looking back now to some twenty years ago—back to the early origins of the program concept—it can be seen both as a landmark breakthrough in international chemicals policy, and as a fairly conventional next step in the political evolution of Massachusetts environmental policy.

Where did this idea come from? How did it develop? How were pieces put together? Why did Massachusetts adopt such an idea into law? And how did the idea change during the early years of implementation? This paper provides a brief history of the development of the concept of toxics use reduction and the process by which it was drafted into law in Massachusetts, followed by an introduction to the articles included in this special edition and their assessment of TURA – past, present, and future.

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1. Introduction

This special edition of the Journal of Cleaner Production celebrates the twentieth anniversary of a piece of legislation that has special significance to the environmental movement – the Massachusetts Toxics Use Reduction Act of 1989 (TURA). Most of the papers in this issue were presented at a symposium to commemorate the twentieth anniversary that was held on November 4, 2009.

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2. State chemical policy making

The 1980s were an active period for environmental advocacy in Massachusetts. Following the revelation of chemical contamination

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in the drinking water at Woburn in 1979, a series of alarming investigations by town officials closed drinking water supplies in some forty communities across Massachusetts. Poorly managed and abandoned hazardous waste sites were appearing throughout the Commonwealth in communities such as Lowell, Acton, Tyngsborough, Braintree, New Bedford and Mashpee (MDEQE, 1981). The official state response to these rising concerns was a major push for the siting of a hazardous waste treatment facility to treat these wastes (Langner, 1980).

However, siting such a facility proved difficult because of public concern about the dangers of hazardous waste treatment. In 1980, a new state law established an innovative process for bringing waste plant developers and town officials together to negotiate terms for siting such facilities (Provost, 1982). However, the process only further excited the popular resistance to such facilities and led to the building of a statewide network of community activists dedicated to blocking the development of hazard waste treatment facilities in Massachusetts (Ackerman, 1983).

Occupational chemical exposure was on the agenda as well. A campaign by a broad coalition of trade unions emerged in 1982 to press for enactment of a workplace “right to know” statute to provide workers with information about the chemical hazards they were exposed to at work. In order to broaden the coalition to include community activists, the Massachusetts AFL-CIO’s so-called “Solidarity Coalition” added a community right to know provision to the bill as well (Dumanoski, 1983) and, in 1983, the bill was passed into law in the form of the Massachusetts Right to Know Act. Only a few months after passage of the Massachusetts Right to Know law, the federal Occupational Safety and Health Administration (OSHA) Hazard Communication Standard preempted the private sector portions of the statute (MEOLWD, 2010). Nonetheless, the Solidarity Coalition left in place a seasoned institutional structure that was capable of passing legislation.

2.1. *Conceiving of toxics use reduction*

Context and motivation are important to social innovation. It takes a promising situation with the right players in the right place, and it takes a clear problem in need of a good solution. However, without leadership—both individual leadership and organizational capacity—good opportunities can evaporate. The mid 1980s spawned a collection of exceptionally talented environmental leaders, many of them based in Massachusetts. Activists combined the local base of the citizen action movement’s Massachusetts Fair Share with the national resources of Clean Water Action to form the National Toxics Campaign (Sirianni and Friedland, 2001). Trade union activists at the Massachusetts Coalition for Occupational Safety and Health (MassCOSH) and environmental activists at the college campus-based Massachusetts Public Interest Research Group (MassPIRG) began to expand their organizations’ advocacy into occupational and environmental health protection. Meanwhile, in the public sector, officials at the Massachusetts Executive Office of Environmental Affairs and the Department of Environmental Protection were promoting source reduction and pollution prevention initiatives in their agencies.

The Massachusetts environmental advocates had a vision. They believed that people could be mobilized around health concerns in their local communities and out of those local communities a multi-class movement could be built focused on hazardous waste clean-up that could become a real force for social change. They sought a strategy that would move the old Solidarity Coalition from “right to know” to “right to act”. Knowledge about toxic chemicals was not enough. People needed a program to reduce or eliminate the toxic chemicals they were exposed to.

The advocates were joined by faculty from the universities and together they saw that a focus on eliminating the toxic chemicals used in production would reduce the generation of hazardous waste, and, thereby eliminate the need for a hazardous waste treatment facility. The term “toxics use reduction” conceptualized the idea well and the advocates began building a strong argument for it.

It soon became apparent that only MassPIRG had the necessary political muscle to build a statewide legislative campaign. MassPIRG had credibility in the legislature and a statewide canvassing operation that could mobilize a grass roots base. In 1986, MassPIRG had bypassed the legislature and organized a highly successful ballot initiative campaign that set timetables and standards for the clean-up of hazardous waste sites. Their leadership decided to turn the TUR concept into a campaign for new legislation.

The last player needed was a legislature leader. Here, MassPIRG turned to Geoff Beckwith, a freshman representative who represented a middle-income Boston suburb. Beckwith joined with MassPIRG and together they converted the TUR concept into a bill.

2.2. *The campaign to enact a law*

The TUR bill was first introduced into the legislature by Beckwith in 1987. Beckwith moved the bill to a House hearing, but, even with the MassPIRG endorsement, it never made it out of committee. MassPIRG broadened the coalition for a second try in 1988. This was a rewritten bill more carefully structured by Beckwith, but full of small add-on sections designed to build the coalition. A worker sign-off had been added to address the concerns of MassCOSH and the trade unions. A state authority to ban hazardous chemical use had been added to be consistent with the National Toxics Campaign. A section on facility planning and a university-based research center, were inserted and MassPIRG added a section on annual chemical use reporting.

The 1988 legislative session proved more conducive and the new bill made it through a vote in the House, but now there was strong business opposition and the bill died for lack of Senate attention. However, defeat proved propitious. By now the bill was being taken seriously by the state’s leadership. Recognizing the threat of the TUR bill’s passage, the new director of the Associated Industries of Massachusetts (AIM) decided to adopt a more positive strategy. Over the fall, AIM wrote its own “Hazardous Materials and Waste Elimination” bill to advocate as an alternative to the TUR bill. The AIM bill included waste reduction incentives, a state technical assistance office and state authority to site a hazardous waste treatment facility. The state environmental agencies were now mobilizing and offering new ideas on implementation. In addition, MassPIRG was not quiet about the possibility of a new ballot initiative campaign on toxics use reduction.

The Speaker of the House, decided to move toward a resolution. He asked Beckwith to sit down and negotiate with AIM and the business community and come up with a consensus bill, which he would advocate for passage. Beckwith took up the challenge.

2.3. *Negotiation and further negotiation*

Beckwith and MassPIRG drew up a proposal for the negotiations. There would be two sides made up of an equal number of representatives and each group would be accountable to a broader range of stakeholder organizations. They would meet to consider both the TUR bill and AIM’s waste elimination bill. They would convene at the beginning of 1989 and negotiate until the summer. The state agencies could sit in on the negotiations as observers and offer technical and implementation advice.

Meanwhile, Beckwith developed a proposal to site the research center, now called the Toxics Use Reduction Institute, at the University of Lowell. Finally, negotiations began in earnest in January 1989. Beckwith chose five stakeholders—three from MassPIRG and two from universities. AIM selected a respected business attorney to lead five members of the business community, including representatives from Polaroid, Digital Equipment and Exxon, as well as two private consultants.

The first meeting that commenced on a snowy day in Boston laid out the rules of the negotiation, the boundaries of the subject, and the schedule. The group then began to meet, at first bi-weekly, and then, weekly. Several of the easy issues were resolved in the first weeks. For instance, everyone agreed that there should be a state technical assistance branch modeled on the existing Safe Waste Management Office, a university research center providing research and education, an overall administrative coordinating council, and a science advisory board to address the scientific issues.

However, the more difficult issues took many more meetings to address. The business advocates pressed for authority to site a waste treatment facility; the environmental advocates pushed for state authority to ban chemicals. Disagreements arose over chemical volume reporting thresholds, the definition of toxics use reduction, the list of regulated chemicals, the industrial sectors to be included, and the size of firms to be covered by the requirements. The list of chemicals to be included in the bill was highly contentious; the business team proposed that it be limited to the approximately three hundred chemicals regulated by OSHA, while MassPIRG proposed that it include all chemicals listed under the federal Toxics Release Inventory and the Comprehensive Environmental Response, Compensation and Liability Act. MassPIRG advocated for annual facility-level chemical use reporting, while AIM sought annual facility-level waste generation reporting (although the federal Toxics Release Inventory already required such chemical release reporting).

A very contentious issue was the ability of the state to ban or restrict the use of specific chemicals, which was strongly pushed by the environmental advocates and just as strongly opposed by the business team, who claimed that this would have the effect of driving companies out of the state. This impasse was broken by agreeing that companies be required to perform a comprehensive review of their production processes using regulated chemicals; Geiser was convinced that this planning process would lead to the identification of production changes that made sense technically and economically. Mandatory facility planning was agreed to, but it was agreed that implementation of the plan would be voluntary. The concept of plan certification by a professional “planner” was accepted, but whether this was an independent, specially trained and licensed individual or a specially designated employee of the firm was hotly debated. (Both options were included in the final text.) The parties agreed to the inclusion of a special program for priority chemical user segments, but there was much disagreement over its scale and authority.

Most contentious was the fee firms would need to pay to raise revenue for administering the program. Based on the scope of the work to be performed by the state agencies under the negotiated law, it was decided that the program would need some \$4.5 to \$5 million annually to cover the technical assistance, university center and regulatory responsibilities. However, there was considerable debate over how many firms would be covered and thus how much each would pay. If, as the business community argued, thousands of firms were covered by the law (they estimated 2500), then the individual firm fees could be small. If, on the other hand, the number of firms turned out to be significantly smaller (the counter estimate was some 600), then the individual fees would need to be larger. The debate was settled by authorizing a statewide survey of firms and

authorizing a one-time fee adjustment to match the fee structure to the desired revenue and the empirically-derived number of firms.

As the summer approached the negotiations got hotter and the weekly negotiating sessions became even more frequent. The final session lasted nearly 24 h, ours but, bleary-eyed and drained, the two sides did ultimately reach consensus bill language.

The final bill contained compromise language on many important points, including chemical reporting thresholds, chemical lists, facility sizes, and definitions of who would qualify as a Toxics Use Reduction Planner (Fig. 1).

3. The early years of the toxics use reduction program

In July of 1989, the legislature passed the Massachusetts Toxics Use Reduction Act by a unanimous vote and the Governor, signed it into law. It was a momentous day and advocates from both sides congratulated themselves on a law that they all hoped would rise to their own somewhat chastened objectives.

During the fall, work began on implementing the new law and establishing the new TURA Program. At the state level, the older Office of Safe Waste Management was reformed into the Office of Technical Assistance (OTA) and at the Department of Environmental Protection, the commissioner appointed several agency professionals to begin regulation development. The Governor appointed an advisory committee and the Toxics Use Reduction Institute was set up at what would soon become the University of Massachusetts Lowell.

Meanwhile, events soon tested the fragile relations that supported the law's consensus history. MassDEP issued a contract for a statewide survey of all firms reporting corporate taxes in the industrial classifications included in the law, to determine which and how many firms were covered under the statutory language. The survey, which covered some 60,000 entities, revealed that the actual number of firms responsible for reporting under the TUR law was closer to 600, contrasting with the business community's estimate of 2500. AIM held to its negotiated agreement and raised no resistance to a fairly significant one-time fee increase for those firms subject to TURA requirements.

By 1990, the DEP was holding hearings on proposed regulations and sending out fee invoices. Technical assistance and training professions were hired at OTA, staff were recruited for the Institute, and a Science Advisory Board was appointed to offer scientific advice on the chemical list. The Massachusetts TURA Program was launched and running.

4. A brief review of the accomplishments of the Massachusetts toxics use reduction program

The reporting data and many program evaluations show that the TUR Act has been a success. Several of the papers in this special edition highlight some aspects of that success, ranging from improved worker health to the widespread adaption of safer solvent substitutes to toxics use reduction in communities and homes. In hindsight, it can easily be seen that the success of this internationally regarded program was strongly influenced by its unique history, period and context. In the years following Oregon (ODEQ, 2010) and New Jersey (NJTAP, 2001) passed similar legislation and several others attempted to do so. However, no other state put forward such a well funded program that contained all of the essential elements of TURA. This was not for lack of effort. Shortly after passage of the Massachusetts Toxics Use Reduction Act, the national chemical industry trade association set out a serious campaign to assure that no other state would pass similar legislation.

It would be misleading to not recognize the unique historical conditions at the time of the law's passage. There was a heady mix of

The bill's Preamble stated five ambitious policy goals:

1. To establish for the commonwealth a statewide goal of reducing toxic waste generated by fifty percent (50%) by the year 1997 using toxics use reduction as the means of meeting this goal.
2. To establish toxics use reduction as the preferred means for achieving compliance with any federal or state law or regulation pertaining to toxics production and use, hazardous waste, industrial hygiene, worker safety, public exposure to toxics, or releases of toxics into the environment and for minimizing the risks associated with the use of toxic or hazardous substances and the production of toxic or hazardous substances or hazardous wastes;
3. To sustain, safeguard and promote the competitive advantage of Massachusetts businesses, large and small, while advancing innovation in toxics use reduction and management;
4. To promote reductions in the production and use of *toxic* and hazardous substances within the commonwealth, both through the programs established in section three of this act and through existing toxics-related state programs;
5. To enhance and strengthen the enforcement of existing environmental laws

Fig. 1. The policy goals of the Massachusetts Toxics Use reduction Act.

young and talented environmental and public health advocates. The public was highly sensitive to environmental issues such as hazardous wastes and workplace chemical exposures. There was a reasonably active labor community, and the state business trade association was under the management of a fairly enlightened leadership. When the bill was first drafted the Massachusetts economy was booming, the state budget was relatively flush and the legislature was under the firm control of strong leaders with no serious opposition party. However, as the legislative process evolved much of this changed as the economy spiraled into recession and various corruption cases reverberated across the legislature.

The bill was not enacted easily. It had a long gestation period before it became a serious candidate for passage and, even then, it had a heavily negotiated development period at the hands of both the business community and the health and environmental advocates. This long development period greatly improved the bill and the fact that it was a consensus bill that was unanimously enacted offered it a long, comfortable honeymoon.

Money mattered as well. The state agencies were well funded with plentiful resources. At one point there were over 60 people employed to implement the program in contrast to the small, under-resourced staffs at other states with pollution prevention or waste reduction laws.

Toxics use reduction, itself, was a strong concept with a clear message and a well crafted definition. Key activities and concepts developed as the program matured include:

- The reliance on facility planning offered an effective instrument for ensuring that firms assessed toxic chemical use and the availability of alternatives.
- The concept of independently trained and licensed planners, now elsewhere called “third party auditors”, provided an opportunity to extend the technical reach of the government and transfer technology or practice information among firms.
- The annual chemical use reporting and its aggregation into an Internet-based, publicly accessible information database provided a means of numeric accountability that has made the program transparent and credible.
- The close working relationship between the public technical assistance branch and the university-based center proved to be beneficial to both.
- As the program matured, the implementing agencies instituted new initiatives such as the Institute's Community Grants Program which extended the program's focus beyond the manufacturers to include concerned citizens.

At the same time, even as the program grew in national and international recognition, there were on-going legislative efforts by external trade groups to kill or weaken the program. By the mid-1990s, several reports from the advocacy community criticized the slow progress of the program. Toward the end of the 1990s, agency staff began working with advocates and business leaders to consider ways to refine and update the provisions of TURA. A special “Blue Ribbon Task Force” convened by the Secretary of Environmental Affairs in 1998 recommended legislative changes in the program to better target the program to “higher hazard toxic substances”, reward companies for going beyond compliance, and to broaden the range of environmental impacts that could be included in facility plans. Many of these recommendations were adopted as part of the amendments to the law in 2006, which allowed facilities to engage in alternative planning methods and allowed the state to designate “Higher Hazard Substances” and “Lower Hazard Substances” from the overall chemical list.

So as the TURA program turns twenty it is useful to reflect. This is a successful program. It has stood the test of time and weathered the years well. A re-read of the original text remains impressive. It is a well-balanced law, providing for both state and business responsibilities, appropriate authorities for the state, mechanisms (facility planning) that provide flexible means for compliance, clear, measurable goals, annual data for tracking progress, professionalized public services to assist in implementation, and a secure and steady revenue stream necessary for operations. The bill includes unique, proven mechanisms for policy decisions that involve input from the scientific community and stakeholders. TURA has provided opportunities for businesses to take a leadership role by integrating toxics use reduction into their core business model and voluntarily reduce their use of toxic chemicals when it makes business sense to do so.

5. Papers in this special edition

The papers presented in this Special Edition cover a wide range of topics, from specific technical advances made under TURA to broad assessments of chemicals use policy. These achievements were accomplished by researchers and managers in companies, in universities, environmental associations and by government program staff. In attempting to organize this review, we have decided to start with the specific and move to the more general. We hope this review transmits to the reader the tremendous range of positive outcomes that the Toxics use Reduction Act has either initiated or contributed to over the past twenty years.

5.1. Specific examples of toxic use reduction in action

The successes and the inherent limitations in the Massachusetts TURA are apparent from reading the papers included in this edition of the Journal. The papers by Morose et al., Onasch et al., and Marshall describe specific successful approaches undertaken within TURA to implement the goals of the law, while those of Bondi, Dunagan et al., González-García et al., Nagarajan et al., Atlee, Winnebeck, and Onasch describe the application of TUR techniques in specific applications. Finally, in this section, Ellenbecker and Tsai look at the application of TUR principles to an emerging industry, and Armenti looks at the impact of TURA on worker health and safety.

Morose (“Supply chain collaboration to achieve toxics use reduction”) describes one of the most successful approaches used by the program, namely, the use of a supply chain to implement significant process change. TURI, with funding support from EPA, assembled a set of new England companies from the entire circuit board supply chain, and worked with dedicated scientists,

engineers and managers from these companies to identify lead-free alternative solders, assemble parts using these alternatives, and subject the parts to the standard range of new product testing. This example, where companies up and down the supply chain in New England came together to develop lead-free circuit boards, shows the power of this cooperative approach to attaining meaningful toxics use reduction.

Another approach that has shown great promise in Massachusetts is the work with communities, non-profit organizations and small businesses to implement TUR on the local level. Onasch (“Small business models created to implement toxics use reduction techniques: Dry cleaning, auto shops, floor finishing, and nail salon sectors assisted in creating safer and healthier work places”) describes the considerable success attained by paying attention to the needs of smaller businesses, who often have the desire to reduce their use of toxic chemicals but do not have easy access to the required resources to identify available changes. Almost one hundred TUR projects have been completed by Massachusetts small businesses and community groups, and the successes of many of the funded projects have spread to other businesses and communities.

One important innovation adapted early in the program was the establishment of a research laboratory at TURI. Originally called the Surface Cleaning Laboratory, and now the TURI Laboratory, the lab was initiated to help companies select safer alternatives to their cleaning solvents. The traditionally-used chlorinated hydrocarbons were widely adopted across industry because of their near-universal cleaning ability, *i.e.*, they can remove almost any contaminant from almost any surface. Safer alternatives, however, such as aqueous-based formulations, must be individually tailored to each contaminant and surface. Kikuchi (“Analysis of risk trade-off relationships between organic solvents and aqueous agents: Case study of metal cleaning processes”) reviews the risks and benefits of organic solvent versus aqueous cleaning, and concludes that the global impact of aqueous cleaning on balance is less than organic solvents.

The effectiveness of aqueous alternatives was largely unknown twenty years ago, so the TURI Laboratory took on the task of testing the cleaning effectiveness of these alternatives. The TURI Laboratory tested hundreds of alternative chemistries applied to many substrates and surface contaminants, and assembled Web-accessible database so the public can access the results. Although the lab was successful at identifying alternatives for specific applications, the client adoption rate was not as high as the program would have liked. Marshall (“Hands-on assistance improves already successful pollution prevention services of the Toxics Use Reduction Institute’s laboratory”) describes the success of recent efforts to engage companies at their facilities, demonstrating that cleaning systems developed in the lab can work effectively on the shop floor.

The principles of TUR have been applied in recent years to many specific applications and industries. Bondi (“Applying the Precautionary Principle to consumer household cleaning product development”) challenges the often-stated opposition to the Precautionary Principle “...that its application stifles innovation by requiring proof of safety prior to introducing a new technology.” She presents the case of quaternary ammonium compounds, sodium hypochlorite, and Triclosan, widely used in surface disinfection and antimicrobial hand washes; after reviewing the evidence for their toxicity, she concludes that the precautionary approach “...effectively eliminates all conventional antimicrobial active ingredients, which introduces a significant challenge for developing an antimicrobial surface disinfectant.” After reviewing active ingredients in EPA-registered products, she makes the case for the use of thymol, the active ingredient in thyme oil. Seventh Generation commissioned a series of toxicity tests on thymol; after their successful completion, they launched their first botanical disinfectant, containing thymol, in

January 2010. She concludes that “rather than stifle innovation, the example of thyme oil based disinfectants illustrates that the Precautionary Principle can actually drive innovation and result in safe and sustainable products and solutions.”

Dunagan et al., in their review of toxic chemical exposures in the home environment (“Toxic use reduction in the home: lessons learned from household exposure studies”), are not reporting on a successful use of TUR; rather, they have outlined the tremendous opportunity that exists for future TUR activities aimed at this important environment. They conclude that, building on the program’s success in reducing toxic chemical use in manufacturing, “...TURA has the potential to extend these benefits to include further reductions in exposure from consumer product use.” While TURA specifically applies to products manufactured in Massachusetts, it has not direct jurisdiction over products imported into the state from elsewhere. Recognizing this, the authors recommend that “...ultimately, a coordinated national approach to chemicals is needed.”

González-García et al., (“Environmental assessment of green hardboard production coupled with a laccase activated system”) attacked the serious problem of formaldehyde emissions from traditionally-made wood-based panels. They performed a comprehensive life cycle assessment (LCA) of a newly-developed alternative technology to produce green hardboard using “...a wood-based phenolic material and a phenol-oxidizing enzyme (*i.e.*, laccase).” They conclude that “...the production of green hardboards using a two-component bioadhesive based on both a wood phenolic material and a phenol-oxidizing enzyme is industrially viable...” but that further research is needed in order to reduce the energy demand of the new system, as well as on the amount required and application conditions in order to obtain the desired mechanical properties.

Traditional flame retardants used in polymer applications are extremely toxic and persistent, and some emit toxic/corrosive gases during combustion. Nagarajan et al., (“A renewable waste material for the synthesis of a novel non-halogenated flame retardant polymer”) studied the flame retardant properties of cardanol, a main component of cashew nut shell liquid, a waste product from the cashew nut industry. Their reactions were carried out in aqueous media, and found that cardanol showed promise as a flame retardant, although more research is needed in order to produce a practical product.

The green building industry has focused more attention in recent years on chemical hazards in building products. Atlee (“Selecting safer building products in practice”) describes a number of tools available to assist architects, engineers, and other building professionals in the assessment of alternative building materials. After a general review of available approaches, she presents a detailed evaluation of one tool – the Greenspec Product Guide. Her evaluation of all of the available tools leads her to conclude that “...ultimately a selection must be made from the available options” and that at present we must face “...the messy reality of product selection in practice in the inevitable absence of perfect information.”

The issue of children’s possible exposure to phthalates has received considerable attention recently. Winnebeck (“An abbreviated alternatives assessment process for product designers: a children’s furniture manufacturing case study”) uses crib mattresses, whose plastic covers can contain phthalates, as a case study for evaluating various alternatives assessment methodologies as applied to the manufacture of children’s furniture. She begins by performing a review of recently-published alternatives assessment methodologies, including that used in TURI’s Five Chemicals Study, Green Screen, the TURI-spearheaded State Alternatives Assessment Forum, and others. Winnebeck used the basic elements in these models in a two-step approach to evaluating mattress cover alternatives – a product-level analysis followed by a more detail component-level analysis

applied to those products that passed the first screen. She concludes that the two-step approach allowed the complete assessment to be completed in six months, and the manufacturer replaced their vinyl-covered mattress with a waterproof cotton mattress.

TURI has been working with the dry cleaning sector for more than ten years to help them move away from perchloroethylene (“PCE”), a very toxic chlorinated solvent. Onasch (“A feasibility and cost comparison of perchloroethylene dry cleaning to professional wet cleaning: case study of Silver Hanger Cleaners, Bellingham, Massachusetts”) discusses the feasibility of using a matching grant as a way to attract a small dry cleaner to switch from PCE cleaning to the new generation of professional wet cleaning machines. TURI provided a matching grant of \$17,000 to Silver hanger Cleaners to assist in the purchase of professional wet cleaning equipment; as part of the grant, the owner agreed to allow TURI to track his costs and technical performance before and after the switch. After one year, Onasch concludes that “...both the cleaner and his employees are happy with the new technology...customers are happy with the conversion...” and net operating costs and natural resource use (electricity, natural gas, and water) all decreased. She concludes that the grant process was useful in convincing one dry cleaner to make the switch, that utilities should be interested in pursuing this approach due to energy savings, and that “the establishment of a national professional wet cleaning assistance program would help provide support to cleaners across the country who currently work with PCE on a daily basis.”

The principles of TUR can be applied both to traditional industrial processes such as surface cleaning and to newly-emerging technologies. Ellenbecker and Tsai (“Engineered nanoparticles: safer substitutes for toxic materials, or a new hazard?”) discuss the potential benefits and possible pitfalls presented by the rapidly growing nanotechnology industry. They conclude that the use of engineered nanoparticles as substitutes for toxic materials “...holds great promise, but also many risks. For every possible application, alternatives assessment tools...must be used to carefully analyze the risks and benefits.”

An important concept underlying the TUR Act is the simultaneous concern for environmental and occupational health. Armenti et al., present the case for TUR or, more broadly, cleaner production and pollution prevention (CPPP), as a primary prevention technique for protecting worker health. They evaluated the effect of TUR on worker health and safety at three printed wire board manufacturing facilities covered by the TURA Program. Using a variety of survey instruments, they conclude that, while waste reduction and cost savings are the primary drivers considered by the surveyed facilities, CPPP/TUR had a positive impact on worker health and safety.

The specific examples of toxics use reduction described in the above papers illustrate the wide reach that TUR and its associated tools have attained in the last twenty years. These concrete examples are strong evidence that the vision and hopes of the bill’s creators have been realized.

5.2. Toxics use reduction from a policy perspective

Several of the papers in this issue look not at specific examples of TUR in action, but rather at its successes and limitations from a policy perspective. Focusing on Massachusetts, Reibstein and Massey investigate the experiences of Massachusetts companies in working with the law, while Eliason discusses the possibilities for using the Massachusetts process as a model for other states. Morse applies the data collected under the Massachusetts law to Connecticut in an attempt to estimate chemical use in that state. Moving to the international stage, Hughey in two papers evaluates the potential for

voluntary pollution prevention programs, both in general and specifically as they apply to New Zealand. Thorpe describes specific examples of new toxic chemical policy initiatives that have grown from the foundation established by TURA. Finally, Lindsey takes a broad view and suggests “sustainable principles” that might guide society as we move forward (hopefully) towards sustainability.

Reibstein (“The experiences of four corporate officials managing compliance with the Massachusetts Toxics Use Reduction Act”) addresses the common misconception that compliance with the law is an unreasonable burden on industry. In order to illustrate his point, he introduces examples of how TUR works in actual practice inside four facilities. His description of the steps taken to implement TURA at Polaroid, AlphaGary, Texas Instruments, and Allegro Microsystems illuminate some of the initial difficulties, but the ultimate great successes, that were obtained when visionary and dedicated industry professionals dedicated their talents and energy to the successful implementation of the Act. He concludes:

The Act did not require that any of these companies invest a single dollar in any chemical substitutions or process changes, but after doing the plan, and sometimes after receiving assistance, these companies chose to do so. Not all companies will respond this way. But if some will, then surely wider application of the prevention strategies used by TURA deserves active consideration.

The TUR program has made regular, periodic attempts to quantify the successes and limitations of the program. The chemical use data reported annually by the participating facilities, certainly tell much of the story, but it is more difficult to determine *how* chemical reductions were obtained, the *financial costs or savings* accompanying chemical use reduction, and the actual personal experiences of individuals working to implement the Act at their facilities. Massey (“Experiences of Massachusetts companies and communities with the Toxics use Reduction Act (TURA) program”) presents and discusses the results of a recent survey of participating facilities done by the program. She concludes:

The results of the survey and interviews conducted with Massachusetts facilities indicate that facilities are continuing to experience benefits from the TURA program, including improved worker protection and financial savings as well as organizational benefits. Facilities also continue to face challenges, ranging from technical feasibility problems to limitations deriving from customer specifications.

When the law was passed, little was known about the actual process which should be followed in order to evaluate alternatives to toxic chemicals being used by participating facilities. One of the principal analytical tools that were developed to meet this need is alternatives assessment, which formalizes and systematizes the process by which alternatives are evaluated. In 2006 the Massachusetts legislature funded TURI to conduct alternatives assessments for five toxic chemicals of particular concern to the Commonwealth, *i.e.*, di (2-ethylhexyl) phthalate (DEHP), formaldehyde, hexavalent chromium, lead, and perchloroethylene. Eliason (“Safer alternative assessment: the Massachusetts model for state governments”) presents a summary of the results of those assessments, and discusses how this approach can be successfully applied to other chemicals in other locations. One of the key findings of this effort was the need to involve interested stakeholders in all phases of the assessment. Many promising alternatives were identified for each chemical, and most of them required further study in order to ensure successful implementation by industry. Eliason concludes that alternatives assessment “...is a useful approach to organizing and evaluating information about chemicals and alternatives, and could be utilized by policy makers as well

as industry to help move our economy towards the use of safer chemicals and materials.”

One of the hopes of the leaders who worked so hard for the passage of TURA, as described above, was that it would serve as a model for implementation of similar laws in other states. Unfortunately, such programs have been slow to emerge, with only a few states such as Oregon, New Jersey, and Maine enacting similar legislation. Recently the Province of Ontario passed a law modeled on TURA, New York and Connecticut have taken initial steps to develop TUR programs, and TURA has been cited as a key model for California’s ambitious overhaul of its approach to regulating chemicals. In preparation for possible legislation, Connecticut scientists were interested in assessing the extent of chemical use in their state. Morse (“Estimated chemical usage by manufacturers in Connecticut”) describes the methodology used to apply Massachusetts chemical use data to the Connecticut manufacturing sector in order to estimate the scope of toxic chemical use which might be addressed by a new Connecticut TUR program. He was able to develop credible estimates for total toxic chemical use and use of carcinogens and reproductive hazards, but with great uncertainties as to chemical use by different industrial sectors. This underscores the need for actual TUR reporting in each state, so that the problems of that state can be targeted.

Moving from the state level to the international stage, two papers by Hughey are included in this edition. The first, by Hughey and colleagues, (“A review of international practice in the design of voluntary pollution prevention programmes”) reviews the recent global impetus towards voluntary approaches to industry-wide pollution prevention. A detailed review of efforts in five countries from around the world identified nine specific features characteristic of successful programs, ranging from “adequate and consistent funding” to “transparent provision of program results.” In a second paper (“Voluntary pollution prevention programs in New Zealand – an evaluation of practice versus design features”) he then evaluates nine programs employed by five regional and district councils in New Zealand against those nine “Best Practice” design features. While finding that most of the programs incorporated most of the design features “on paper”, many of the elements were generic and lacked specificity and depth; for example, none of the programs had any elements that were industry specific. He is particularly critical of the lack of setting specific goals for pollution prevention – a key element in the Massachusetts TUR Act.

Thorpe begins her article (“How the Toxic Use Reduction Act continues to promote clean production internationally”) with a statement that brings joy to the hearts of those who have worked for twenty years to make TUR a success: “The Massachusetts Toxic Use Reduction Act (TURA) continues to be a catalyst for pollution prevention planning in regions far beyond its state’s jurisdiction. This is due in large part to the success of the Act.” She goes on to describe three international programs that she believes had their genesis in TURA, *i.e.*, the Sewer Use Bylaw in Toronto, Canada; the European Union’s REACH chemicals legislation, and the international campaign by Greenpeace in Asia and Latin America to achieve zero discharge of hazardous substances into rivers. She describes each of these efforts in some detail, identifying their successes and weaknesses, and analyzing TURA’s impact on their implementation. One is struck by how different these programs are; that Thorpe can identify TURA’s strong influence on all of them is testament to TURA’s fundamental strengths.

Finally, Lindsey (“Sustainable principles: common values for achieving sustainability”) proposes what he believes are “sustainable principles,” rooted in techniques of pollution prevention, that “can optimize resource utilization across all system components for the entire life cycle of the systems.” After reviewing the

sustainability literature, he proposes the following fundamental sustainable principles:

Principle #1:

Improved Sustainability is achieved through **Reducing Wastefulness**.

Principle #2:

Improving Quality Improves Sustainability.

Principle #3:

Sustainability is best achieved through **Implementing Better Systems**.

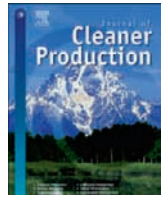
We believe that this statement of principles is an excellent way to conclude this special edition. The Massachusetts TUR program, at its core, involves companies, government workers, and the public working together to develop and implement **better systems** that **reduce wastefulness** through **improved quality** of products and manufacturing processes. If the past twenty years have taught the people of Massachusetts anything, it is that individuals from all parts of society can work together to improve the quality of our workplaces and our environment, as long as they are dedicated to a common goal and a regulatory framework is in place that encourages all parties to work together in a creative way to reach that goal.

The world faces severe environmental problems, including toxic chemicals but encompassing much more in the form of global warming and natural resource depletion. It is our hope that this

special edition will encourage others from throughout the world to join us in the effort to reduce toxic chemical use and make ours a truly sustainable society. It is up to all of us to rededicate ourselves to working even harder over the next twenty years to make this planet a safer, healthier, and sustainable place for our children and their children for many generations.

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Supply chain collaboration to achieve toxics use reduction

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ABSTRACT

The use of lead poses significant hazardous occupational exposure to workers in the electronics industry, and also causes environmental challenges at the end of product life. For the past decade, there has been a global effort in the electronics industry to initiate a move towards using lead-free materials for the production of printed circuit boards. However, there are technical and economic challenges, such as long term reliability and rework capability, that remain to hinder the universal implementation of lead-free materials. As a result, many electronics products are still currently manufactured and assembled using materials containing lead.

The costs for investigating and evaluating the various lead-free electronics materials and manufacturing processes can be cost prohibitive for an individual company to undertake alone. Consequently, the New England Lead-free Electronics Consortium was formed as a collaborative effort of New England companies spanning the electronics supply chain to help move the industry towards lead-free electronics. The Consortium is a working collaboration of industry, government, and academia. For the past several years, the Consortium has conducted research and testing for using various lead-free materials for the manufacture of printed circuit boards. The Consortium has been successful in identifying lead-free materials and processes to address the challenges of assembly and rework. The Consortium is currently conducting research to address the long-term reliability challenge of lead-free electronics.

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1. Introduction

1.1. Use of lead in electronics

Since the emergence of etched printed wiring board technology, lead has been used in a variety of ways for manufacturing printed circuit boards. Lead can be used as a conductive surface finish on printed circuit boards, as a conductive component finish, as solder paste for the assembly of surface mount components, and as bar solder for assembly of through-hole components. Lead is used as a material in electronics because it has many desirable properties such as a low melting temperature and low cost, and also because it forms reliable solder joints (Hwang, 2001).

Printed circuit boards are found in electronics products. The printed circuit board is crucial to the manufacture and sales of approximately \$1 trillion in electronic products each year. The printed circuit board is the platform upon which electrical components such as semiconductor chips and capacitors are

mounted, and it provides the electrical interconnections between components. In 2003, the United States produced approximately 15% of the world's printed circuit boards (LaDou, 2007).

In the United States during 2003, approximately 13.9 million pounds of lead were used in solder for the manufacture of electronics products (U.S. Geological Survey, 2006).

1.2. Hazards of lead

The use of lead materials provides a potential exposure pathway to workers in companies throughout the entire supply chain of the electronics industry. This involves companies involved in transportation, solder and solder paste manufacturing, electronics component manufacturing, circuit board manufacturing, assembly of circuit boards, final product assembly, use and repair of electronic products, recycling of electronics products, and disposal of electronic products.

The acute and chronic toxic effects of lead to humans have been well studied. Brain damage, kidney damage, and gastrointestinal distress result from acute exposure to high levels of lead in humans. The most sensitive targets for the acute toxic effects of lead are the

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kidneys and the hematological, cardiovascular, and nervous systems. Because of the multi-modes of action of lead in biological systems, lead could potentially affect any system or organ in the body. Approximately 99% of the amount of lead entering the human adult body will leave in urine or fecal waste within a couple of weeks, but only about 32% of lead entering a child's body will leave in the waste. Under conditions of continued human exposure to lead, not all of the lead that enters the body will be excreted, resulting in accumulation of lead in body tissues (ATSDR, 2007).

There are a wide variety of chronic health effects for human exposure to lead. Animal studies have reported kidney tumors in rats and mice exposed to lead. The U.S. EPA considers lead to be a Group B2, probable human carcinogen (EPA, Lead and Compounds, 2007). The International Agency for Research on Cancer (IARC) considers lead to be a Group 2B, possibly carcinogenic to humans. (IARC, 2006) Studies on male lead workers have reported severe depression of sperm count and decreased function of the prostate and/or seminal vesicles. Occupational exposure to high levels of lead has been associated with a high likelihood of spontaneous abortion in pregnant women. Exposure to lead during pregnancy produces toxic effects on the human fetus, including increased risk of preterm delivery, low birth weight, and impaired mental development. Chronic exposure to lead in humans can affect the blood and the nervous system. Neurological symptoms have been reported in adults with elevated blood lead levels of greater than 40 $\mu\text{g}/\text{dL}$ (ATSDR, 2007).

Human exposure to lead typically occurs through a combination of inhalation and oral exposure. For companies that are involved with circuit board assembly operations, inhalation of lead can occur during soldering processes. The primary solder operations occur during reflow soldering of surface mount components, wave soldering of through-hole components, and manual soldering of reworked components.

The Leadout Project is a European funded initiative to help companies across Europe develop technological solutions for implementing lead-free solution in the electronics industry (Leadout, 2007). A study was conducted by the Leadout Project to measure the occupational exposure to lead during reflow and wave soldering operations. Occupational exposure measurements were performed at three different electronics companies using personal sampling pumps at the breathing zone of workers who were conducting reflow and wave solder operations using tin/lead solder. The action level limit ($30 \mu\text{g}/\text{m}^3$) was exceeded by two out of the three companies for reflow solder operations, and the permissible exposure limit ($50 \mu\text{g}/\text{m}^3$) was exceeded by two out of the three companies for wave solder operations. The lead emission results from this study are shown in the Table 1 below (Aguirre, 2006).

During the many and varied processes of electronics assembly, there is considerable handling of lead solder, lead solder paste, components with lead finish, and circuit boards with lead finish. For example, the printing operator must pick up circuit boards with a lead finish, as well as manually apply lead solder paste to the printing machine. The handling of these lead containing materials can result in lead contamination of workers hands and clothing. This contamination of hands and clothing can ultimately cause lead

ingestion if proper hand and clothing washing procedures are not conducted. Ingestion of lead can also occur through contact with lead-contaminated hands, food, cigarettes, and clothing. Further, lead contaminated clothing and other objects that are brought into the home environment also represent a potential exposure hazard to occupants in the home, especially to children (NIOSH, 1995).

The environmental hazards involved with the use of lead solder in electronics often occur during the disposal stage. At the end of life, electronics products often end up at incinerators without proper control technology, or at landfills or dumping areas that are not properly lined to prevent the migration of lead to soil and groundwater. Lead can enter the ambient atmosphere if it is not incinerated with appropriate control technology.

1.3. Drivers of lead-free electronics

For the past decade, there has been a global effort in the electronics industry to initiate a move towards using lead-free materials for the production of printed circuit boards. The major types of drivers for moving manufacturers towards lead-free electronics include regulatory and market drivers. A major regulatory driver has been the European Union's Restriction on the use of certain Hazardous Substances (RoHS) Directive that was enacted in 2003. This directive limits the amount of lead and five other substances that are used in electrical and electronic equipment. This directive covers some, but not all, electrical and electronic equipment placed on the European Union market as of July 2006. There are several types of electronics products (e.g. medical equipment, aerospace, etc.) that are either exempt or considered out of scope from this directive.

Even in the absence of regulatory requirements, several companies have responded to market drivers to eliminate lead from their electronics products. Many progressive companies are trying to produce more environmentally friendly and recyclable products, as well as providing a safer working environment for their employees. These efforts can become market drivers for the remainder of the supply chain, as suppliers must provide materials, components, and assemblies that are lead-free, or otherwise risk losing the business of these progressive companies. Another market driver occurs when companies leverage marketing their product as 'green'; this forces competitors to follow suit, or lose market share.

1.4. Challenges of lead-free electronics

Despite the environmental and occupational hazards described in the preceding section, there is continued use of lead solder. There are many reasons for this practice, including the presence of technical and economic challenges with transitioning to lead-free materials. A common source for many of these challenges is that the melting temperature of lead-free solders is typically higher than that of tin/lead solder. For example, the melting temperature of tin/lead solder is $183 \text{ }^\circ\text{C}$, and the melting temperature of tin/silver/copper solder (a common lead-free solder material) is approximately $217 \text{ }^\circ\text{C}$. Therefore, the manufacturing process equipment must be run at higher temperatures. For surface mount components, the reflow oven temperature must be higher when using lead-free solder pastes. For through hole components, the solder pot temperature must be higher for wave solder, selective solder, and rework machines when using lead-free solders.

The elevated temperatures necessary to accommodate lead-free solders pose technical challenges. Most common components and printed circuit board laminate materials are rated for the lower processing temperatures required for a tin/lead electronics assembly environment. Therefore, the increased processing

Table 1
Lead emission measurements (Aguirre, 2006).

Company	Wave solder: lead exposure ($\mu\text{g}/\text{m}^3$)	Reflow solder lead exposure ($\mu\text{g}/\text{m}^3$)
IDK (Spain)	68	30
ALCAD (Spain)	18	16
TELCA (Portugal)	115	< 33

temperatures can cause issues such as printed circuit board delamination and component failure.

During the assembly of printed circuit boards, there is often the need to rework the boards due to failures or defects encountered during the assembly process. This rework involves the removal and replacement of components on the printed circuit board. Also, rework of printed circuit boards can occur anytime during the life of the electronics product. For example, if there are component failures during the use of the product, the printed circuit board may have to be sent back to the manufacturer for rework.

The elevated solder temperatures and solder flow required for rework of through hole components can result in copper dissolution on the printed circuit board. Copper dissolution is the erosion of the copper thickness of the pad and barrel wall for plated through holes. The presence of copper dissolution can result in adverse effects on solder alloy performance, can increase the required frequency for solder analysis, increase the required solder pot maintenance, and potentially compromise the long-term reliability of the printed circuit board.

For rework with lead-free solders, copper dissolution can be a greater challenge than with tin/lead solders. First, the melting temperatures of lead-free solder alloys are often higher than tin/lead solders. Therefore, the solder temperature needs to be higher to conduct the rework with lead-free solders which generates more thermal stress to the printed circuit board. Second, the lead-free solders such as tin/silver/copper alloys do not flow as well as tin/lead solders and need more contact time between the solder and the printed circuit board. This also generates additional thermal stress to the printed circuit board. Another issue with lead-free solders is that they have a higher tin content than tin/lead solders. The tin component of most solders reacts with the copper substrate.

The most challenging technical barrier to the widespread adoption of lead-free electronics is the impact on the long-term reliability of the lead-free products. Lead solder has been used extensively for the past sixty years and there is a large reservoir of reliability data available. It has been proven that electronics products containing lead solder can have operational lives of twenty or more years. However, this reliability data has not yet been generated for lead-free electronics, and consequently there is reluctance to use lead-free materials for products that require a long operational life. Since there are outstanding issues with the long term reliability of electronics products manufactured with lead-free materials, there are numerous electronics product applications that continue to use materials containing lead. This includes electronics products requiring high reliability and long product life such as network infrastructure, aerospace, defense, information technology, and medical applications (Pecht et al., 2004).

There are also economic barriers to the widespread adoption of lead-free electronics. For example, the most common lead-free solder used is a tin/silver/copper alloy that is more expensive than tin/lead solder, mostly due to the silver content. Also, new circuit board laminate materials would have to be purchased to accommodate the higher processing temperatures. These higher temperature rated circuit board materials typically cost more than traditional circuit board materials. Another economic issue is the increased energy requirement that is necessary to operate the processing equipment at a higher temperature to accommodate the lead-free solder. This increased energy usage is approximately 20% higher for a reflow oven processing lead-free assemblies rather than tin/lead assemblies, resulting in a corresponding increase in utility costs that the manufacturer must incur.

1.4.1. New England lead-free electronics consortium

The costs for investigating and evaluating the various lead-free electronics materials and manufacturing processes are usually

prohibitive for an individual company to undertake alone. The New England Lead-free Electronics Consortium was formed as a collaborative effort of New England companies spanning the electronics supply chain to help move the industry towards lead-free electronics. The Consortium has been sponsored and supported by the Toxics Use Reduction Institute (TURI), the U.S. Environmental Protection Agency (EPA), and the University of Massachusetts Lowell.

The Consortium is a working collaboration of industry, government, and academia. Companies in the electronics industry supply chain include original equipment manufacturers (OEMs), printed circuit board assemblers, electronics component suppliers, and material suppliers. A study was conducted in order to examine the role of partnerships between OEMs and suppliers in improving the environmental performance or manufacturing operations. The results of the study indicate that the closer the relations, then the greater the improved environmental performance through implementing innovative materials and manufacturing processes. It was found that as suppliers learned more about the manufacturing operations of the end product, then they were better able to understand the type of product that best meet the needs of the end customer (Tsoufas and Pappis, 2006). As a result, significant opportunities exist along the supply chain to reduce a company's environmental impact, including substituting chemicals in order to reduce the generation and management of hazardous materials (Cote et al., 2008).

For the past several years, the Consortium has conducted research and testing for using various lead-free materials for the assembly of printed circuit boards. These efforts were conducted in a collaborative manner by the members of the Consortium. The companies in the New England Lead-free Electronics Consortium that contributed to the current phase of research include:

- AIM Solder
- Benchmark Electronics
- Cobham (M/A-COM)
- Dynamic Details Inc.
- EMC Corporation
- Freedom CAD
- International Rectifier
- Isola
- Enthone Inc. (previously Ormecon)
- PWB Interconnect Solutions
- Raytheon
- Stentech
- Teradyne
- Texas Instruments
- Textron Systems
- Wall Industries
- Yankee Soldering

2. Materials and methods

Based upon the input from the consortium members, the consortium conducted the research in the following three areas.

1. Assembly of test vehicles

The first research area included an evaluation of the assembly of test vehicles using various lead-free materials. The lead-free materials evaluated during the assembly included the component finish, the board surface finish, the through hole component solder, and the surface mount component solder paste. In addition, a nano-material based surface finish was also included. The results of the lead-free assemblies were compared against baseline data obtained

by assembling test vehicles with tin/lead materials. It is essential that quality lead-free solder joints are achieved during the initial assembly before subsequent research in rework and reliability areas can be undertaken.

2. Rework with lead-free materials

The second area of research was a comparison of rework capabilities for the various lead-free solders and surface finishes for through hole components. This research included the evaluation of three different rework processes using lead-free materials. This research also included the evaluation of a rework nozzle that was specifically designed and fabricated to address the rework challenges encountered when using lead-free materials.

3. Reliability of lead-free electronics

The third research area is an evaluation of the long-term reliability of test vehicles that were assembled using lead-free materials. The long-term reliability testing is based on accelerated testing techniques to assess the long-term product life of these electronic assemblies. The primary testing techniques used for the reliability testing are thermal cycling and internal stress testing. The results of this research will include a comparison against baseline data for test vehicles assembled using tin/lead solder.

The ultimate goal of the combined research in all three areas described above was to attain and publish results in these needed areas of original research. The research results should help to further advance the electronics industry towards the implementation of lead-free electronics for all applications, including those demanding high reliability and long product life. The research for the first two areas (assembly and rework) has been completed and the results are provided in this paper. The research for the third area (reliability) is still in progress and will be published in a subsequent paper.

The equipment and materials required for the research in all three areas were obtained by donations by member companies from the New England Lead-free Electronics Consortium, as well as funding provided by the U.S. EPA. The following Table 2 provides a summary of the types of contributions made by companies to support the research conducted by the Consortium over the past several years. These contributions demonstrate the willingness of the electronics supply chain in New England to collaborate for a common purpose of eliminating the use of lead in electronics.

A key step for providing research that is of value to the electronics industry representatives, is to use industry accepted standards and guidelines for the research conducted in the areas of assembly, rework, and reliability. The Association Connecting Electronics Industries (IPC) is a trade organization dedicated to furthering the competitive success of its members in the electronics industry. IPC has developed industry standards for various electronic assembly activities such as: fabrication, acceptance, assembly, inspection, solderability, and testing of printed circuit

boards. Throughout the documentation for this research, these IPC standards were referenced and adhered to whenever possible. This is necessary to ensure that the companies in the electronics industry can accept the validity of these research results.

2.1. Overview of materials included in the research

The research included numerous types of lead-free materials to be used for assembly, rework, and reliability testing efforts. The consortium members selected materials and components that had appropriate temperature ratings for lead-free electronics assembly. There were thirty different types of surface mount components and ten different types of through hole components included in this research. The research included four different printed circuit board surface finishes. The purpose of the surface finish is to provide solderability protection, a contact surface, and a solder joint interface (Hwang, 2005). The first finish used was electroless nickel immersion gold (ENIG). This surface finish involved using both electroless and immersion technologies to deposit the metallic surface finish. The second finish used was hot air solder leveling (HASL) technology to apply the surface finish to the printed circuit board. HASL is a method that entails dipping a bare printed circuit board that into a solder bath. The excess solder is then removed from the printed circuit board by an air stream (Scimeca et al., 2008). For this research, the HASL surface finish used the tin/copper lead-free alloy was 99.4% tin with approximately 0.6% copper. The third surface finish used an organic protection system for the copper pads on the printed circuit board. This surface finish is referred to as organic solderability preservatives (OSP). The fourth surface finish included for this research was a surface finish using nano materials. The nano surface finish consists of nano silver particles (approximately 4 nm) dispersed in a polymer (polyaniline). The thickness of the nano surface finish applied to the test vehicles is approximately 50 nm. This finish is referred to as an organic metal finish. Ninety percent of the layer volume is organic metal, and silver comprises the remainder (Wessling et al., 2007).

Solder paste is comprised of the solder alloy and a flux that is necessary to clean the surfaces that are to be soldered. This research included the following four different solder pastes for assembly of the surface mount components.

- Tin/silver/copper alloy (SAC 305, 96.5% tin, 3% silver, and 0.5% copper) with no clean chemistry flux (from two different suppliers)
- Tin/silver/copper alloy (SAC 305) with organic acid chemistry flux
- Tin/lead alloy with no clean chemistry flux for baseline purposes

Three different solder alloys were used in this research for the assembly of the through-hole components. The solders used were as follows:

- Tin/silver/copper alloy (SAC 305)
- Tin/copper alloy (99.4% tin, 0.6% copper)
- Tin/lead alloy (63% tin and 37% lead, lead-tin eutectic alloy) for baseline purposes

For this research, the three factors under investigation in the Design of Experiments were surface mount component solder paste, through hole component solder, and surface finish. The Design of Experiments (including solder paste, solder, surface finish, and laminate material) that was used for the 24 lead-free test vehicles is provided in the Table 3 below (Morose et al., 2009).

Table 2
Contributions for consortium research.

Contribution	Value
Production equipment and technical support	\$90,000
Analysis and project management	\$185,000
U.S. EPA funding	\$62,000
Engineering support	\$240,000
Testing, inspection, and support	\$245,000
Components and materials	\$195,000
Total	\$1,017,000

Table 3
Lead-free test vehicles – design of experiments.

Test vehicle	SMT solder paste	Through hole solder	Surface finish
1	SAC 305 NC-1	SAC 305	ENIG
2	SAC 305 NC-1	SAC 305	ENIG
3	SAC 305 NC-1	SAC 305	LF HASL
4	SAC 305 NC-1	SAC 305	LF HASL
5	SAC 305 NC-1	SAC 305	OSP
6	SAC 305 NC-1	SAC 305	OSP
7	SAC 305 NC-1	SAC 305	Nanofinish
8	SAC 305 NC-1	SAC 305	Nanofinish
9	SAC 305 (OA)	Tin/copper (295 °C)	ENIG
10	SAC 305 (OA)	Tin/copper (295 °C)	ENIG
11	SAC 305 (OA)	Tin/copper (295 °C)	LF HASL
12	SAC 305 (OA)	Tin/copper (295 °C)	LF HASL
13	SAC 305 (OA)	Tin/copper (295 °C)	OSP
14	SAC 305 (OA)	Tin/copper (295 °C)	OSP
15	SAC 305 (OA)	Tin/copper (295 °C)	Nanofinish
16	SAC 305 (OA)	Tin/copper (295 °C)	Nanofinish
17	SAC 305 NC-2	Tin/copper (310 °C)	ENIG
18	SAC 305 NC-2	Tin/copper (310 °C)	ENIG
19	SAC 305 NC-2	Tin/copper (310 °C)	LF HASL
20	SAC 305 NC-2	Tin/copper (310 °C)	LF HASL
21	SAC 305 NC-2	Tin/copper (310 °C)	OSP
22	SAC 305 NC-2	Tin/copper (310 °C)	OSP
23	SAC 305 NC-2	Tin/copper (310 °C)	Nanofinish
24	SAC 305 NC-2	Tin/copper (310 °C)	Nanofinish

The Design of Experiments that was used for the eight tin/lead test vehicles is provided in the Table 4 below. These tin/lead test vehicles provided a baseline for comparison with the lead-free test vehicles.

2.2. Assembly of test vehicles methodology

The Fig. 1 below shows the assembled test vehicle that was used for the basis of this research. The test vehicle thickness is the 0.110 inches, has 20 layers of copper, is 8 inches wide by 10 inches long, and contains both surface mount and through hole components.

There were 886 surface mount components, and 21 through hole components assembled on each test vehicle. The test vehicles were manufactured by Dynamic Details Inc. at their board fabrication plant in Sterling, Virginia. The assembly and inspection of the components to the lead-free and tin/lead test vehicles occurred at the Benchmark Electronics facilities in Hudson, New Hampshire, and Guadalajara, Mexico.

The temperature profile of the test vehicle and surface mount components during passage through the reflow oven is a critical determinant of solder joint quality. The test vehicle used for this research was very challenging to obtain a desirable thermal profile because the test vehicle was thick (0.110 inches) and contained many different types of components with greatly varying thermal masses.

Lead-free solder paste using the SAC 305 tin/silver/copper alloy solder melts at 217–220 °C, and the time that is spent above this

Table 4
Tin/lead boards – design of experiments.

Board	SMT solder paste	Through hole solder	Surface finish
25	Tin/lead NC	Tin/Lead	ENIG
26	Tin/lead NC	Tin/Lead	ENIG
27	Tin/lead NC	Tin/Lead	LF HASL
28	Tin/lead NC	Tin/Lead	LF HASL
29	Tin/lead NC	Tin/Lead	OSP
30	Tin/lead NC	Tin/Lead	OSP
31	Tin/lead NC	Tin/Lead	Nanofinish
32	Tin/lead NC	Tin/Lead	Nanofinish

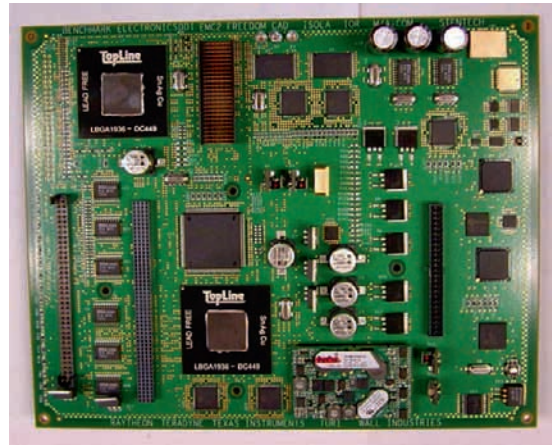


Fig. 1. Assembled test vehicle.

temperature while in the reflow oven is called time above liquidus (TAL). All three lead-free solder pastes in this research contained the lead-free tin/silver/copper alloy. The target peak temperature for test vehicles assembled with lead-free solder was in the range of 240–248 °C, and the target time above liquidus is in the range of 60–90 s. The target thermal profile was a ramp to peak method. The actual top side temperature profile used for the lead-free test vehicles can be seen in the Fig. 2 below.

The second temperature profile was for the tin/lead solder paste that melts at 183 °C. The target peak temperature in the reflow oven for test vehicles assembled with tin/lead solder was in the range of 210–218 °C, and the target time for the test vehicles to be above the liquidus temperature was in the range of 60–90 s.

The third temperature profile generated was for the top side of the test vehicles assembled with tin/lead solder paste. The top side of these test vehicles contain ball grid array (BGA) components that contain lead-free solder balls. Therefore, a hybrid temperature profile is needed to melt the tin/lead solder pastes as well as the lead-free solder on the BGA components. The target peak temperature for the hybrid profile is in the range of 222–230 °C, and the target time above liquidus is in the range of 60–90 s (Shina, 2008).

The three major steps for the assembly of the through hole components were: flux application, preheating, and soldering. The flux needs to be applied to each through hole on the test vehicle prior to soldering to help prevent the oxidation of the metal that may occur at the elevated soldering temperatures. The flux was applied automatically to the bottom side of the test vehicle.

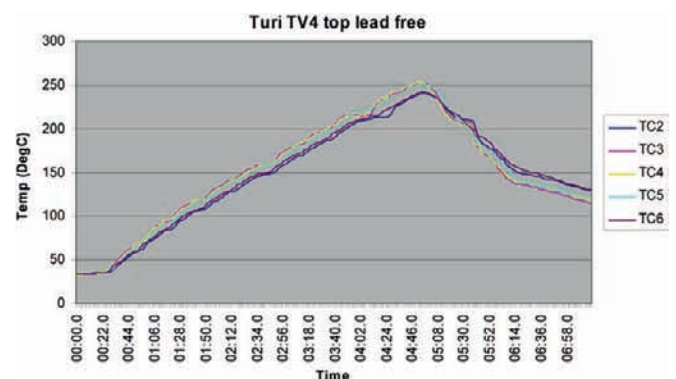


Fig. 2. Top side reflow profile for lead-free test vehicles.

The preheating of the test vehicle was necessary to minimize the thermal stress that occurs when the test vehicle is exposed to the high soldering temperatures. The intent was to gradually raise the temperature of the test vehicle closer to the soldering temperature to minimize thermal stress. However, the preheat temperature cannot be too high or it may burn off the flux before the soldering occurs. For this research, the target preheat temperature was between 110 and 115 °C.

The IPC-A-610 Revision D standard was used as the guideline for conducting the visual inspection for this research. This standard is a collection of visual quality acceptability requirements that is used for electronic assemblies. The standard provides different requirements depending on the classification of the electronics assembly. The visual inspection for this research was conducted to meet the requirements of Class 3: High Performance Electronic Products. This classification was chosen because it covers electronics assemblies that must meet high reliability applications (IPC, 2005). For this research, only soldering related defects were considered.

2.3. Rework with lead-free materials methodology

The rework subgroup established the following three criteria for the rework success of through hole components:

- Meet IPC Class III visual inspection criteria
- No laminate material degradation (e.g. delamination, pad lifting)
- Achieve minimal copper dissolution: primary target is to meet 0.001" minimum copper thickness at the knee (Class 3), secondary target is 0.0008" minimum copper thickness (Class 2)

The rework effort was conducted on rework coupons, and not on the actual test vehicles. The panel design included both test vehicles and rework coupons to ensure that the rework research was done on the same laminate material and board stackup as the actual test vehicles.

The through-hole component selected for the through hole rework process was the Samtec 200 pin connector. This component was selected because it would be a challenge to successfully rework this component given the thickness of the rework coupon (0.110 inches). The Fig. 3 below shows the Samtec 200 pin through hole connector mounted on the upper left hand corner at component location J5 of the rework coupon.

The through hole component rework process included the following four surface finishes: OSP, ENIG, lead-free HASL (using the tin/copper alloy), and nano. Nine rework coupons with OSP

surface finish were sent to Ormecon to apply the nano surface finish. Applying the nano surface to bare copper is the preferred method by Ormecon, however, the only rework coupons available for this research already had the OSP surface finish applied. Consequently, the OSP finish had to be stripped off by Ormecon before applying the nano surface finish. It is difficult to strip the coupon of its previous surface finish while maintaining an optimal, homogenous copper surface. This could affect the visual appearance of the nanofinish and the solderability of the coupons (Ormecon, 2008).

Two different lead-free solder alloys were used for this experiment: SAC 305 solder and tin/copper solder. Because of time and resource constraints, the tin/lead solder was not included as a baseline measurement for these efforts.

There were twenty-four rework coupons included in the through hole component rework effort. This provided a balanced Design of Experiments for the rework efforts. The rework process took place at Benchmark Electronics in Hudson, New Hampshire. The rework coupons had to undergo two passes through the reflow oven to simulate the thermal stresses that would have been encountered during an actual surface mount assembly process.

The primary machine that was used for the rework efforts was the Premier Rework RW116 machine. There were two types of nozzles used on the Premier Rework machine for the rework efforts. The first was a standard nozzle which is shown in the Fig. 4 below.

The second type of nozzle used for the through hole rework was a hybrid nozzle. The hybrid nozzle was a special proprietary design to address the challenges of copper dissolution during the rework process with lead-free solders. The intent of the design is to minimize solder flow at the surface of the test vehicle, but maintain adequate heat transfer to the solder so that there is not a significant drop in solder temperatures during rework operations. The Fig. 5 below shows the hybrid nozzle with solder flow during actual rework operations.

There were three different rework processes that were used for reworking the through hole components. For each of these processes, a board preheat temperature of 130 °C was used for the rework machine, and Alpha EF2202 no clean flux was used at the component site. These three processes are described below:

Process 1: The Premier Rework RW116 machine was used for initial component installation, component removal and second component installation. This process used the standard nozzle design.

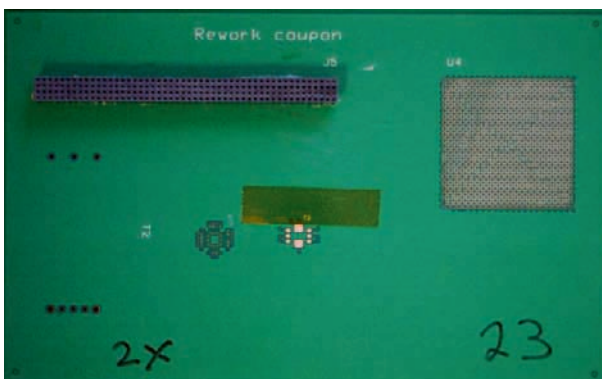


Fig. 3. Rework coupon with through hole connector.

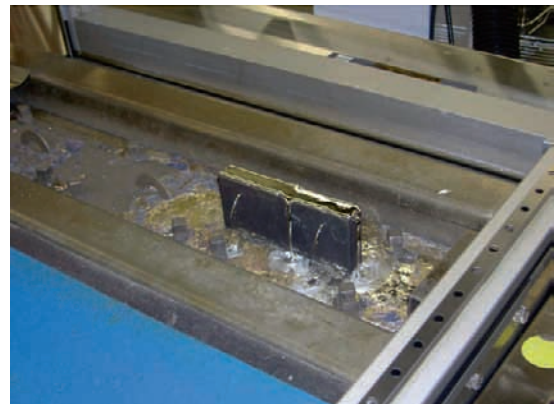


Fig. 4. Standard nozzle during rework operations.

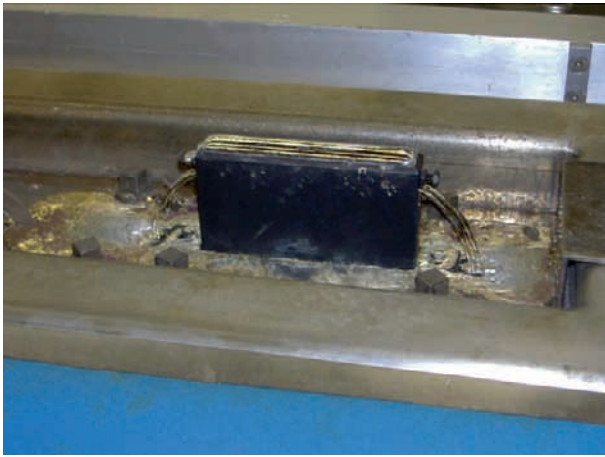


Fig. 5. Hybrid nozzle during rework operations.

Process 2: The Premier Rework RW116 machine was used for initial component installation, component removal and second component installation. This process used the hybrid nozzle design.

Process 3: The Premier Rework RW116 was used for the initial and second component installation. This process used the standard nozzle design for component installation. The Air Vac DRS25 was used for component removal. Previous studies have found that forced convection for component removal together with solder fountain for component installation during rework can have an impact on decreasing copper dissolution rates (Farrell et al., 2007).

The objective was to have a solder pot temperature of 270 °C for the SAC 305 solder. The tin/copper solder has a higher melting temperature than SAC 305, and therefore it is more desirable to use this solder at a higher temperature. Therefore, the solder pot temperature was raised to 287 °C for the tin/copper solder.

For Process 3, the component removal was accomplished by using the Air Vac DRS25XLT machine. The rework coupon was preheated prior to the start of reflow. Once the reflow was complete, the heat nozzle was taken off the component so that the connector could be removed from the rework coupon. The following Fig. 6 shows the use of the Air Vac heat nozzle applying heat to the connector and rework coupon.

Once the connector was removed from the rework coupon, then heat was continuously applied to the rework coupon, and finally

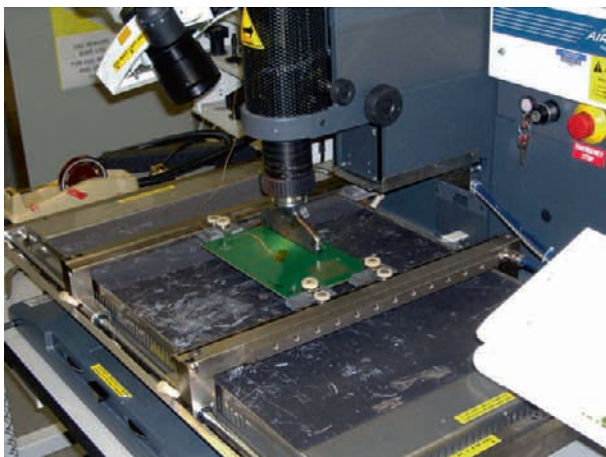


Fig. 6. Air vac machine using heat nozzle.

the vacuum nozzle was used to remove the solder from the connector holes. The key measurements made during the through hole rework process were contact time and copper dissolution. The contact time when the solder in the nozzle is in contact with the bottom surface of the rework coupon was measured for each step in the rework process. For Processes 1 and 2, this included contact time during initial component installation, component removal, and second component installation. For Process 3, this included contact time during initial component installation and second component installation. Microsectional analysis was used to evaluate the level of copper dissolution. Microsections of the connector and rework coupon were conducted to obtain copper dissolution measurements.

3. Results

3.1. Assembly research results: through hole components

Two examples of defects identified during the inspection process are provided. The following Fig. 7 illustrates the insufficient solder defect for one of the leads of component Q17 on the top side of test vehicle number 22.

The following Fig. 8 illustrates the solder bridge defect for component J5 on the bottom-side of test vehicle number 28.

For this research, Analysis of Variance (ANOVA) was utilized to understand the relationship between the lead-free materials used and the assembly results. The overall mean for defects per test vehicle for all combinations was 105 defects per test vehicle. The two best performing solders were tin/copper (2) and the SAC 305 solders with 79 and 96 defects per test vehicle respectively. The two lesser performing solders were tin/lead and tin/copper (1) solders with 115 and 131 defects per test vehicle respectively. The two best performing surface finishes were lead-free HASL and ENIG surface finishes with 51 and 84 defects per test vehicle respectively. The two lesser performing surface finishes were the OSP and nano surface finishes with 142 and 143 defects per test vehicle respectively. The results of the main effects are shown in the Fig. 9 below.

The interaction plot reveals that the ENIG surface finish had a lot of variability across the different solder types. The ENIG surface finish had the lowest defect rate when using the SAC 305 and tin/lead solders, however the ENIG surface finish had the highest defect rate when used with the tin/copper (1) and tin/copper (2) solders. The lead-free HASL had the lowest defect rate for the tin/copper (1) and tin/copper (2) solders, and had the second lowest defect rate for SAC 305 and tin/lead solders. This positive result was expected given that the lead-free HASL finish is comprised of the tin/copper solder alloy. The lead-free HASL surface finish is a good choice for



Fig. 7. THT defect on test vehicle number 22.

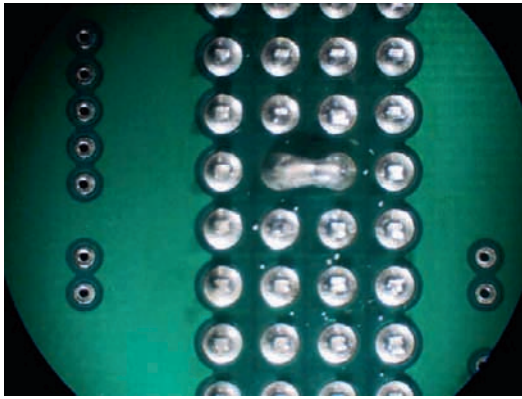


Fig. 8. THT defect on test vehicle number 28.

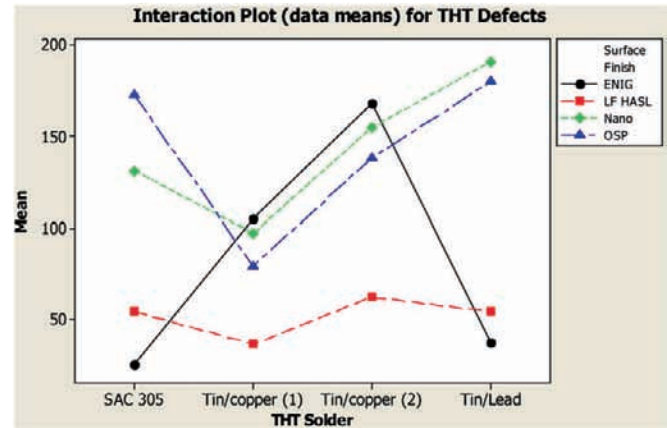


Fig. 10. Interactions plot for through hole component defects.

a company that may use more than one solder type. The performance of the nano and OSP surface finishes were comparable for each of the four solders. The following Fig. 10 illustrates the effect of the interactions for the various combinations.

3.2. Assembly research results: surface mount components

Upon review of the mean values and the main effects plot for this research, it was determined that the SAC 305 OA solder paste had a much higher mean defect rate (8.0 defects per test vehicle) than the overall average of 4.25 as well as all of the other three solder pastes. The other three solder pastes (SAC 305 NC-1, SAC 305 NC-2, and Tin/lead NC) had defect rates between 2.75 and 3.25 defects per test vehicle and each had no-clean flux. For the surface finishes, it can be seen that the nano surface finish had the lowest mean defect rate (2.75 defects per test vehicle), while the other three surface finishes had defect rates between 4.0 and 5.5 defects per test vehicle. The following Fig. 11 is the main effects plot for the surface mount components for all solder types.

3.3. Rework with lead-free materials results

3.3.1. Contact time

Upon review of the means for the main effects and the main effects plot, it was found that the SAC 305 solder had a much lower mean contact time of 65 s as compared to 88 s for tin/copper solder. Process #1 had a much lower mean contact time of 68 s as compared to the mean contact time of 139 s for Process #2. The

only difference between these two processes was the type of nozzle used. Process #1 used the standard nozzle and Process #2 used the hybrid nozzle. The contact time required for solder flow through to the top side of the rework coupon was much greater for the hybrid nozzle than for the standard nozzle. Process #3 had the lowest mean contact time of 32 s because there was no contact time during the component removal process when using the Air Vac machine.

The mean contact time for the ENIG (72 s), nano (70 s), and HASL (77 s) surface finishes were all between 70 and 77 s. The contact time for the OSP surface finish was the highest of the four surface finishes with a mean time of 89 s. The Fig. 12 below show the main effects plot for contact time.

Upon review of the interaction plot, it appears that the main effect of the process is predominate over any of the possible interactions. For example, the Process #2 had the highest contact time for all four surface finishes (ENIG, HASL, Nano, and OSP), Process #1 had the second highest contact time for all four surface finishes, and Process #3 had the lowest contact time for all four surface finishes. In addition, Process #2 had the highest contact time for both solders (Tin/copper and SAC 305), Process #1 had the second highest contact time for both solders, and Process #3 had the lowest contact time for both solders. The following Fig. 13 shows the interaction plot for contact time.

3.3.2. Copper dissolution

The key measurement used to assess the degree of copper dissolution during the rework process is the thickness of the copper at the knee location of the plated through hole. This measurement was taken during the microsectioning process.

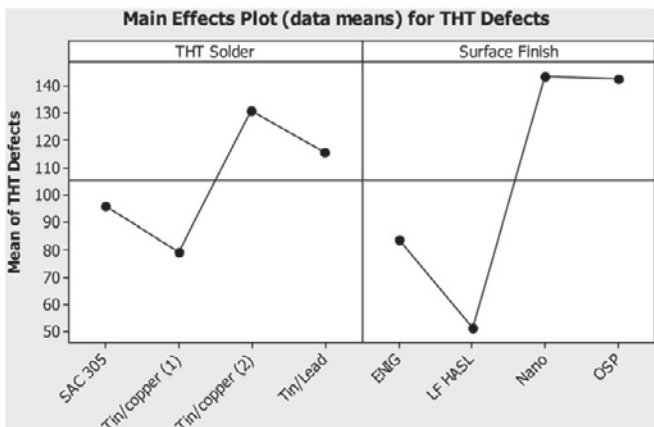


Fig. 9. Main effects plot for through hole component defects.

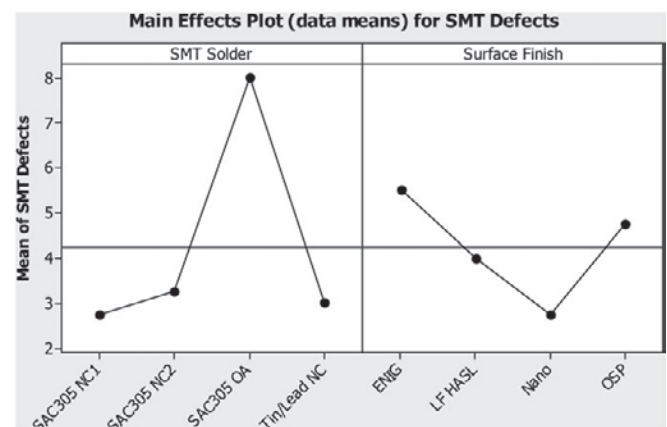


Fig. 11. Main effects plot for the surface mount components for all solder types.

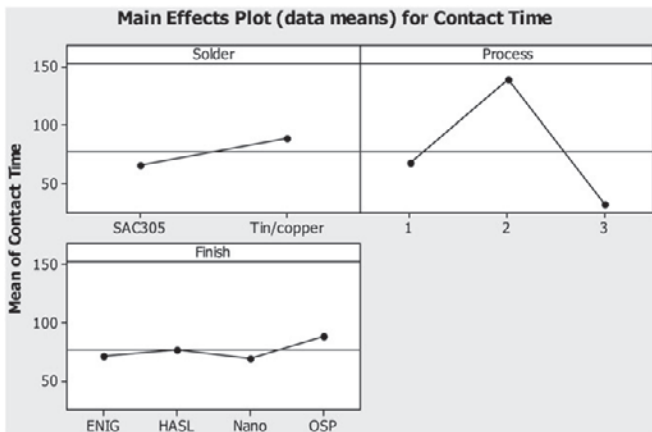


Fig. 12. Main effects plot for contact time.

Microsectioning is a labor intensive process, and only the necessary rework coupons were microsectioned in order to reduce labor needs for this research. Since rework coupons with a ENIG surface finish have a nickel barrier, copper dissolution is typically not considered an issue for these coupons. Consequently, micro-sections were taken on only two out of the six ENIG rework coupons to validate that this assumption was accurate.

The microsectioning was done at the same location on the 200 pin through hole connector for each of the rework coupons. The plated through hole with the most copper dissolution was selected for cross section pictures and copper thickness measurements.

The copper thickness at the bottom side knee location was considered to be the minimum thickness of the copper for the rework coupon. The bottom side knee copper thickness was compared to IPC 6012B “Qualification and Performance Specification for Rigid Printed Boards” standards for minimum copper thickness (IPC, 2004). The target level for the rework efforts was to achieve a Class 3 level which is a minimum of 1.0 mil copper thickness. The IPC 6012B standards for minimum copper thickness are provided below. There were no signs of thermal degradation to the laminate or the component during the rework process.

- Class 3: minimum of 0.001” copper (1.0 mil)
- Class 2: minimum of 0.0008” copper (0.8 mils)
- Class 1: minimum of 0.0006” copper (0.6 mils)

The Main Effects Plot was generated to show the copper dissolution measurements in relation to the solder alloy used, the rework process used, and the surface finish on the rework coupon.

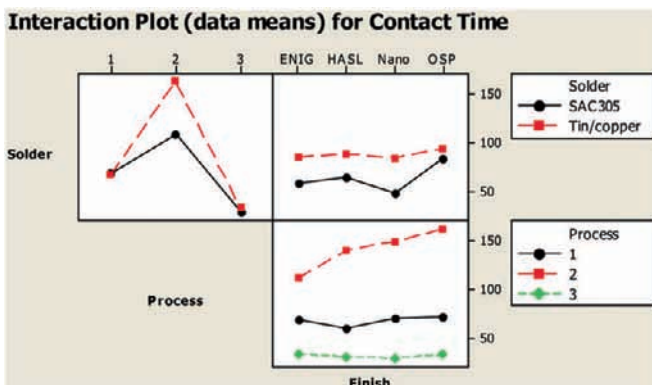


Fig. 13. Interaction plot for contact time.

The following Fig. 14 shows the Main Effects Plot for copper dissolution after completion of the rework process.

Upon review of the Main Effects Plot for Copper dissolution, the following results were obtained.

- Tin/copper solder had 42% less copper dissolution than SAC 305 solder.
- The hybrid nozzle used in Process 2 had 6% less copper dissolution than the standard nozzle used in Process 1.
- Use of the Air Vac for component removal (Process 3) provided 43% less copper dissolution than Process 1.
- ENIG had the lowest copper dissolution, and the nano surface finish had the least amount of copper dissolution for a surface finish without a nickel barrier.

4. Discussion

4.1. Assembly

4.1.1. Surface mount component assembly

The test vehicles assembled with the SAC 305 NC1 solder paste had the lowest defect rate for all the solder pastes evaluated in this research. For test vehicles assembled with lead-free solder pastes, the nano and lead-free HASL surface finishes had the lowest defect rate. For the various lead-free solder paste and surface finish combinations, the combination of SAC 305 NC1 solder paste and the HASL surface finish had the overall lowest defect rate for the test vehicles assembled for this research.

4.1.2. Through hole component assembly

Overall, the test vehicles assembled with the tin/copper (1) solder had the lowest defect rate for all three solders evaluated in this research. For boards assembled with lead-free solders, tin/copper (1) solder had the lowest defect rate, and the HASL surface finish had the lowest defect rate. There was significant variation with the performance of the ENIG surface finish with the various solders. For the tin/lead and SAC 305 solders, ENIG was the surface finish with the least defects, and for both tin/copper solder parameters, ENIG was the surface finish with the most defects. The lead-free HASL surface finish provided the most consistent results as it had either the lowest or second lowest defect rate across all solders.

For through-hole component assembly, the test vehicles assembled with the OSP and nano surface finishes had the highest level of defects. For the test vehicles with an OSP finish,

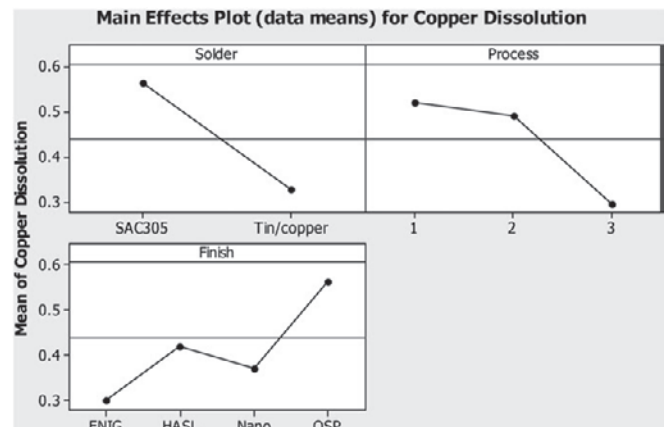


Fig. 14. Main effects plot for copper dissolution.

a contributor to this high failure rate was the time delay between conducting the surface mount assembly and through hole assembly. During this delay, there is potential for degradation of the OSP surface finish that can have a negative impact on subsequent soldering efforts. A key recommendation is to try to minimize the time delay between surface mount and through hole component assembly efforts. Preferably, both procedures should be conducted during the same day.

The best method for applying the nano surface finish to printed circuit boards is to apply it directly to bare copper. However, for the test vehicles used in this research, this method was not followed. Instead, an OSP finish had been previously applied to the test vehicle, then the OSP finish was stripped off, and then the nano surface finish was applied to the test vehicles. The soldering results would most likely be better if the nano surface finish was applied directly to bare copper for further research or assembly efforts.

4.2. Rework

4.2.1. Contact time

Contact time between the test vehicle and the liquid solder in the rework nozzle can be a contributing factor to the generation of copper dissolution. In general, the greater the contact the greater the copper dissolution if all other contributing factors (e.g. solder, surface finish, nozzle design, etc.) are equal. Process #1 had a much lower mean contact time as compared to the mean contact time for Process #2. The only difference between these two processes was the type of nozzle used, where Process #1 used the standard nozzle and Process #2 used the hybrid nozzle. Therefore, the contact time required for solder flow through to the top side of the rework coupon was much greater for the hybrid nozzle than for the standard nozzle.

Process #3 had the lowest mean contact time which can be attributed to no contact time during the component removal process when using the Air Vac machine. The SAC 305 solder had a much lower mean contact time as compared to tin/copper. The contact time for the ENIG was the lowest of the four surface finishes, and the nano surface finish was the lowest of the three other surface finishes without a nickel barrier. The combination of process and surface finish with the lowest contact time was Process #3 with the nano surface finish.

4.2.2. Copper dissolution

The target objective for the rework efforts were to achieve IPC 6012B Class 3 standards for a minimum copper thickness of 1.0 mils or greater. This target was achieved for several rework coupons that underwent rework with lead-free solder and surface finishes. The rework coupons that used the tin/copper solder had greater contact time, but less copper dissolution than the coupons using the SAC 305 solder for the rework efforts. Therefore, the type of solder alloy was a greater contributing factor to copper dissolution than the contact time.

The rework coupons that used Process 2 (hybrid nozzle) had greater contact time but less copper dissolution than Process 1 (standard nozzle). Therefore, the hybrid nozzle was effective at reducing the copper dissolution even though it required additional contact time. The rework coupons that used Process 3 had less contact time and less copper dissolution than both Process 1 and Process 2. The reduction in contact time is attributed to the use of the Air Vac equipment for the component removal. The rework coupons with the ENIG surface finish had the lowest copper dissolution because of the protective nickel barrier. The rework coupons with the nano surface finish had the least amount of copper dissolution for a surface finish without a nickel barrier. Finally, there were no signs of thermal degradation to the laminate or the components during the rework efforts.

5. Conclusions

The cooperation and assistance provided by the members of the Consortium was essential for the ability to successfully carry out this research. From an assembly perspective, the research conducted by the consortium was successful in providing needed information to help companies transition to lead-free electronics assembly. Based on the assembly results achieved by the Consortium, with the careful selection of solder paste and surface finish, it was demonstrated that surface mount and through hole components can be assembled with lead-free materials and achieve equal to or less defects than boards assembled with tin/lead materials. From a rework standpoint, the research was successful in demonstrating that rework with lead-free materials can meet IPC Class 3 standards for minimum copper thickness.

The success of the New England Lead-free Electronics Consortium further demonstrates that the toxics use reduction model can be applied on a supply chain basis. There were benefits from this collaboration to the academic, government, and industry participants. For example, the industry participants were able to have direct input and influence on the type of research that was undertaken. Further, the industry participants were able to share the costs to address a major industry challenge, and as a result were able to derive competitive advantage for early preparedness for transitioning to lead-free electronics.

The academic participants were able to forge collaborative relationships between the university and regional businesses. The research efforts also provided real world learning opportunities for the graduate and undergraduate students that participated at various stages of the research. The government participants were able to reduce the use of a toxic material (lead) which helps create a safer occupational setting and an improved environment. Overall, the government, industry, and academia collaboration was a successful model for applying toxics use reduction principles for a challenging and important application.

Acknowledgements

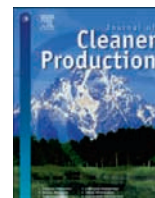
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Note from the field

Helping small businesses implement toxics use reduction techniques: dry cleaners, auto shops, and floor finishers assisted in creating safer and healthier work places

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ABSTRACT

The Toxics Use Reduction Institute (TURI), Boston Public Health Commission (BPHC), and Vietnamese American Initiative for Development (Viet-AID) have worked with small business sectors to reduce their use of toxic chemicals. Three cases, described here, in dry cleaning, auto shops and floor finishing share common approaches for creating successful models of effective dissemination of toxics use reduction in small businesses. These include direct business support, peer-to-peer training and promotion of alternatives, and collaborations with stakeholders to achieve greener businesses. These results were achieved despite predictable barriers of lack of resources, suspicion of safer alternatives, and language and cultural barriers.

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1. Introduction

The mission of the Toxics Use Reduction Institute (TURI)'s Community Program is to help community organizations raise awareness of the hazards of toxic chemical use and introduce safer alternatives within their neighborhoods. The Community Program's small grants to non-profit organizations and municipalities assist them in undertaking their prioritized toxics use reduction projects. Here we describe current initiatives of the Community Program aimed at reducing toxics use in local communities by targeting three small business sectors. The Community Grants program provided support to a municipal health department, a community-based organization and directly to a small business to demonstrate and promote safer alternatives.

The Boston Public Health Commission (BPHC) received a grant from TURI to enable their Safe Shops Project to work with auto

mechanics and auto body shops to replace toxic brake cleaners, parts washers, and painting products with less-toxic and aqueous alternatives. In conjunction with occupational health and safety training, the project helped shops learn from one another by sharing their successes implementing alternative technologies. With the help of TURI, the Vietnamese American Initiative for Development (Viet-AID) worked with floor finishers, a largely Vietnamese population in the Boston area, to educate them about the hazards of toxic and flammable floor finishing products and to learn about the water-based alternatives. The project obtained the most success when they implemented a hands-on training taught by floor finishers and assisted the trained businesses in marketing the safer and healthier alternative materials. TURI's own project—conversion of dry cleaning shops into dedicated professional wet cleaning shops, was a direct effort of the Institute in collaboration with stakeholders. The goal of each of these projects was to build community awareness and support for toxics use reduction and improved working conditions so that the efforts to support change in the participating small businesses might be leveraged and extended. The cases are described in detail below.

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2. Case 1: dry cleaning

2.1. Overview

For over 10 years, TURI has researched alternatives to the use of the carcinogen perchloroethylene (PCE or perc) in garment cleaning and has worked with the Massachusetts professional garment cleaning industry to inform dry cleaners about safer garment cleaning strategies. Through hands-on learning experiences, financial assistance, and technical support, TURI has promoted adoption of wet cleaning processes in particular. Commercial scale demonstrations in Europe and California have shown that wet cleaning is a feasible and safer alternative to solvent-based dry cleaning. The wet cleaning system consists of a washer and a dryer and tensioning equipment. The system is designed to wash “dry-clean-only” clothes with water and detergents in computer-controlled machines and then finish with tensioning and pressing equipment.

TURI first assisted a dry cleaner to convert to 100% wet cleaning in 1995. However, because the technology was not advanced enough at the time to clean all types of garments, the cleaner reverted to solvent-based cleaning. Keoleian et al.'s articles in *The Journal of Cleaner Production* reviewed the status of dry versus wet cleaning technology in 1997 and 1998.¹ Since then, significant advances have been made that have improved wet cleaning equipment and processes, yet the garment cleaning industry has been slow to embrace the alternative technology.

2.2. Promoting and implementing cleaner technology

In 2007, TURI ramped up efforts to promote the new and improved wet cleaning approach. This coincided with an information campaign to make dry cleaning businesses aware that Massachusetts had recently listed PCE as a higher hazard substance under the TURA program, requiring facilities that use PCE in quantities over 1000 pounds in a year to report and plan to reduce their use of the chemical under the Toxics Use Reduction Act (TURA) program. A successful state-sponsored professional garment care project in California served as a model as TURI worked to set up a demonstration site and grant program.² TURI sought to engage the garment cleaning industry in Massachusetts with a positive message about the opportunities to promote their businesses and reap financial benefits from converting to off-the-shelf reliable wet cleaning equipment. We sought out the advice of California experts and cleaners, as well as Massachusetts trade associations, academics, community organizations, media, vendors, and electricity suppliers. This stakeholder group was engaged at the beginning of our work in order that they might feel fully committed to the project.

We began our outreach campaign with a mailing to Massachusetts garment cleaners using the Massachusetts Environmental Results Program (ERP) mailing list (the ERP regulates all dry cleaners using PCE). The mailing included information about the hazards of PCE and about available alternative garment cleaning technologies. TURI then hosted a demonstration day to allow cleaners to see wet cleaning equipment first hand (Photo 1). The Institute then advertised the availability of grant funds to support the conversion of a dry cleaner to wet cleaning equipment. Two Massachusetts cleaners were selected to receive approximately

\$17,000 to convert their facilities. In return, the cleaners collected performance, operation, and resource use data for TURI to analyze. The sites also hosted demonstration events at their facilities in order to educate other cleaners about wet cleaning and demonstrate it as a feasible alternative.

2.3. Barriers and opportunities for promoting TUR in dry cleaning

Small businesses need support and encouragement to adopt cleaner technologies. Regulations that level the playing field with universal requirements facilitate such changes and open the minds of reluctant businesses to new approaches. There are no significant regulatory incentives to induce change in the garment cleaning sector with the exception of the recent higher hazard substance listing of PCE in the TURA program that may induce larger cleaners to move towards wet cleaning or other alternatives to avoid the reporting and planning requirements.

TURI found that the garment cleaning trade associations and many cleaners are dubious about the feasibility and effectiveness of 100% wet cleaning. TURI has continuously engaged with the trade associations to gain their support in our efforts to convert shops to 100% wet cleaning. Our University-sponsored demonstration events helped to convince cleaners and the trade associations by allowing them to scrutinize the technology first hand.

In California, public utilities have financially-supported garment cleaning conversion programs in order to promote the energy and pollution savings that such conversions provide.³ However, Massachusetts utilities have only provided limited support of this project in Massachusetts (National Grid did provide \$2500 to one of the cleaners toward the conversion to wet cleaning). TURI continues to inform them of our work and provide them with resource use data from our demonstration sites to help make the case for wet cleaning as an energy saving technology.

For many dry cleaners in Massachusetts, English is not their first language. To help overcome this barrier, we provided much of our information in Korean as well as English. In addition, the second grantee dedicated wet cleaner is Vietnamese and is able to communicate his experience with wet cleaning to other Vietnamese cleaners.

Our main objective with this project has been to broaden acceptance and use of wet cleaning technology. Through our demonstration sites we have been able to educate over sixty cleaners about the updated wet cleaning technology. TURI has also engaged in conversations both on a regional and national level about the project, teaching other states and pollution prevention experts about our methods and lessons learned on this project. Throughout the project, TURI has solicited feedback from partners and stakeholders – especially from dry cleaners. While requests for written evaluation of our program efforts were not fruitful, we were able to gain guidance from cleaners in feedback sessions during events that will help guide us in future work with this sector.

3. Case 2: auto shops

3.1. Overview

Small automotive businesses represent a major source of both well paying jobs and exposure to hazardous chemicals for workers and their neighbors. The more than 550 automotive repair and body shops in Boston are primarily small independent garages

¹ Keoleian, G.A. et al. Comparative Assessment of Wet and Dry Garment Cleaning. *Journal of Cleaner Production* 1997; 5(4):279–289 and 1998; 6: 23–36.

² Sinsheimer, P., Grout, C., Namkoong, A., Gottlieb, R., & Latid, A. (2007). The Viability of Professional Wet Cleaning as a Pollution Prevention Alternative to Perchloroethylene Dry Cleaning. *Journal of the Air & Waste Management Association* (1995), 57(2), 172–178.

³ Sinsheimer, P. “Demonstrating the viability of professional wet cleaning: California and beyond.” Presentation to the Northeast Waste Management Officers’ Association, March 8, 2008. Available at: <http://www.njsbdc.com/njwetcleaning/OxyPPC.pdf>.



Photo 1. TURI wet cleaning demonstration event.

employing no more than three or four people including the owner/manager himself. Boston's auto shop workers are predominantly lower income Black and Latino (often recent immigrants) younger men with limited English fluency and limited education. Auto shops are clustered in several Boston lower income neighborhoods, often in close proximity to homes, schools, and daycare centers. Too numerous and small to be effectively targeted by enforcement agencies, many are not in compliance with existing occupational, environmental, and safe use regulations. City inspector case files paint a telling picture of improperly stored chemicals and wastes, illegal disposal of materials, uncontrolled releases of hazardous chemicals into the air, and unsafe working conditions at shops across the city.

With support from federal, city and state funds, including a grant from TURI, the Boston Public Health Commission created the Safe Shops Project in 2003 to assist these businesses in improving their operations to reduce pollution, protect their workers and neighbors, and comply with regulations. The Project takes an integrated approach to business assistance by providing worker education, connection to health care/insurance resources, toxics use reduction technical assistance, and connection to financial resources to assist in implementing changes. The worker education component includes information about shop hazards, how to find information on products, best work practices and personal protective equipment to prevent worker exposure and pollution.

The Project's technical assistance focuses on efforts to help shop owners identify products, equipment, or processes that can be upgraded or replaced in order to prevent pollution and toxic exposures. For example, most small auto repair shops use aerosol spray cans to clean brake drums and rotors before installing new brake pads. These products contain perchloroethylene or similar toxic organic solvents associated with cancer, organ damage, and neurological impairment.⁴ Additionally, the use of a spray can may result in the release of asbestos fibers from brake rotors. In auto

body shops, paint spray gun washing can result in significant worker exposures and release of solvents to the neighborhood.

3.2. Promoting and implementing cleaner technology

With a grant from TURI, the Safe Shops Project worked with three auto repair shops to implement a trial of an alternative water-based system to replace the aerosol brake cleaner and with two auto body shops to initiate use of an alternative spray gun cleaner recommended by the US EPA. The Safe Shops Project negotiated an agreement with each shop to use the water-based products exclusively for three months and the Project would pay for the cost of the safer alternative during that time. Each shop agreed to provide their feedback and comments on the experience for inclusion in the Safe Shops Newsletter mailed to all auto shops in the City of Boston. Shops that wished to continue using the product after the three-month trial period at their own expense were given large promotional banners to hang in their shop advertising the work they are doing to protect the environment and their workers.

The alternative spray gun cleaner recommended by the U.S. Environmental Protection Agency (EPA), Acrastrip 400 made by US Polychemical Corp., is a less-toxic alternative to lacquer thinner or mineral spirits. This replacement greatly improved the air quality in the shops resulting in a 98% reduction of acetone and a 59% reduction in toluene in the air in one shop, and a 94% decrease of the presence of acetone, and an 88% decrease in the presence of toluene in the air of the other (Photo 2).

The alternative brake cleaning product is a water-based non-toxic, non-flammable cleaner produced by Safety-Kleen. The product qualifies as a "wet method" under the U.S. Occupational Safety and Health Administration's (OSHA) recommendations for reducing asbestos dust exposure during brake cleaning.⁵ Normally,

⁴ Contra Costa Health Services, Hazardous Materials Program. "Aerosol cleaner use in auto repair." In *The Haz Mat Recorder*, October–December, 2007. Available at: http://cchealth.org/groups/hazmat/pdf/recorder_volume_55.pdf.

⁵ United States Department of Labor, Occupational Safety and Health Administration. "Asbestos-automotive brake and clutch repair work." *Safety and Health Information Bulletin* 07-26-2006. Available at <http://www.osha.gov/dts/shib/shib072606.html>.



Photo 2. Auto body shop demonstrates new equipment.

Safety-Kleen requires a one-year contract for the cleaning equipment (a special rolling sink/reservoir and pump) and servicing. However, the Safe Shops Project was able to negotiate an agreement with the local sales representative to pre-pay for the three-month trials for the individual shops without a contract.

After the trial period, three of the five shops (one body shop and two repair shops) adopted the water-based products. The costs of both of these systems were identical to the monthly expense of using their normal product. Both auto body and repair shops appreciated the improvement in the air quality in the shop and believed that the quality of the cleaning was comparable to the solvent-based methods. The auto repair shops observed that the aqueous brake cleaner resulted in quicker brake jobs because it eliminated brushing and scraping processes.

The Safe Shops Project staff incorporated the comments and experiences of the volunteer shops into articles in a Safe Shops Newsletter. This newsletter (<http://www.bphc.org/programs/cib/environmentalhealth/environmentalhazards/safeshops/recognitionandpress/Forms%20Documents/2007%20Safe%20Shops%20Newsletter.pdf>) was mailed to all of the known auto shops in the City of Boston to promote the program. The newsletter is printed in both Spanish and English and features the stories of local shops so that others can see real world examples from people they know and can follow up with. The Safe Shops Project continues to promote conversion to aqueous brake cleaner and the US EPA recommended gun washer as logical and affordable pollution prevention and toxic use reduction strategies for small auto shops.

3.3. Barriers and opportunities for promoting TUR in auto shops

Many auto shop owners and workers had had some experience with unsatisfactory alternative products many years earlier. The Safe Shops Project worked hard to dispel myths that the current generation of safer alternatives was expensive and inferior products. This required that funding be available to place alternatives

into the hands of auto shops on a free-trial basis. Shop owners are reluctant to experiment with new chemicals or devices (which may require a long-term contract) when business income is at stake. TURI funding was critical to overcoming this barrier. The promotion of successful TUR trials by the shops themselves via banners and their own words and pictures in newsletters was key to getting the attention of other shops. The Safe Shops Project hopes to continue to leverage and promote the successful demonstrations to other shops throughout the city.

4. Case 3: floor finishing

4.1. Overview

Since 2002, Viet-AID has worked with the Dorchester Occupational Health Initiative and researchers from the University of Massachusetts Lowell to better understand and address Vietnamese workers' occupational health issues. Special attention has been paid to hardwood floor refinishing, a sector that employs a high concentration of Vietnamese workers and that is an important economic anchor for the Boston Vietnamese community. There are numerous occupational and environmental health and safety issues in this sector and most workers are offered little protection from exposure to hazardous chemicals in conventional products.

In the early 2000s, house fires left three Vietnamese floor finishers dead, four badly burned, and two homes destroyed in two Massachusetts communities.⁶ Investigation of these fires found that they were caused by ignition of the highly flammable chemicals used in lacquer sealers. In response to these devastating fires and the on-going concerns about occupational and environmental

⁶ Massachusetts Department of Fire Services. "Board of Fire Prevention regulations address floor refinishing." December 14, 2009. Available at: http://www.mass.gov/Eeops/docs/dfs/news/press/20091214_floor_finishing.pdf.



Photo 3. Water-based floor finishing training.

exposures common in these small businesses, Viet-AID founded the Healthy Floor Finishing Project to promote product substitution in the sector. The first most urgent task was to promote the use of non-flammable floor finishing products to replace highly flammable products. The Project has also promoted the use of alternative hardwood floor finishing products that, in addition to being non-flammable, are less toxic and less damaging to the environment than products in common use. Many non-flammable floor finishing products contain high levels of volatile organic compounds (VOCs). Even products that comply with new the Ozone Transport Commission regulations in effect in some states (in the Northeast and Mid-Atlantic regions) can contain up to 450 g/l of VOCs. However, very-low-VOC, water-based products are available.

4.2. Promoting and implementing cleaner technology

Over the last three years, the Healthy Floor Finishing Project has engaged a wide range of stakeholders – floor finishing product manufacturers and distributors, floor finishing companies, industry, labor, community, health and safety professionals and state and municipal agencies – in efforts to promote awareness of less-toxic products in the Greater Boston area, and, in particular, among floor finishing small business owners and workers and consumers through outreach campaigns. The Project has conducted numerous hands-on trainings by floor finishers for floor finishers demonstrating the less-toxic products and has also provided technical assistance to companies switching over to alternative products.

The education and training program includes information about fire prevention and basic health and safety issues with an emphasis on product substitution to prevent fires. Hands-on segments demonstrate the application of non-flammable products, use of safer machinery, and other basic health and safety practices. The project used these trainings to make a Vietnamese-language

training film produced as a DVD for distribution to floor finishing businesses.⁷

The Project also developed content for newspapers, television and brochures about product substitution for fire prevention and to protect health and the environment. Our public education campaign included: a monthly 20-minute segment on the local Vietnamese community affairs cable television public access program; a monthly column in the Massachusetts Vietnamese-language newspaper, *Tieng Chuong*; brochures and posters on display in the largest floor finishing product supply stores serving Boston-area floor finishers; and through verbal communications via the Vietnamese–American Small Business Association.

Technical assistance for floor finishers focused on strategies for marketing healthier, environmentally-friendly floor finishing to consumers and ways to strengthen their business operations overall by improving planning, bookkeeping and regulatory compliance. The Project guided floor finishing company owners in integrating healthier products and practices into their business and marketing plans. The Project focused intensively on a group of six to eight trainees to build a model crew of “green floor finishers.” These model companies received a combination loan package for marketing activities, safer equipment and materials, such as dust-less sanding equipment and high quality water-based finishes, and financial planning. The Project worked with stakeholders to develop standards of practice that would be required to be met to qualify “green floor finishers.” Floor finishers that meet these criteria benefit from listing and marketing services, such as use of the Green Floor Finisher logo on their business cards. Program staff worked with participants to develop marketing binders featuring photos of their jobs, testimonials and references from happy customers, and information on product safety and quality. Marketing plans include identifying and targeting customers who

⁷ See <http://www.youtube.com/watch?v=elA0uGbPPE0> for the English-language version of the video.

value healthier service. Floor finishers who meet defined standards for health and safety are promoted to potential customers on the Project website.

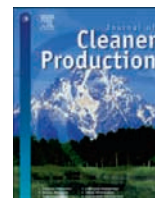
4.3. Barriers and opportunities for promoting TUR in floor finishing

A lack of experience with the alternative products resulted in some business owners believing that they result in a finished floor not meeting high standards. Some products do require a modification in the standard floor finishing process including small changes in tools and methods to produce good finishes. The Healthy Floor Finishing Project included testimonials and demonstrations of high quality finishes produced using water-based products and described how to modify standard methods where appropriate (Photo 3).

The greater cost to purchase water-borne and other safer products has emerged as a barrier to adoption for small companies in this highly competitive industry. The Project therefore had to teach businesses how to achieve higher fees for providing safer and healthier services. One key lesson from our project is the important role played by consumer demand in pushing product substitution in the wood floor finishing industry. Time and again, training participants and members of the floor finishing community reported that they would shift to safer and healthier products if customers requested them. The Project's marketing of the availability of greener finishers and increasing concerns about the hazards of floor finishing products did generate many calls for information on safer products and practices, and, specifically, references for floor finishers skilled at using the preferred products. Several community leaders seeking to promote safer floor finishing in their neighborhoods or residential developments expressed an urgent need for facts and materials to use in their advocacy. An important next step will be a focus on consumer education about the advantages of a less-toxic and safer approach to floor finishing.

5. Conclusion

These projects have had success by including four key elements: 1) direct funding and support to small businesses in form of grants or loans to purchase alternative materials and equipment, 2) hands-on training opportunities to learn about cleaner technologies, most often in a peer-to-peer model; 3) collaboration with industry associations, community groups, and other advocates and stakeholders; and 4) promotion and dissemination of successes to encourage similar small businesses to learn about safer alternatives. Additionally, each project was acutely sensitive to the intense demands on small businesses and their limited resources for innovation. These cases demonstrate that a model of toxics use reduction technical assistance tailored to the needs of small immigrant businesses can yield tangible results including significant reduction in both worker and community exposure to toxics. Pollution prevention agencies, health departments and community assistance programs can help implement toxics use reduction in these same sectors or expand into others, bearing in mind the common barriers and opportunities described in the cases above, such as the need to provide general business assistance and education; including information to help overcome a legacy of inferior "green" products. The need also exists to incorporate occupational health and safety concerns into toxics use reduction technical assistance in order to enable and entice small businesses to make fundamental changes. In addition to education of workers, the education of consumers and clients is also critical to the furthering of this work. Such success stories can have policy implications as regulators and elected officials feel more comfortable turning best practices into required ones. Based on these successes and with the support of TURI, the organizations involved continue to push to expand the model to other businesses. For example, the Safe Shops Project has partnered with Viet-AID to reduce hazardous exposures in nail salons throughout Boston.



Analysis of risk trade-off relationships between organic solvents and aqueous agents: case study of metal cleaning processes

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ABSTRACT

When substance substitution is implemented to reduce the target risk of production processes, countervailing risks may occur. The goal of this study is to analyze the risk trade-off relationships between organic solvents and aqueous agents in the case study of metal cleaning processes. Global environmental impacts and local risks were evaluated for the eight scenarios by life cycle and risk assessments, respectively. The results show that the contribution of the processes using chlorinated solvents to photochemical ozone creation, human toxicity, ozone depletion, and ecotoxicity was larger than processes using aqueous detergents, while the contribution of aqueous processes to eutrophication was larger than chlorinated processes. Neighbors' health risk around a cleaning site using chlorinated solvents was sufficiently small in all scenarios, whereas ecological risk due to surfactants which are contained in aqueous detergents and emitted to the local aquatic environment should be reduced. Cleansing agents and process facilities should be selected on the basis of the comprehensive analysis of risk trade-off relationships for feasible and cleaner production.

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1. Introduction

Various chemical substances are used in industry as product materials and process chemicals. As issues related to the environment and human health are considered important, possible risks of production processes need to be identified and reduced at the process design stage (Cano-Ruiz and McRae, 1998; Chen and Shonnard, 2004). Organic solvents are used for many purposes, e.g., as cleansing agents in metal cleaning processes and as components of inks and paints in printing and painting processes. Some organic solvents have been an issue of public concern in Japan owing to their human toxicity and contribution to air pollution (METI-Kanto, 2009). The replacement of volatile organic compounds (VOC) with a chemical substance that is less toxic or less volatile has been recommended, and aqueous agents have been suggested as alternatives (Verschoor and Reijnders, 2001). For example, aqueous detergents have been substituted for chlorinated organic solvents, such as dichloromethane, trichloroethylene, and perchloroethylene in the cleaning industry (Rydberg, 1994). As a result, the sales volume of aqueous detergents in Japan increased from 22,978 ton in 1999 to 37,247 ton in 2007 (JICC, 2001; METI, 2009b). Water-based inks and paints have been developed as

alternatives to conventional solvent-based inks and paints in the printing and painting industries (Geldermann and Rentz, 2004; Vachon and Klassen, 2006).

Although VOC emission can be reduced by substance substitution, the adverse effects of alternative aqueous agents originating from their hazards have not been taken into account. Processes using aqueous agents generally emit a large amount of wastewater, and thus adverse effects of contaminants in wastewater may occur as a result of the substitution (Lavoué et al., 2003). Such a phenomenon in which the countervailing risk is generated by an intervention to reduce the target risk is referred to as a risk trade-off relationship (Graham and Wiener, 1997). The countervailing risk may offset reductions in the target risk (Gray and Hammitt, 2000), or the type and affected population of the countervailing risk are different from those of the target risk (Hofstetter et al., 2002). Thus, it is necessary to evaluate various risks originating from chemical substances and identify risk trade-off relationships among them in order to design an appropriate cleaner process.

Life cycle assessment (LCA) is a tool for quantifying potential impacts on the environment by analyzing emissions of chemical substances from processes throughout the whole life cycle of a product. It enables the evaluation and comparison of design options for process modifications with regard to various impacts on the global environment, e.g., global warming, acidification, ozone depletion, and eutrophication (Azapagic, 1999). In general, the absolute magnitude of such impacts is not important in LCA,

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because evaluation results are presented with marginal values that indicate changes in environmental impacts due to process modifications. In contrast, risk assessment (RA) (Kolluru et al., 1996), which has been used as an assessment tool in process design, is aimed at evaluating the absolute magnitude of risks by comparing evaluation results with absolute standards (Cowell et al., 2002). The acceptability of risks should be the major concern of a process plant, particularly for the health risk of workers and neighbors around the plant, and the ecological risk in the local environment. RA can be applied to the evaluation of such local risks. The integration of LCA and RA has been discussed in several studies. Similarities and differences between LCA and RA are examined (Cowell et al., 2002; Tukker, 2002), and procedures and required information for the integration are clarified (Kikuchi and Hirao, 2009). The application of the integrated LCA and RA to process evaluation has been studied (Kikuchi and Hirao, 2008a, 2010; Sonnemann et al., 2000), and the framework to evaluate both of the environmental performance and local health and safety issues related to solvents has been proposed (Capello et al., 2007) by implementing case studies.

The utilization of organic solvents in industry has been the subject of many studies. Technologies for treating VOC in exhausted gas have been developed (Peishi et al., 2004; Stehlik et al., 2004), and their engineering and economic performance have been evaluated (Mulholland and Dyer, 1999). Technological tests on alternative solvents and their hazard assessment have been implemented (Sikdar and El-Halwagi, 2000; Trivedi et al., 2004). The impacts of chlorinated organic solvents in metal cleaning processes have also been analyzed by LCA (Hellweg et al., 2005; Kikuchi and Hirao, 2008b) and by integrated LCA and RA (Kikuchi and Hirao, 2008a, 2010). As to the comparison between organic solvents and alternative aqueous agents, an LCA study was performed for metal parts degreasing processes (ECSA, 1996). It is necessary to evaluate and compare organic solvents and aqueous agents in terms of both global impacts and local risks. Risk reduction measures including substance substitution should be selected on the basis of a comprehensive interpretation of such evaluation results.

In this study, the risk trade-off relationships between organic solvents and aqueous agents are analyzed in a case study of metal cleaning processes. Impacts on the global environment and risks in the local environment are evaluated by LCA and RA, respectively, for cleaning processes using chlorinated solvents and aqueous detergents. The cleaning processes evaluated in the case study are those using washing machines and other process facilities that are conventionally used in Japan. Risk trade-off relationships are illustrated by clarifying the differences in the major risks between organic solvents and aqueous agents on the basis of comprehensive interpretation of LCA and RA results.

2. Materials and methods

2.1. Introduction to metal cleaning

Metal cleaning is an essential process in metal processing, e.g., metal finishing, fabrication, and assembly. Metal parts are greased before cutting or pressing in order to reduce friction. As process oils on the surface of metal parts can be impurities in the following process, cleaning processes are needed to remove them with cleansing agents. A variety of chemical substances are used as cleansing agents. They can be categorized into three groups: solvents, aqueous detergents, and semiaqueous detergents. Although various solvents, such as chlorinated organic solvents, brominated organic solvents, hydrocarbons, fluorocarbons, and alcohols, are used according to cleaning requirements, chlorinated

solvents are most widely used in Japan, accounting for 31% of the total shipment of cleansing agents in 2007. This is followed by aqueous detergents (27%), hydrocarbons (19%), and alcohols (16%) (METI, 2009b).

Fig. 1(a) shows a typical metal cleaning process using chlorinated solvents with an open-top washing machine. The process entails washing, rinsing, vapor washing, and drying. An open-top washing machine has three tanks equipped with heaters at the bottom for heating solvents and coolers for recovering vaporized solvents. A significant amount of solvents, which are not condensed and recovered by coolers, is emitted from the top of the machine. To reduce solvent emission from cleaning machines, semiclosed washing machines equipped with a shutter are installed in some cleaning sites. Solvent emission can be reduced by 75–90% compared with that of an open-top machine if the shutter is closed while input metal parts are automatically conveyed inside a machine (T.C.C., 2006).

Using an alternative cleansing agent is another possible measure of eliminating the adverse effects of chlorinated solvents from the perspective of hazard management. Some Japanese cleaning sites have substituted aqueous detergents for chlorinated solvents (MOE, 2007). Alkaline detergents, which are the most used aqueous detergents in Japan, are composed of inorganic alkali compounds, surfactants, and other additives. A typical cleaning process using aqueous detergents is shown in Fig. 1(b). This process entails washing, rinsing, and drying. Washing tanks are filled with a water solution of aqueous detergents, and rinsing tanks are filled with water. The number of tanks and the purity of water for washing and rinsing may vary according to required cleanliness. Rinsed metal parts are dried using drying machines such as a hot-air-blowing dryer and a spin dryer.

There are similarities and differences between chlorinated solvents and aqueous detergents used in metal cleaning processes. They both play a role as process chemicals rather than as product materials. Chlorinated solvents dissolve and detach oils from the surface of metal parts, whereas aqueous detergents saponify or emulsify them (JICC, 2004). They are removed after playing their role: Chlorinated solvents are vaporized, and aqueous detergents are rinsed. Regarding their differences, chlorinated solvents are emitted mainly to the atmosphere during and after utilization, because they can be easily vaporized and released from a process. On the other hand, aqueous detergents are released as part of wastewater and released into public water bodies or sewers.

2.2. Analysis of risk trade-off relationships

When aqueous detergents are used as an alternative to chlorinated solvents, risk trade-off relationships result. First, the trade-off relationships of global impacts may appear between processes using chlorinated solvents and aqueous detergents. VOC emitted from processes using chlorinated solvents to the atmosphere can create photochemical ozone and cause air pollution, while wastewater emitted from processes using aqueous detergents can contribute to eutrophication.

Second, local risks that appear in a cleaning site and its surrounding environment differ between processes using chlorinated solvents and aqueous detergents. If a large amount of chlorinated solvents is emitted from a washing machine, human health risks in the neighborhood are a serious concern. Meanwhile, if components of aqueous detergents contained in wastewater are emitted to the local aquatic environment, they may pose risks to aquatic lives. As locations where those risks may be posed and populations bearing the risks are clearer than potential impacts on the global environment, the acceptability of each local risk should be carefully considered.

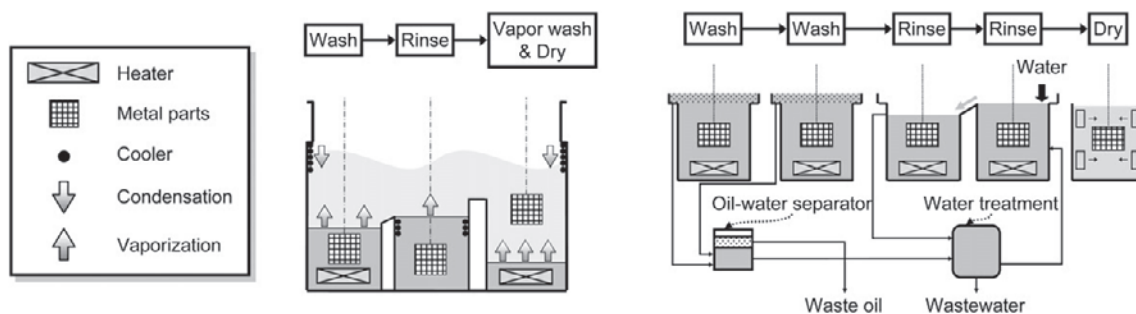


Fig. 1. Typical metal cleaning processes in Japan: (a) process using an open-top washing machine and a chlorinated organic solvent (Kikuchi and Hirao, 2008a) and (b) process using an aqueous detergent.

2.3. LCA and RA

Although LCA and RA are both evaluation tools for products and processes by quantifying the impacts of the emission of chemical substances on the environment and humans, they differ in data used for evaluation and in information obtained from evaluation results. Environmental impacts evaluated in LCA are related to a functional unit that is a measure of the service delivered during the life cycle of a product under study. The amount of all chemical substances emitted from the life cycle is calculated in life cycle inventory analysis (LCI). Although those chemical substances may be emitted on different temporal and spatial scales, they are summed up in order to evaluate their potential impacts on the global environment (Tukker, 2002). In life cycle impact assessment (LCIA), midpoint indicators of impact categories, such as global warming and ozone depletion, can be used to measure the potencies of such impacts on the global environment. Endpoint indicators are available in some LCIA methods in order to analyze damage to areas of protection (AoP) as a result of the impacts. Changes in global impacts, rather than the absolute magnitude of impacts, are quantified in LCA, because LCA results are mainly used for the purpose of environmental improvements (Sonnemann et al., 2000), i.e., LCA results show the relative magnitude of potential impacts on the global environment.

In contrast, RA is aimed at evaluating the likelihood and severity of a specific harmful effect originating from products or processes (Cowell et al., 2002). It generally focuses on toxicological risks due to emissions of individual chemical substances. As local risks that may be posed in one or a limited number of sites are a concern in RA, the location of emission sources and the temporal variation in the emission of chemical substances need to be defined during evaluation (Tukker, 2002). The significant feature of RA is that its results show the absolute magnitude of actual risks. The acceptability of risks can be judged by comparing risk indicators and absolute standards.

3. Case study

3.1. Scenario settings

Fig. 2 shows the life cycles of chlorinated solvents and aqueous detergents used in metal cleaning processes. The life cycle of chlorinated solvents comprises four stages: agent production, cleaning, distillation recycle, and incineration. Waste fluid containing solvents and process oils can be recycled by distillation. A residue of the waste fluid, which is mostly composed of process oils, is incinerated. The life cycle of aqueous detergents includes wastewater treatment and sludge incineration as well as agent production and cleaning. Wastewater from the processes using

aqueous detergents contains process oils and aqueous detergents. The effluent standards established by the Water Pollution Control Act (MIC, 2009) in Japan restrict the concentration of toxic substances and the values of water quality indices, such as pH, chemical oxygen demand (COD), and phosphorus content, for wastewater to be discharged into public water bodies and sewers. They are further restricted by the ordinance of some municipalities. To satisfy such restrictions, contaminants contained in wastewater from the cleaning site need to be treated before discharging. The neutralization of inorganic alkali compounds in wastewater is implemented in most cleaning sites, and additional equipment for oil–water separation and coagulation sedimentation is installed in some cleaning sites. Wastewater may be further diluted before discharging in order to lower the concentration of contaminants, although dilution is not recommended by the pollution control ordinance in some municipalities. Finally, treated wastewater is discharged into public water bodies or sewers, while sludge composed of process oils, surfactants, and phosphates is incinerated.

Eight scenarios were developed and evaluated in this case study. Metal cleaning processes using chlorinated solvents were analyzed in three scenarios (SOL1–3), and processes using aqueous detergents were analyzed in five scenarios (AQU1–5). Table 1 shows a summary of the conditions of the eight scenarios. Primitive cleaning processes that are still operated in some cleaning sites in Japan were analyzed in SOL1 and AQU1. An open-top machine is used in the process of SOL1. Processes that are modified to reduce expected risk were investigated in SOL2 and SOL3 in order to see the effectiveness of risk reduction measures implemented in Japan. An open-top washing machine in the process of SOL2 can recover more solvents than that in the process of SOL1, because its chiller is improved. The process of SOL3 uses a semiclosed washing machine that can significantly reduce solvent emission.

Aqueous processes of AQU2 and AQU3 differ from that of AQU1 in the purity of water used for cleaning and wastewater treatment. Although the purity of water affects cleanliness, and thus these three processes have different functions of metal cleaning, the processes were still evaluated to see how water selection can affect environmental impacts. Although wastewater is treated by only neutralization, and then diluted to meet the effluent standards in AQU1–3, additional equipment for removing organic contaminants and phosphates is installed in AQU4 and AQU5. An oil–water separator installed for the processes of the two scenarios can separate process oils. In the process of AQU5, coagulation sedimentation equipment, which can remove not only process oils but also surfactants and phosphates, is installed in addition to the oil–water separator. Finally, treated wastewater is discharged into public water bodies, whereas collected sludge is incinerated.

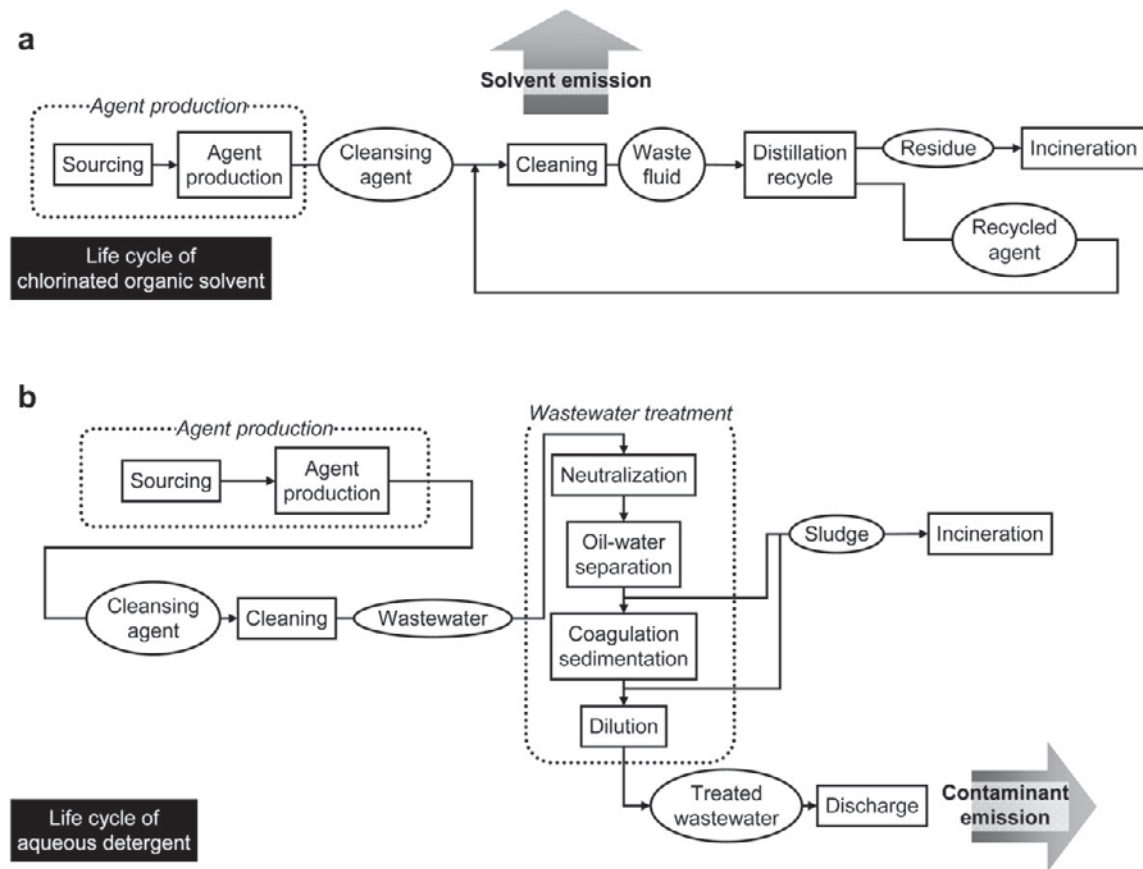


Fig. 2. Life cycle of cleansing agents: (a) chlorinated organic solvent (Kikuchi and Hirao, 2008a) and (b) aqueous detergent.

3.2. Analysis settings

Detailed data used for evaluation are summarized in Table 2. Process data of cleaning processes owned by electroplating plants were obtained from the literature (JMF, 1993) and used in evaluation, although some data were assumed on the basis of statistics from the cleaning industry. Trichloroethylene (TCE) is used in processes of SOL1–3. The amount of inputted solvents including recycled solvents is the largest in SOL1. Reductions in solvent emissions in SOL2 and SOL3 would lead to reduced solvent consumption by 47% and 90%, respectively. Aqueous detergents were assumed to be composed of sodium hydroxide, sodium silicate, sodium phosphate, sodium carbonate, and polyoxyethylene alkyl ether (POER) on the basis of the typical composition of aqueous detergents used in Japan (Mamiya, 1998). The oil–water

separator installed in the processes of AQU4 and AQU5 can separate 90% of oils from wastewater as sludge, and the coagulation sedimentation equipment installed in the process of AQU5 can separate 99% of oils, 96% of surfactants, and 90% of phosphates as sludge (MITI, 1980). It was assumed that treated wastewater is discharged into the Tama River in Japan.

The functional unit in LCA was defined as “daily cleaning of 300 kg metal parts.” The second version of the Life cycle Impact assessment Method based on Endpoint modeling (LIME2) (Itsubo and Inaba, 2003, 2005) was used as an LCIA method. The environmental impacts of nine categories were evaluated: global warming, ozone depletion, acidification, urban air pollution, eutrophication, photochemical ozone creation, human toxicity, ecotoxicity, and waste. Background inventory data, such as utilities required for the production of cleansing agents and associated

Table 1
Conditions of the eight scenarios analyzed in this case study.

Scenario	Cleansing agent	Washing machine		Wastewater treatment	Water for cleaning and dilution	Fuels for distillation and recycle
		Type	Utility			
SOL1	Trichloroethylene	3 tanks, open-top	Electricity	–	–	Kerosene, electricity
SOL2		3 tanks, open-top, chiller is improved	Electricity	–	–	Kerosene, electricity
SOL3		Semiclosed	Electricity	–	–	Kerosene, electricity
AQU1	Aqueous detergent	4 tanks (washing)	Electricity	Neutralization, dilution	City water	–
AQU2		(2 tanks), rinsing,	Electricity	Neutralization, dilution	Industrial water	–
AQU3		drying)	Electricity	Neutralization, dilution	Deionized water	–
AQU4			Electricity	Neutralization, oil–water separation, dilution	City water	–
AQU5			Electricity	Neutralization, oil–water separation, coagulation sedimentation, dilution	City water	–

Table 2
Data used for evaluation in this case study.

		SOL1	SOL2	SOL3	AQU1	AQU2	AQU3	AQU4	AQU5
Throughput of metal parts [kg day ⁻¹]		300	300	300	300	300	300	300	300
Cleansing agent	Composition	Trichloroethylene			Aqueous detergent (sodium hydroxide (15%), sodium silicate (10%), sodium phosphate (25%), sodium carbonate (40%) and POER (10%))				
	Input [kg day ⁻¹]	47	25	4.7	5.9	5.9	5.9	5.9	5.9
Washing machine	Electricity use [kWh day ⁻¹]	18	18	24	16	16	16	16	16
Wastewater	Removal rate from wastewater	–	–	–	–	–	–	Oil: 90%	Oil: 99%, surfactants: 96%, phosphates: 90%
Process oil content [kg day ⁻¹]		–	–	–	0.12	0.12	0.12	0.012	0.000059
Phosphate content [kg day ⁻¹]		–	–	–	1.5	1.5	1.5	1.5	0.15
Discharged into		–	–	–	The Tama River				
Effluent standard		–	–	–	COD: 20 mg L ⁻¹				
Data for risk assessment	Emission of cleansing agent [kg day ⁻¹]	Trichloroethylene emission to the neighborhood (from cleaning sites)			POER emission to the river				
	Threshold	44	22	1.7	0.59	0.59	0.59	0.59	0.022
Background concentration UFs		NOAEL of trichloroethylene: 22 mg kg ⁻¹ day ⁻¹			NOEC of POER: 0.15 mg L ⁻¹				
		2.5 μg m ⁻³			48 μg L ⁻¹				
		100			10				

emissions, which are necessary for calculating these impacts, were obtained from several databases (JEMAI, 2007; JLCA, 2009).

With regard to RA, the health risk to neighbors around a cleaning site due to TCE emission was evaluated for processes using chlorinated solvents, while the ecological risk in the Tama River due to the emission of POER contained in aqueous detergents as a surfactant was evaluated for processes using aqueous detergents. Margin of exposure (MOE) (US-EPA, 2009), which is given by Eq. (1), was used as the indicator.

$$\text{MOE} = (\text{no observed adverse effect level}) / (\text{actual exposure level}) \quad (1)$$

No observed adverse effect level (NOAEL) can be derived from animal experiments and epidemiological studies. The amount of intake of a chemical substance by humans can be used as the actual exposure level for humans. In the case of the human health risk due to inhalational exposure to a chemical substance, it is given by.

$$\text{PDI}_{\text{inh}} = (V_{\text{inh}}/h_{\text{day}}) \cdot \sum_i (C_i \cdot \Delta t_{\text{exposure}, i}) \quad (2)$$

where PDI_{inh} [mg of intake person⁻¹ day⁻¹] is the predicted daily intake per person, C_i [mg m⁻³] is the concentration of the chemical substance in the air to which the person is exposed, V_{inh} [m³ person⁻¹] is the daily inhalation volume per person (20 m³ person⁻¹), $\Delta t_{\text{exposure}, i}$ [h] is the exposure time at C_i , and h_{day} [h day⁻¹] is hours per day (24 h day⁻¹).

Meanwhile, the concentration of a chemical substance in an aquatic environment is often adopted as the actual exposure level to evaluate ecological risk. It is common to compare MOE with uncertainty factors (UFs), which explain interspecific, interindividual, and other variabilities of the adopted NOAEL, in order to judge whether risks are negligible or not. If MOE is larger than UFs, the risk can be considered sufficiently small.

The NOAEL of TCE, which was 22 mg kg⁻¹ day⁻¹, was adopted. This was derived from epidemiological studies of people exposed to TCE (Nakanishi et al., 2008). The total uncertainty of the NOAEL was 100, which was derived from the interindividual variability (10) and the use of data of short-term exposure to evaluate risks of chronic exposure (10). The TCE concentration in the selected neighborhood was estimated using METI-LIS, (Ministry of Economy, Trade and Industry – Low rise Industrial Source

dispersion Model) (METI, 2009a), a type of software for simulating the behavior of pollutants emitted from industrial plants into the atmosphere. The monthly averaged concentration of 0.075 km² around a cleaning site was simulated using METI-LIS, assuming that TCE is emitted during working hours from AM 9:00 to PM 5:00. The MOE of neighbors' health risk was then estimated.

The chronic toxicity of POER to aquatic lives has been indicated by a number of ecological toxicity tests. The no observed effect concentration (NOEC) of POER, which was 0.15 mg L⁻¹ (Nakanishi and Rin, 2007), was adopted for calculating MOE. POER is contained not only in aqueous detergents for metal cleaning processes but also in detergents for household and other purposes. As POER can be removed by a sewage treatment system, the background POER concentration originating from other emission sources would be high in densely populated areas with an insufficient-sewage treatment system. It is reported that the POER concentrations of the Tama River basin under such conditions ranged from 5.9 to 48 μg L⁻¹ (Nakanishi and Rin, 2007). A background POER concentration of 48.1 μg L⁻¹ was adopted in this study, and it is assumed that wastewater from the metal cleaning site using aqueous detergents is discharged to this basin. An increase in POER concentration due to the emission of wastewater from the cleaning site was estimated using AIST-SHANEL (National Institute of Advanced Industrial Science and Technology - Standardized Hydrology-based Assessment tool for chemical Exposure Load) (AIST, 2005), a type of software for the exposure assessment of chemical substances in Japanese rivers. MOE was then calculated and compared with the uncertainty factors of the NOEC (10), which are derived from the uncertainty due to the use of results of experimental toxicity tests.

3.3. Results

3.3.1. LCA results

Among the environmental impacts of the nine impact categories evaluated by LCA, the five in which the contribution of metal cleaning processes is expected to be relatively large are presented in Fig. 3: global warming, urban air pollution, eutrophication, photochemical ozone creation, and human toxicity. The LCA results at the midpoint level are shown herein except for the impact of urban air pollution, whose characterization factors for the midpoint assessment are not developed in LIME2. As to urban air pollution,

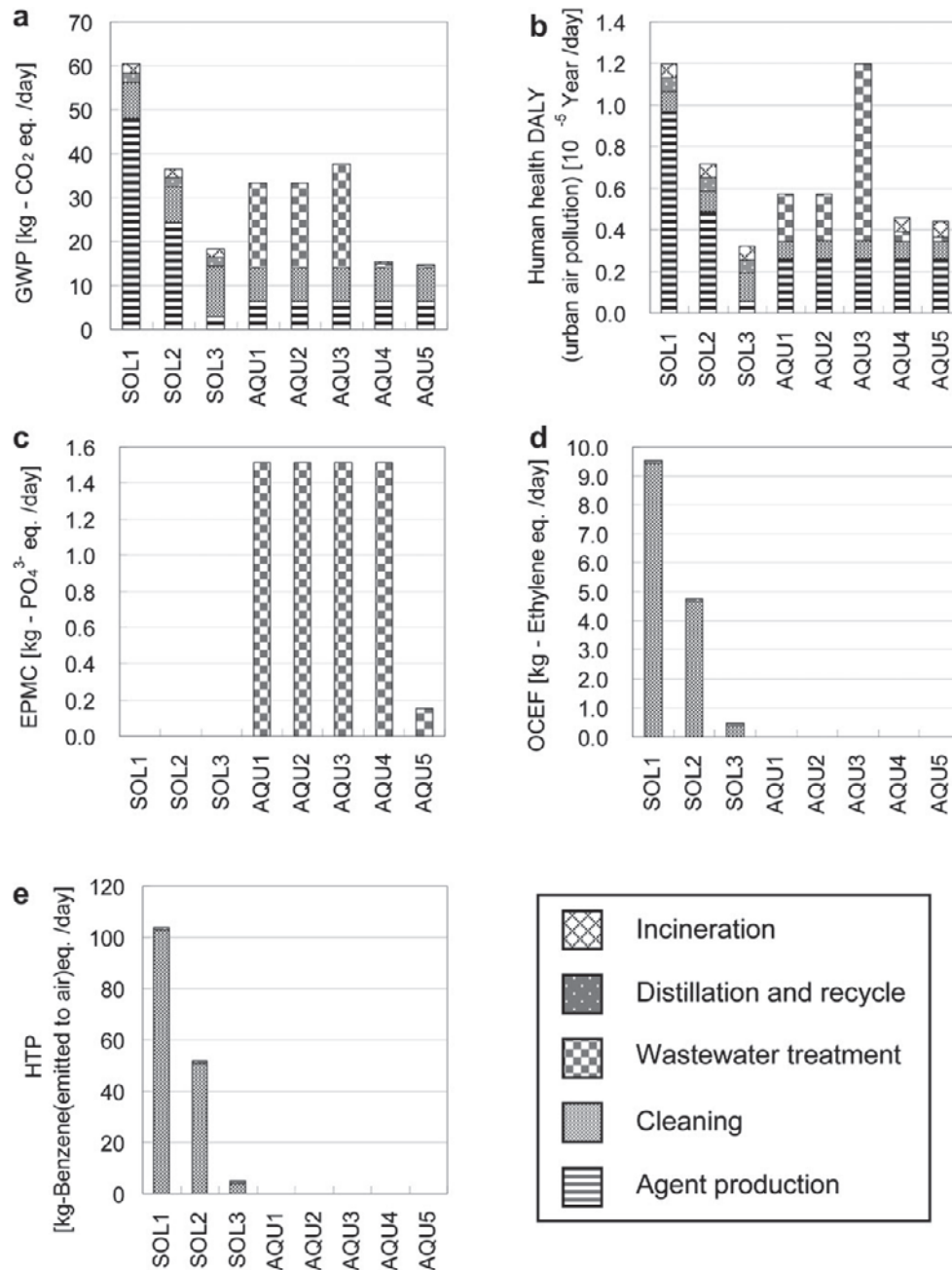


Fig. 3. Life cycle environmental impacts by impact categories of LIME2: (a) global warming presented by Global Warming Potential (GWP), (b) urban air pollution presented by Disability Adjusted Life Years (DALY), (c) eutrophication presented by Eutrophication Potential considered marine Material Circulation (EPMC), (d) photochemical ozone creation presented by Ozone Conversion Equivalency Factor (OCEF), (e) human toxicity presented by Human Toxicity Potential (HTP).

the results at the endpoint level are presented, using disability adjusted life years (DALY) to quantify its impacts on human health.

In the evaluation results of global warming shown in Fig. 3(a), the impact of solvent production accounts for 80% of the total global warming impact in SOL1. Reductions in solvent consumption in SOL2 and SOL3 would lead to a marked decrease in the impact of solvent production. The results also show that the total global warming impact of the process using chlorinated solvents and a semiclosed washing machine in SOL3 is less than or comparable to that of the processes using aqueous detergents. As to the processes using aqueous detergents, the results of AQU1 show that the impact of wastewater treatment accounts for approximately 60% of the total. This is mainly due to the consumption of a large amount of

water for diluting wastewater to meet the effluent standards. Installing additional equipment for wastewater treatment can reduce water consumption, leading to a reduction in the total impact by approximately 55%, as can be seen from the results of AQU4 and AQU5. The use of deionized water in the process of AQU3 resulted in a 13% increase in the total impact from that of AQU1.

Fig. 3(b) shows the impact of urban air pollution due to emissions of NO_x, SO₂, and particulate matter. As to the processes using chlorinated solvents, trends similar to that of global warming can be observed. The impact of the process using a semiclosed machine in SOL3 is the least among the impacts of all the scenarios. The impact of wastewater treatment for the processes of AQU1-3 account for 40%, 40%, and 71%, respectively. They are due to water

production for diluting wastewater. The impact of the process using deionized water in AQU3 is twice as much as that of the process using city water in AQU1 or industrial water in AQU2. Water consumption for dilution can be decreased by installing additional equipment for wastewater treatment although the impact of the incineration of residual sludge may be increased.

In the evaluation results of eutrophication shown in Fig. 3(c), the impact of the processes using chlorinated solvents are negligible compared with that of the processes using aqueous detergents. Process oils, surfactants, and phosphates contained in wastewater from the processes using aqueous detergents can cause eutrophication when they are released to the aquatic environment. Although the oil–water separator installed in the aqueous process of AQU4 can remove process oils from wastewater, it cannot separate phosphates whose impact factor is much larger than organic contaminants. As a result, installing an oil–water separator contributed to only a small reduction in the impact, while installing coagulation sedimentation equipment that can remove phosphates in AQU5 led to a reduction of 90% from AQU1.

Fig. 3(d) and (e) shows the impacts of photochemical ozone creation and human toxicity. TCE released from cleaning processes and during its distillation for recycling is the main causative agent of these impacts, and thus similar trends can be recognized in their results. Improving a chiller in SOL2 and installing a semiclosed washing machine in SOL3 would lead to reduction in the impacts by 50% and 95%, respectively, relative to that of SOL1. The impact of the processes using aqueous detergents would be negligible compared with that of the processes using chlorinated solvents.

3.3.2. RA results

Fig. 4 shows RA results. Neighbors' health risks of the processes using chlorinated solvents and the ecological risks of the processes using aqueous detergents are presented with MOE. The MOE of neighbors' health risks due to TCE emissions is much larger than the uncertainty factors of 100 in all the scenarios of the processes using chlorinated solvents. This means that neighbors' health risks are sufficiently small even in the primitive process of SOL1. Process modifications may not be necessary for the purpose of reducing neighbors' health risks.

Meanwhile, the MOE of the ecological risks due to POER emissions is less than the uncertainty factors of 10 in all the

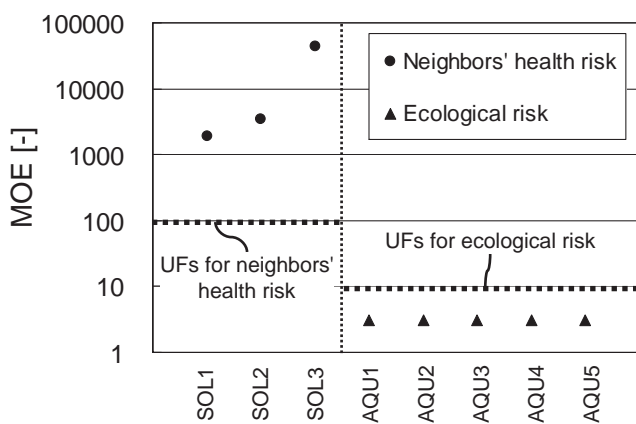


Fig. 4. Results of risk assessment presented with MOE. Neighbors' health risk around a cleaning site using trichloroethylene (TCE) and the ecological risk due to polyoxyethylene alkyl ether (POER) emission from a cleaning site using aqueous detergents were evaluated. [-] after MOE means that MOE is a non-dimensional index. The uncertainty factors (UFs) of the NOAEL for TCE were 100 (interindividual variability of 10 and the use of data of short-term exposure to evaluate risks of chronic exposure of 10), while those of the NOEC for POER was 10 (the use of results of experimental toxicity tests).

scenarios of the processes using aqueous detergents. The results indicate that the ecological risks are not negligible in the analyzed area of the Tama River. The contribution of wastewater from the metal cleaning site was further analyzed as follows. First, MOE was calculated from the POER concentration derived from household, agricultural, and industrial emission sources other than the cleaning site. The MOE calculated in this way was 3.1, which is less than the uncertainty factor. Second, MOE was calculated from the POER concentration derived from all the emission sources including the cleaning site. The difference between the two values of MOE (Δ MOE) was then calculated and regarded as a change in the ecological risk due to emissions of wastewater from the cleaning site. Negative values of Δ MOE mean an increase in the ecological risk due to wastewater from the cleaning site. The Δ MOE values were -5.0×10^{-7} in AQU1-3, -5.0×10^{-7} in AQU4, and -1.8×10^{-8} in AQU5. The Δ MOE values of AQU2 and AQU3 were the same as that of AQU1, because the amount of POER emissions and the wastewater treatment equipment used were the same in these scenarios. As the additional oil–water separator installed in the process of AQU3 cannot remove POER, there was no difference in Δ MOE between AQU1 and AQU4. Installing coagulation sedimentation equipment that can remove surfactants in AQU5 would lead to a 96% reduction in Δ MOE compared with that of AQU1.

4. Risk trade-offs between organic solvents and aqueous detergents

Table 3 shows a summary of the evaluation results of this case study. As to the global impacts evaluated by LCA, the results of each impact category were compared among the scenarios and rated in three levels: large, comparative, and small. If the results of all the solvent scenarios are larger than those of any of the aqueous detergent scenarios, the impacts of the processes using chlorinated solvents and aqueous detergents are rated as large and small, respectively, and vice versa. If their relations of magnitude vary among the scenarios, the impacts are rated as comparative. The contribution of the processes using chlorinated solvents is larger in terms of the impact of ozone depletion, photochemical ozone creation, human toxicity, and ecotoxicity. TCE emitted to the atmosphere is the main causative substance of photochemical ozone creation, human toxicity, and ecotoxicity in these scenarios. Solvent emissions from the processes using chlorinated solvents with an open-top washing machine can be markedly reduced by improving the chiller of such a machine or by substituting a semiclosed machine. Such process modifications can be also effective to reduce the impact of global warming, acidification, urban air pollution, and waste, which are rated as comparative. As the contribution of solvent production is large in these impact categories, solvent emission reductions and associated solvent consumption reductions would also reduce the impacts. Meanwhile, the contribution of the processes using aqueous detergents is larger in terms of the impact of eutrophication. Equipment for wastewater treatment that can remove not only organic contaminants but also phosphates is needed to reduce this impact. Installing additional equipment for wastewater treatment can also reduce water consumption, leading to a reduction in the other impacts rated as comparative.

Trade-off relationships are also identified in local risks: human health risks are an issue of concerns for the processes using chlorinated solvents, whereas the aquatic ecological risks are expected for processes using aqueous detergents. The evaluation results of neighbors' health risks show that the risks of all the scenarios were negligible. On the other hand, the ecological risks of POER exceed the negligible level in the analyzed area along the Tama River. Δ MOE, which was regarded as the contribution of wastewater from the cleaning site to the risk increase, indicates

Table 3

Comparison of the global impacts and local risks between chlorinated organic solvents and aqueous detergents used in metal cleaning processes.

	Chlorinated organic solvent	Aqueous detergent
Global impact		
Global warming	Comparative: solvent consumption needs to be reduced.	Comparative: wastewater treatment to remove organic contaminants is needed.
Ozone depletion	Large: solvent consumption needs to be reduced.	Small
Acidification	Comparative: solvent consumption needs to be reduced.	Comparative: wastewater treatment to remove organic contaminants is needed.
Urban air pollution	Comparative: solvent consumption needs to be reduced.	Comparative: Wastewater treatment to remove organic contaminants is needed.
Eutrophication	Small	Large: wastewater treatment to remove phosphates as well as organic contaminants is needed.
Photochemical ozone creation	Large: solvent emission needs to be reduced.	Small
Human toxicity	Large: solvent emission needs to be reduced.	Small
Ecotoxicity	Large: solvent consumption needs to be reduced.	Small
Waste	Comparative: solvent consumption needs to be reduced.	Comparative: the purity of water may have an effect.
Local risk		
Human health	Neighbors' health risk due to solvent emission is negligible. – Measures to reduce workers' health risk are needed.	–
Environment	–	Ecological risk in the river where cleaning wastewater is released is not negligible. Surfactants in wastewater need to be removed before discharging to public water bodies.

that installing coagulation sedimentation equipment would be effective in reducing the contribution.

Trade-off relationships may also occur between the global impacts evaluated by LCA and the local risks evaluated by RA. In the case study, cleansing agents emitted to the outside of cleaning sites are the causative agents of both global impacts and local risks. Chlorinated solvents pose neighbors' health risk and have impacts on photochemical ozone creation and human toxicity. Surfactants contained in aqueous detergents pose aquatic ecological risk. Phosphates, also one of the components of aqueous detergents, contribute to eutrophication. Therefore, reduced emissions of cleansing agents would lead to reductions in both the global impacts and the local risks and would result in no trade-off relationships between them. If the risks that can be posed inside a cleaning site are further taken into account, such trade-offs may result, as has been demonstrated in a study entailing the assessment of metal degreasing processes using chlorinated solvents (Kikuchi and Hirao, 2008a). Occupational health risks due to the inhalation of chlorinated solvents are often a serious concern, and ventilation systems are equipped in cleaning sites to avoid solvent emission to the workplace. Although solvent emission to the workplace can be decreased by increasing ventilation rate, more solvents would be lost from a washing machine and emitted to the environment outside cleaning sites through a ventilation system. In other words, the measure of reducing occupational health risk may lead to an increase in global impact.

5. Discussion

The LCA results of this case study show the trade-off relationships of the global impacts between the cleaning processes using chlorinated solvents and aqueous detergents. These impacts can be aggregated into a single index in order to avoid such trade-off relationships. Fig. 5 shows the environmental impacts of the nine categories aggregated by a single index of LIME2. The results show that photochemical ozone creation accounts for a large fraction of the total impact in SOL1, whereas eutrophication is a significant impact of AQU1. When they are compared, the impact of photochemical ozone creation in SOL1 is larger than that of eutrophication in AQU1. The partial improvement of a washing machine in SOL2 and the substitution of a semiclosed machine in SOL3 would reduce the total impact by 49% and 93%, respectively, compared

with that in the case of SOL1. The total impact of SOL3 is comparable to that of AQU5, which is the smallest of all.

Fig. 6 shows the evaluation results of the eight scenarios in this case study. The horizontal axis means total global impact in Fig. 5, and the vertical axis shows MOE of neighbors' health risk and the ecological risk presented in Fig. 4. Pareto-optimal scenarios in terms of global impacts and local risks would appear on the lower left side. The evaluation results of the three scenarios using chlorinated solvents can be recognized on the lower side. Although the local risks of these processes are low, global impact can vary according to the washing machines used in the processes. Meanwhile, the evaluation results of the five scenarios using aqueous detergents can be found on the upper left side, and the differences among the scenarios are small. Although the global impacts of the processes using aqueous detergents are relatively small, their local risks are high and non-negligible.

The results of the analysis of risk trade-off relationships can be used to support decision making for cleaner process design. The results indicate that the substitution of aqueous detergents for chlorinated solvents would lead to a marked reduction in total global impact. Local health risks originating from the toxicity of chlorinated solvents can also be eliminated. However, instead of their reduction, the countervailing risks might be posed as a result of the substitution. The local ecological risk in the river where

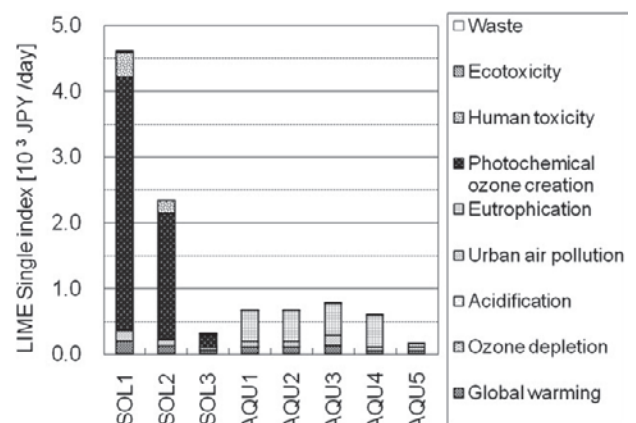


Fig. 5. Results of the aggregation of the life cycle environmental impacts of the nine impact categories by LIME2. JPY means Japanese Yen.

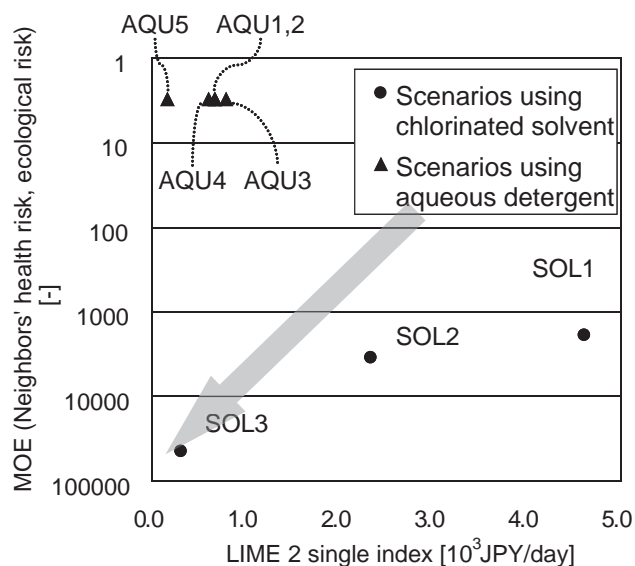


Fig. 6. Results of LCA and risk assessment. The horizontal axis means total global impact in Fig. 5, and the vertical axis shows MOE of neighbors' health risk and the ecological risk presented in Fig. 4. Pareto-optimal scenarios are shown on the lower left side.

wastewater from the cleaning site containing surfactants was discharged was high. Although the contribution of the cleaning site is smaller than that of other emission sources, this situation would be problematic in terms of social responsibility of enterprises owning metal cleaning processes.

Meanwhile, factors other than impacts on the environment and humans should also be considered in process design. The compatibility with metal parts to be cleaned is important in selecting cleansing agents. Alkali compounds contained in aqueous detergents can corrode metal parts made of aluminum. Water has a higher surface tension than solvents, and thus can less effectively penetrate a hole. Consequently, chlorinated solvents are often selected for cleaning metal parts made of aluminum or with a small hole. There are also other differences in functions as cleansing agents between chlorinated solvents and aqueous detergents. Furthermore, the choice of cleansing agents will often depend on required expense and space, because most cleaning sites in Japan are small and medium-sized enterprises (SMEs) that have severe restrictions on investible funds and available space (Kikuchi and Hirao, 2008a). The feasibility of process modifications under such restrictions should be examined in decision making for process design (Suh et al., 2005). In general, washing machines for aqueous cleaning processes are larger, and their initial cost is higher than those for solvent processes. The installation of an aqueous washing machine and equipment for wastewater treatment would require considerable space and expense. The large-scale modifications of a cleaning process would not be easily implemented under restrictions on funds and space. If chlorinated solvents are continued to be used for such reasons, design options without changing cleansing agents should be proposed for risk reduction. The results of this case study show that neighbors' health risks were sufficiently small in all the scenarios of the processes using chlorinated solvents. Installing a semiclosed washing machine instead of a primitive open-top machine led to a reduction in total global impact to a level less than or comparable to that of the processes using aqueous detergents. This would be a more feasible means of process improvement for cleaning sites where the substitution of aqueous detergents is difficult due to restrictions related to cleansing agent functions, funds and space.

LCA results presented in a single index can be applied to process design in another way. LIME2 adopts a monetary value as a single index. Integration factors were derived by conjoint analysis, which is aimed at determining the subjective values of four AoPs: human health, social welfare, biodiversity, and plant production. The value is intended to represent the amount of an environmental tax that Japanese people are willing to pay. From that viewpoint, the results presented in a single index can be regarded as the investible amount of money required to reduce the global impact due to the processes. The cost-effectiveness of process modifications aimed at the reductions in global impact can be evaluated on the basis of LCA results. For example, the difference in the results of scenarios SOL1 and SOL3 is 4300 JPY (Japanese Yen) whose functional unit is daily metal cleaning. The cost-effectiveness of installing a semiclosed washing machine in place of a primitive open-top machine can be evaluated by comparing this value with the incremental cost per day.

It must be noted, however, that there are other process modifications that may reduce the risk of cleaning processes. For instance, improving the operational conditions for the processes can be effective in reducing solvent emission. It is reported that the amount of solvent taken out by the metal parts to be cleaned can be reduced by 80% if the time for drying metal parts after washing is prolonged by 30 s (MOE, 2007). As to aqueous processes, discharging wastewater to sewers may be effective, because some surfactants can be treated before reaching public water bodies.

6. Conclusion

The global impacts and local risks due to the use of organic solvents and aqueous agents were respectively evaluated by LCA and RA in a case study of metal cleaning processes. Three scenarios using chlorinated solvents and five scenarios using aqueous detergents were developed and evaluated. Evaluation results were comprehensively analyzed to investigate the risk trade-off relationships between chlorinated solvents and aqueous detergents.

The trade-off relationships of the global impacts evaluated by LCA were identified in several impact categories. For example, the contribution of the processes using chlorinated solvents to photochemical ozone creation was much larger than that of the processes using aqueous detergents. In contrast, the contribution of aqueous processes to eutrophication was significant, whereas that of the solvent processes was negligible.

Trade-off relationships were also recognized in the local risks. Neighbors' health risks due to solvent emissions and the aquatic ecological risks due to surfactant emissions were evaluated by RA. The results show that neighbors' health risks were sufficiently small in all the scenarios developed in this case study. Meanwhile, the ecological risks in the river where wastewater from the cleaning site was discharged were not negligible. Wastewater treatment for removing surfactants is necessary for processes using aqueous detergents to reduce the contribution to the risk increase.

Substance substitution has been implemented in the industry to reduce the target risk. Decision makers who select an alternative substance should recognize the countervailing risk that may be posed as a result of the substitution. In this study, we demonstrated the trade-off relationships between chemical substances by evaluating the global impacts and local risks by LCA and RA, respectively. A comprehensive analysis of the evaluation results enables feasible and cleaner process design in which constraints beyond impacts on the environment and humans are taken into account. In this case study, the results indicate that a measure of reducing aquatic ecological risk should be implemented, when aqueous detergents are substituted for chlorinated solvents. If the use of aqueous detergents is difficult owing to constraints related to cleansing agent functions, space, and investible funds, installing

a semiclosed washing machine without changing cleansing agents would be a feasible solution.

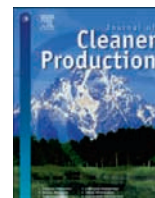
The analysis implemented in this study by LCA and RA can be applied to chemical substances used in other industrial processes. For example, in printing and painting processes where solvent-based and water-based inks and paints are used, the impacts of these substances on the environment and humans can be evaluated in a similar way.

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Government Initiatives

Hands-on assistance improves already successful pollution prevention services of the toxics use reduction institute's laboratory

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ABSTRACT

In an attempt to improve the adoption rate of the work conducted at the Toxics Use Reduction Institute Lab, a more comprehensive on-site follow-up assistance program was implemented in 2006. The effort was piloted for trichloroethylene replacement in Rhode Island in conjunction with Environmental Protection Agency (EPA) Region 1.

Through hands-on workshops and on-site assistance efforts, the TURI Lab project was able to achieve an 82% reduction in TCE in a two year period. This new methodology for on-site assistance follow-up to the preexisting TURI Lab testing program has been incorporated into the work the Lab conducts for companies in Massachusetts. The Lab had an implementation rate of around 30% without on-site assistance. During the first year of the new process, the adoption rate has jumped to 80% of all companies working with the lab.

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1. Introduction

The passage of the Toxics Use Reduction Act (TURA) in 1989 by the Massachusetts legislature marked the creation of the Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell. Fully operational since late 1993, the TURI Laboratory (TURI Lab) is the research and testing facility of TURI. The objective of the laboratory is to assist in the development and promotion of safer alternatives to the traditional hazardous materials, primarily organic and chlorinated solvents used to clean metal surfaces without causing economic hardship or a loss in cleaning performance.

Technical assistance in pollution prevention (P2) activities has had marginal success over the years due to the relatively slow diffusion across most industry sectors (Lindsey, 1999). A study by Waste Management Resource Center in Illinois found that in one sector of pollution prevention (membrane filtration) more than 80% of the companies made no or little inroads into adopting the technology (Lindsey, 1999). The TURI Lab has had slightly higher success for companies serviced around the country with a major focus on Massachusetts companies, with about a third of companies adopting recommended changes in solvent substitution for cleaning

applications (Kusz, 2002). Further research documents that implementation rates for the Worcester area, suggests that one in seven companies is successful in carrying out solvent substitution at the plant without additional assistance from the TURI Lab (LeBlanc, 2001).

From research conducted by the Waste Management Resource Center in Illinois, the traditional fact sheets, case studies and vendor databases have limited impact on a company's willingness to adopt a new pollution prevention technology (Lindsey, 1998). On the other end of the pollution prevention spectrum, when introducing hands-on piloting of the potential equipment, adoption rates range from 60–80% as compared to 0% adoption of the recipients of the traditional fact sheet/case study (Lindsey, 2000).

In an attempt to improve the adoption rate of the work conducted at the TURI Lab, a more comprehensive on-site follow-up assistance program was implemented in 2006. The effort was piloted for trichloroethylene replacement in Rhode Island in conjunction with Environmental Protection Agency (EPA) Region 1.

Trichloroethylene (TCE) has historically been used for various cleaning and degreasing applications. Because of the human and environmental health effects associated with exposure to TCE, it has been the target of many states' P2 programs over the past decade. Many P2 assistance providers consider this field to be "conquered" and have moved on to other niches to focus their efforts on the next battle. In many cases, particularly among larger companies, uses and emissions of TCE have been minimized through substitution and other engineering controls. Unfortunately

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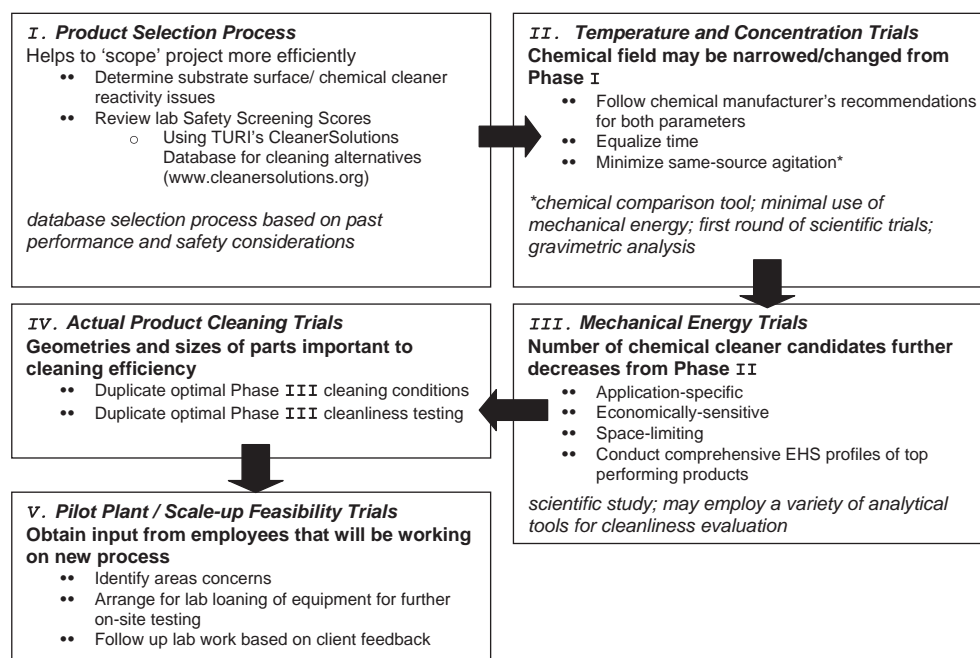


Fig. 1. TURI lab cleaning project steps.

the use of TCE has not been eliminated. Alarming, there are many small users of TCE that continue the same cleaning and degreasing practices they have used for decades, and have not reduced their use of TCE at all.

In the summer of 2006, EPA Region 1 found TCE at elevated levels as part of its routine air monitoring system evaluation in the Providence, Rhode Island (RI) area (specifically Olneyville). Therefore, EPA Region 1 made TCE the focus of intense scrutiny over the next year as part of its environmental justice efforts. A list of approximately 40 companies potentially using TCE was generated and subsequently visited by a member of EPA Region 1. Of these companies, 24 were still in operation in 2006. Many of the companies that were identified made materials for the Department of Defense (DoD). When the DoD learned of TCE being used by its suppliers it took a vested interest in the project, encouraging its suppliers to eliminate the use of this chemical.

With the list of companies in hand, the EPA and the RI Department of Environmental Management (DEM) needed to come up with a way to eliminate/reduce the usage of TCE in this community. Enforcement actions were considered but the regulatory partners agreed that a more effective method for improving air quality in the communities affected could be found. EPA Region 1 funded the TURI Lab to provide technical assistance and/or training to the identified companies with the goal of supporting the companies in voluntarily reducing or eliminating their uses of TCE.

The TURI Lab determined that the initial step in this project would be to convene a one-day hands-on-training workshop for these companies. Prior to the workshop, dirty parts and soils were collected from a sampling of the 40 identified companies by the EPA Region 1 staff and brought to the TURI Lab. Testing was then conducted to determine which alternatives would be appropriate for each company's exact needs. This end user specific testing was deemed necessary as solvent substitution in cleaning applications does not have a single drop-in. By providing testing services to companies, the TURI Lab was able to come to the Rhode Island based workshop with the specific products that were most likely to be effective for individual companies.

To keep the TCE substitution project moving forward, follow-up assistance on a one-to-one basis was made available to attendees of

the workshops. TURI Lab and EPA Region 1 staff members brought laboratory proven products and bench scale equipment to the individual companies to conduct on-site piloting. The piloting was demonstrated by the TURI Lab first and then by the workers who were responsible for the cleaning process. This activity had the added benefit of opening up critical lines of communication relative to what actually goes on in the process.

2. Work performed

2.1. Workshop training

The initial workshop had twelve companies in attendance. During the workshop companies brought their dirty parts to be cleaned using the alternatives that the TURI Lab had previously identified and tested. The workshop allowed these companies to see first hand that alternatives do exist that are effective for their needs. In addition, the workshop gave these small companies the opportunity to talk with their peers to see what others have tried or experienced. This networking provided the companies with a sense of comfort knowing that they were not alone and emboldened them to begin the TCE replacement process.

Following the workshop efforts, the TURI Lab continued to work with six of the companies that attended. TURI's Field Implementation Specialist went on-site with each company to assist in the adoption of the identified alternatives. The TURI Lab provided these companies with a small cleaning unit (i.e., immersion and/or ultrasonic tank) and concentrated samples of safer cleaning alternatives. Cleaning was conducted by both the Field Implementation Specialist and the worker(s) involved with cleaning at the company. During the field work, the cleaning process was adjusted to meet the needs of the company.

After determining the appropriate cleaning cycle, the cleaning unit and alternative cleaning products were left with the company to conduct piloting on their own. This loaning was a new service that the TURI Lab implemented in its effort to improve adoption rates. Typical piloting lasted from one to two weeks after which the equipment was returned to the TURI Lab. During the pilot phase, the companies were provided with a list of possible equipment

Table 1
Company project status and TCE reduction achieved.

Locations visited/type	Actions taken on-site	Notes	Date	TCE used gal/yr	Gallons eliminated	Pounds used/year	Pounds eliminated
IRA Green/Metal finishing – military insignia	Set up a test tank w/alternative in Ira Green's facility. Determined that alternative solution works as well as TCE. TURI provided free gallon of alternative solution Viewed new machine	Initial switched to alternative in existing ultrasonic tanks for 30% of product line, using n-propyl bromide as a drop-in replacement while waiting to purchase additional ultrasonic equipment. Stopped using TCE, now using steam cleaning – won't be attending workshop but said it was okay for companies to contact them.	10/31/2006	1023	1023	12500	12500
3 As/Fine jewelry and statue figurines	Viewed more parts, dropped of cleaned parts	Results looked promising for drop-in solvent vapor degreasing – signed up for workshop. Wanted information on n-propyl bromide regulation potential. Signed up for workshop. Conducted lab testing, visited facility to arrange for parts cleaning. Waiting on samples to complete work.	10/18/2007	55	55	672	672
Nulco/Brass light fixtures	Collected more parts, dropped of cleaned parts	Results looked promising for drop-in solvent vapor degreasing – signed up for workshop. Wanted information on n-propyl bromide regulation potential. Signed up for workshop. Conducted lab testing, visited facility to arrange for parts cleaning. Waiting on samples to complete work.	2/11/2008	330	0	4089	0
Mel-co-ed/Military insignia, brass and steel parts	Walk through, collection of parts – Had reduced 7000 lbs TCE to 3000 lbs and working toward being below 1000 lbs	Walk through, review of new system – reduced TCE following last workshop – eliminated 7000 lbs	2/11/2008	500	400	6196	4957
Teknicote/Metal shop, small springs	Walk through, review of new system – reduced TCE following last workshop – eliminated 7000 lbs	Switched to aqueous power washing, purchased drying equipment similar to what lab has in-house (just larger). Quality maintained but scheduling more challenging	2/11/2008	500	500	6196	6196
Herff Jones/Jewelry, class rings	Conducted work with lab from previous year of work. Wanted to attend workshop	Completed work. Switched from TCE to nPB and a 3M product and some aqueous. Want to do case study	4/1/2008	161	153	2000	1900
Mereco/Make resins and use large aluminum and stainless steel buckets	Replaced TCE with n-propyl bromide but are interested in replacing nPB.	Identified several options for resin cleaning applications with no loss of performance	6/23/2008			6000 ^a	
Providence Metalizing/ Electroplating	Combination of ultrasonics and power washing. 500 lbs a month of TCE	Based on information provided on TCE alternatives, company began investigating alternative processes. No data	11/27/2008	484	444	6000	5500
Whittier Higgins/Industrial retaining devices		No data					
Chemart Co/Etch decorative brass ornaments		No data					
G Tanury Plating/ Electroplating jewelry, eyewear	Significantly cut down usage. (10,000) At this rate they believe the can be well under the 1000-lb/year	Following workshop, company set out to reduce their TCE usage below the new threshold of 1000 lbs	4/10/08	97	30	1200	370
GaHan Chain (MA)/Metal fence		No data					
Tech Etch (MA)/Photo etching, flexible circuits							
Totals				3150	2605	39033	32095
					% Reduction		82

^a nPB replaced.

Table 2
Expected and actual pollution prevention results.

Project Name: Cleaning Workshop			
Measures/Results for 2007–8			
Activity Measures:	Results		
	Projected	Actual	
Number of conferences/workshops/training sessions held			
Hands-on-training workshops	1	1	
Number of attendees	20	13	
Number of clients/facilities that received assistance	12	8	
Outcome Measures: From workshop only	Projected	Actual	
Gallons of TCE reduced by participants per year (pounds/year)	100 (1240)	1037 (12850)	
Project Name: Laboratory Evaluations			
Activity Measures:	Projected Actual		
	Projected	Actual	
Number of laboratory Tests	25	11	
Number of clients that received on-site visits/assistance	8	5	
Outcome Measures: From Lab evaluations only	Projected	Actual	
Gallons of TCE reduced by participants per year (pounds/year)	350 (4340)	150 (1860)	
Project Name: Field Testing and Implementation			
Activity Measures:	Projected Actual		
	Projected	Actual	
Number of site visits	18	8	
Number of clients that received on-site visits/assistance	6	4	
Number of unique documents developed	3	6	
Outcome Measures: From field evaluations only	Projected	Actual	
Gallons of TCE reduced by participants per year (pounds/year)	1000 (1240)	2093 (25760)	

vendors that could assist in the purchase of equipment or in the modification of existing equipment.

From September of 2006 through April of 2007, half of the originally identified companies suspected of using TCE in the Providence area participated in the hands-on-training workshop. Six of the original attendees from the workshop participated in piloting projects. Most of these have or will be eliminating or reducing TCE in their facilities.

A second hands-on-training workshop was held in March 2008. The target audience was those companies that could not attend the previously offered workshop in September 2006. This new training was modified from the original workshop to incorporate the lessons learned by the TURI Lab from the original workshop. The materials provided included a tip sheet generated by the joint effort of EPA Region 1 and TURI, and short case studies of companies that had gone through the complete substitution process. While these companies could not speak at the workshop, they did allow TURI and EPA to mention them by name and to provide personal contact information to anyone who wanted to speak directly to them on the projects conducted at their facilities.

The original list of companies possibly using TCE (provided by EPA), about 30 companies (some of the original 40 were determined to not be in business), was contacted via a mailing from TURI about the workshop. In addition, the Narragansett Bay Commission (NBC) sent a copy of the flyer to more than 80 companies that the NBC thought would benefit from the workshop. A handful of Massachusetts companies located close to RI also were invited to the conference. In total, there were 8 companies that signed up for the workshop, 6 from RI and 2 from Massachusetts. In addition to TURI Lab staff and EPA Region 1 contacts, representatives from the RI DEM, NBC and RI Occupational Safety and Health Agency (OSHA) attended the workshop and were available for companies to discuss how each agency could assist companies to replace/reduce TCE.

At the end of the March 2008 workshop, on-site assistance was offered to the attendees. Follow-up email contact was attempted for six of the eight attending companies. One company did not provide contact information. The remaining company previously worked with the TURI Lab and was ready to complete the

transition efforts to a new cleaning process. They wanted to make contact with the TURI Lab to offer their company as a possible case study.

In addition to the workshop, laboratory services were provided to other companies that participated in the first round of on-site and laboratory testing offered by TURI in 2006–7. On-site assistance was provided to these companies through the use of laboratory loaned equipment and cleaning products.

3. Results and discussions

The goal of the project was to increase the adoption rate of the TURI Lab testing program thereby reducing the amount of TCE used by small companies in Rhode Island. During the period after conducting the workshops for twenty companies, the TURI Lab had further contact with twelve companies. The amount of TCE that was being used by attendees and other contacted companies was calculated to be about 39,000 pounds/year. This number was based on the preliminary questionnaire and/or registration forms for new companies serviced and those that continued on during the second year of work by TURI. (For five of the companies, the lab was unable to determine the amount of TCE being used.)

Services provided to companies included preliminary site visits by TURI and EPA Region 1 staff, laboratory testing, follow-up site visits and onsite testing assistance. The visits allowed TURI to conduct a walk through of the facility and to collect sample materials for laboratory testing.

Laboratory testing conducted by TURI allowed for the identification and evaluation of alternative cleaning products that were specific to each company's needs. A dozen trials were conducted for 3 of the 8 companies that attended the workshop in March 2008. In addition a handful of testing was done for companies that attended the previous workshop in September 2006.

With safer alternatives to TCE identified and evaluated, the TURI Lab provided companies with the opportunity to have equipment loaned to them (free of charge) from the TURI Lab to evaluate the identified products on-site. Equipment and cleaning alternative supplies were left with a company for a period of 2–4 weeks. At the end of the lending period, the equipment was retrieved and the status of the alternative cleaning product was determined.

3.1. Implementation adoption – TCE reduction

Through the combined efforts of the workshop training, laboratory testing and on-site assistance, the TURI Lab assisted nine of the companies in eliminating 82% of the reported total TCE usage of 12 companies. Solvent usage dropped from the 39,000 pounds/year to less than 7000 pounds/year. Additional solvent reduction of n-propyl bromide (nPB) was achieved for one of these eight companies; their initial usage of nPB was 6000 pounds a year.

Some of the companies that received testing from the TURI Lab did not adopt the suggested alternative cleaning products that were identified. However, the proof from peer companies that the alternatives to TCE could work prompted these companies to investigate other possible substitutes. Once such example was a small plating job shop. Several commercial products were identified by TURI for removing buffing compounds from the various brass pieces being manufactured at this facility. Upon further investigation by this company, a steam cleaning system was piloted and eventually adopted, eliminating more than 670 pounds/year of TCE.

For other companies, the use of drop-in organic solvents for cleaning was considered to be necessary for the continued success

of these companies due to economic considerations. The TURI Lab made attempts to identify suitable drop-in solvents for these companies. In addition, work was conducted to determine when and where these drop-in solvents were needed. Whenever possible the solvents were replaced by aqueous based alternatives. A large jewelry manufacturer was one such company that opted to diversify their cleaning process, using the more expensive drop-in solvents in only the most challenging situations. By following this method, nearly 2000 pounds/year of TCE was eliminated.

Table 1 lists the companies that received some kind of service during the grant period, the status of the project and the TCE usage/reduction values obtained.

To collect data for the companies in and around Providence, RI, TURI used checklists for on-site visits at facilities and pre-post testing for workshop attendees. In addition, follow-up phone interviews and additional site visits were made to identify P2 results. Table 2 outlines the expected and actual measurements for each pollution prevention project.

Through the collection of data for the grant, two of the three areas exceeded projected results. The most dramatic result was the amount of TCE reduced by those only attending the workshop. Based on previous outcomes, TURI assumed that 100 gallons per year (1240 pounds/year) of TCE would be replaced as a result of the information presented on during the workshop training. According to responses from attendees, the actual TCE replaced following the workshop was determined to be more than 1000 gallons (12,400 pounds/year).

An assumption that 1000 gallons (12,400 pounds/year) of TCE would be replaced after the TURI Lab conducted on-site assistance for companies considering the adoption of the alternative cleaning products/processes. At the conclusion of the grant period, the actual TCE replacement was higher, resulting in 2093 gallons (25,600 pounds/year) eliminated.

For the companies that received laboratory evaluations without on-site assistance, it was anticipated that 350 gallons (4340 pounds/year) would be replaced. Unfortunately the companies realized less than half this reduction, replacing only 150 gallons (1860 pounds/year). At the end of the grant time frame there were a few companies that had received successful lab testing of alternatives, but had not been able to move toward adoption due to financial restrictions.

The new TURI Lab assistance process has expanded beyond the traditional lab work to include on-site assistance. Fig. 1 shows the five step process that has helped to improve the pollution prevention adoption rate.

4. Conclusions

The lack of adoption by companies receiving lab testing only confirms the importance of providing the on-site assistance aspect of the TURI Lab. By conducting the on-site work, questions or concerns can be met in real time, facilitating a successful adoption of safer cleaning practices.

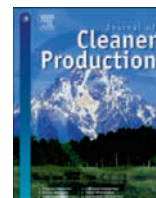
The lessons learned and the connections made with TCE users in Rhode Island can easily be applied to other areas with concentrated industry regions. Connecticut may be one such region with localized job shops and metal working facilities. According to EPA sources, Bridgeport, Danbury and New Haven may be ideal locations to provide future hands-on workshops and on-site cleaning assistance by the TURI Lab or an operation similar to the TURI Lab. The methodology for on-site assistance follow-up to the preexisting TURI Lab testing program has been incorporated into the work the TURI Lab conducts for companies in Massachusetts. As previously mentioned, the Lab had an implementation rate of around 30% without on-site assistance. During the first year of the new process, the adoption rate has jumped to 80% of all companies working with the lab.

Acknowledgements

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Applying the precautionary principle to consumer household cleaning product development

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ABSTRACT

Hazardous chemicals are pervasive in household disinfectant products. Many ingredients have established associations with acute and chronic human health conditions as well as with environmental damage. Although these associations are suggested but not proven, they are of great concern. This article describes the application of the precautionary principle to the selection of an anti-microbial active ingredient for a botanical disinfectant when significant uncertainty exists around the hazard and risk of traditional disinfectant active ingredients. We show that application of the precautionary principle does not stifle innovation and facilitates a responsible approach to product development.

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1. Introduction

Protecting the environment and human health through responsible consumerism has emerged as an important shift in buyer behavior (Thøgersen, 2006). As a result, both consumer demand for and availability of green household cleaners have significantly increased. Although many factors influenced this change, the direct relationships demonstrated between conventional cleaning product ingredients and negative environmental and human health effects such as eutrophication (Conley et al., 2009), air pollution (Nazaroff and Weschler, 2004; Destailats et al., 2006; Kwon et al., 2008), and endocrine disruption (Diamanti-Kandarakis et al., 2009; Rudel et al., 2003) have had a significant impact on the consumer view of household product safety. In addition to the negative relationships that have been established, there are also ingredients that are suspected of having unintended negative consequences but for which direct relationships to health and the environment have not been demonstrated (Ahn et al., 2008).

This level of uncertainty introduces a formidable challenge for product development scientists who aim to formulate products with superior human health and environmental safety profiles. Due to the complexity of biological systems, establishing causal

relationships between an ingredient and an ecological or physiological effect requires such rigorous inquiry that by the time a cause–effect relationship is established and accepted, myriad exposures have occurred which could have been prevented. Managing scientific uncertainty in ingredient safety assessments requires a well-designed system of evaluation and ranking to categorize the severity of potential hazards that ingredients and formulated products pose to consumers and to the environment. The most widely used principle to guide such characterization in the face of scientific uncertainty is the Precautionary Principle (PP) which can be summarized as follows: “when an activity raises the threat of harm to human health and the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically” (Raffersperger and Tickner, 1996). By taking preventive action in the face of uncertainty and developing alternatives, the PP prevents additional exposures and can protect human health and the environment despite the absence of conclusive evidence of a negative effect.

One of the major points of opposition to the use of the PP, particularly in product development, is that its application stifles innovation by requiring proof of safety prior to introducing a new technology (Kriebel et al., 2001). In the case of pharmaceutical development, the benefit of innovation can often outweigh the risk or hazard associated with uncertain effects. For example, innovation in treatment for terminal illnesses such as stage IV cancers or HIV/AIDS can result in saving or significantly extending a patient's life, therefore, the benefit of remission or cure outweighs the risk of

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unknown adverse effects. Conversely, from the perspective of a green household cleaning formulation the risk of harming human health and/or the environment far outweighs the benefit of providing consumers with the latest innovation in household cleaning. In addition, launching a product that is later found to be wholly or in part unsafe for health or the environment contradicts the central tenant of green chemistry, which is to provide safer alternatives. This does not suggest that innovation is not the goal of green product developers; however, safety as defined by the developer supersedes innovation as a priority. For this reason, the early green product lines followed a “less bad” philosophy in order to provide alternatives to existing products on the market. Due to the increase in demand for sustainable, safe products the market has changed and product developers have more raw material options thereby evolving green product development from the pursuit of “less bad” to the pursuit of true innovation.

Despite the introduction of green offerings in almost every household cleaner category, disinfectants and sanitizers have had no significant green alternatives introduced to date. As these products are required to be registered with the US Environmental Protection Agency, are classified as pesticides, and have highly regulated claims it may be a function of the inability to communicate human health or environmental safety claims that has prevented the greening of the category. Notwithstanding the constraints imparted by the regulations, green consumers are faced with a situation in which they must use a conventional anti-microbial pesticide if they desire to kill microorganisms in their homes. Considering the green consumer's awareness around chemical exposure they are faced with a disinfection dilemma: protecting their family from germs or protecting their family from potentially harmful chemical exposures. As such, developing a hard surface disinfectant formulated with safer active and inert ingredients would not only present a significant innovation in the green and disinfectant spaces, but would also provide a solution to this consumer dilemma.

In January 2010 this concept became a reality with the introduction of an EPA registered disinfectant that kills germs botanically. This article describes the application of the PP to anti-microbial ingredient selection for and development of this natural hard surface disinfectant, and describes how its application in consumer product development can act to foster innovation and produce viable alternatives to potentially hazardous chemistries.

2. Determining uncertainty: anti-microbial active ingredients

Of the registered disinfectants available in the consumer market, the most common active ingredients are quaternary ammonium compounds and sodium hypochlorite. Another ingredient, Triclosan, is used more predominately in anti-microbial hand washes but is also utilized in several registered surface disinfectants. A review of the scientific literature reveals evidence which suggests relationships between these conventional disinfectant active ingredients and serious human health and environmental issues such as asthma and respiratory sensitization (Bernstein et al., 1994; Burge and Richardson, 1994; Leroyer et al., 1998; Nickmilder et al., 2007; Nielsen et al., 2007; Preller et al., 1996; Purohit et al., 2000; Shakeri et al., 2008; Zock et al., 2001; Medina-Ramon et al., 2005), air pollution (Kwon et al., 2008; Odabasi, 2008; Fiss et al., 2007), bioaccumulation and reproductive toxicity in wildlife (Fair et al., 2009; Fry, 2005), and bacterial resistance (Levy, 2001; Gaze et al., 2005; Russell et al., 1998; Sundheim et al., 1998; Aiello and Larson, 2003). However, causal relationships have not been definitively established. As such, in considering active ingredients for a natural surface disinfectant with a superior human

health and environmental safety profile evaluating the uncertain effects of these ingredients is necessary.

2.1. Triclosan

Used as an anti-microbial since the 1960s, triclosan (TCS) is a broad spectrum anti-microbial commonly found in anti-bacterial products spanning personal and household care. TCS prevents fatty acid synthesis in the cell membrane by inhibiting the activity of the NADH-dependent enoyl-acyl carrier protein reductase (FabI enzyme), or its homolog, the *InhA* gene (McMurry et al., 1998, 1999; Heath and Rock, 2000; Slyden et al., 2000; Parikh et al., 2000; Chauncheon et al., 2001; Heath et al., 1998; Hoang and Schweizer, 1999; Heath et al., 2000). This mechanism of action is similar to some antibiotics and research suggests that TCS may confer cross-resistance to antibiotics (Aiello and Larson, 2003; McMurry et al., 1988). However, the true potential for TCS containing household products to cause cross-resistance to antibiotics is unknown.

TCS has been linked to hormone disruption in animals, specifically fish, frogs, and rats (Ciniglia et al., 2005; Ishibashi et al., 2004; Matsumura et al., 2005; Zorrilla et al., 2009; Foran et al., 2000; Veldhoen et al., 2006). More recently, studies suggest that TCS may have the potential to disrupt the endocrine system in humans which is of significant concern as the chemical is essentially ubiquitous and has been measured in breast milk at levels of 2000 µg/kg lipid and 3790 µg/L in human urine (Ahn et al., 2008; Allmyra et al., 2006; Calafat et al., 2008; Gee et al., 2008; Chen et al., 2007; Adolfsson-Erici et al., 2002). However, a cause–effect relationship between TCS and endocrine disruption has not been definitively proven in humans or in wildlife. Therefore, the risk of endocrine disruption resulting from human or animal exposure to TCS containing cleaning products is unknown.

Due to its structural similarity to toxic and environmentally persistent compounds such as dioxins, the secondary reactions and environmental fate of TCS have been of special interest. For example, one study showed that TCS in formulation has the ability to react with chlorine in tap water to produce 2,4-dichlorophenol, 2,4,6-trichlorophenol, and chloroform although the risk introduced by these exposures was not determined (Fiss et al., 2007). In other studies, the photodegradation of TCS also resulted in the formation of 2,4-dichlorophenol as well as other toxic compounds such as, 2,8 dichlorodibenzodioxin, and dichlorohydroxydiphenyl (Latch et al., 2003; Sanchez-Prado et al., 2006). As several reports show that TCS is commonly found in sources that are directly exposed to sunlight, such as surface water and streams, it can be suggested the presence of TCS increases the risk of exposure to its toxic degradation products (Hua et al., 2005; Kolpin et al., 2002). In addition to streams and surface water, there have been reports that TCS present in wastewater is difficult to remove, remains after sewage treatment, and also remains in sludge and biosolids (Chu and Metcalfe, 2007; Heidler and Halden, 2007). However, the presence of TCS degradation products in the environment has not been connected to the presence of TCS in the environment; therefore, it is uncertain what proportion of the environmental load is the result of degradation of TCS versus other sources. In addition, no relationships have been established regarding the presence of TCS in wastewater, sludge, and biosolids to specific human health or environmental issues.

2.2. Quaternary ammonium compounds

Among the most common biocides found in household disinfectants are quaternary ammonium compounds (QACs). While the mechanism of action can differ according to structure and, specifically, chain length, QACs typically kill bacteria by inserting

themselves into the microorganism's lipid bilayer thereby causing a membrane disruption that results in the leakage of intracellular constituents (Ioannou et al., 2007). The antibiotic resistance potential of QACs has been well characterized and several resistance genes have been identified (Chapman, 2003). The QAC resistance genes are found on mobile genetic elements that can spread through horizontal genetic transfer, but serial transfer has also been reported. Despite the well characterized resistance genes, the presence and expression of such genes do not necessarily confer resistance to antibiotics and disinfectants and, as such, QAC disinfectants continue to be a commonly used anti-microbial technology and have not been identified as a major risk for causing resistance (McCay et al., 2010).

The most significant area of debate related to QACs is the suggested potential for exposure to result in respiratory sensitization and asthma. Several studies have demonstrated the relationship between prolonged exposure to QACs and occupational asthma or respiratory sensitization (Bernstein et al., 1994; Burge and Richardson, 1994; Preller et al., 1996; Purohit et al., 2000; Rosenman et al., 2003; Zock et al., 2007). However, despite the significant evidence in professional settings, the risk of developing asthma or respiratory sensitization from using disinfectants with QAC active ingredients has not been described in a household setting. Overall, no definitive link between QAC exposure and respiratory effects has been established in professional or domestic settings. However, the strong correlation between exposure, illness and the biochemical evidence that QACs are immune adjuvants suggests that certain health effects such as the dramatic increases in pediatric asthma and dermatitis may be related to QAC exposure (Militello et al., 2006; Akinbami and Schoendorf, 2002).

Reproductive and developmental issues related to QAC exposure have also been reported (Maher, 2008). In one report, a murine colony experienced significant developmental and reproductive effects after transferring research institutions. Upon careful examination of all variables, the investigator determined that the change to a QAC disinfectant to clean housing for the colony was the source of the breeding problem. After transitioning back to a non-QAC disinfectant the breeding issues within the colony resolved (Maher, 2008). While these results have not been reproduced in humans and QACs have not been specifically identified as human reproductive or developmental toxicants, there are several epidemiological studies that show significant associations between occupation as a cleaning person/biocide exposure and increased odds of birth defects including cleft palate and neural tube defects such as spina bifida (Blatter et al., 1996; Brender et al., 2002; Lorente et al., 2000). Similar relationships were found by the National Birth Defects Prevention Study which associated the largest number of birth defects with occupation as a cleaning person where central nervous system defects were the most prevalent abnormalities (Herdt-Losavio et al., 2010). However, while these higher rates of birth defects may be related to QAC exposure, additional research is required to determine causation.

Skin irritation and sensitization are other areas of concern related to QACs and health (Basketter et al., 2004; Schallreuter et al., 1986). While it is widely agreed that QACs can be irritating, like other irritants, QACs may be formulated in a way that mitigates irritation which can be confirmed by clinical studies. The potential for skin sensitization after repeated exposure is more widely debated and the data are inconsistent. Unlike irritants, skin sensitization cannot be mitigated through formulation as this is the result of an immune response (Schallreuter et al., 1986; Larsen et al., 2004). However, because the data are inconclusive QACs have not been classified as dermal sensitizers.

The data available for characterizing the environmental persistence of anti-microbial QACs are inconsistent. Several studies

report successful biodegradation of anti-microbial QACs in activated sludge and other environments by *Pseudomonas*, *Aeromonas*, and *Serratia* species (Patrauchan and Oriel, 2003; Sautter et al., 1984; van Ginkel et al., 1992). Conversely, anti-microbial QACs are commonly detected in treated wastewater and sewage sludge with the highest concentrations being reported in sediment near sites of wastewater discharge (Ferrer and Furlong, 2002; Ford et al., 2002; Garca et al., 2001; Li and Brownawell, 2009; Shibukawa et al., 1999). Due to their positive charge, it is not surprising that QACs readily adsorb to the negatively charged surfaces of sludge, soil and sediment, although their ability to biodegrade in these environments is not certain. As a result, the environmental persistence of QACs has not been determined.

2.3. Sodium hypochlorite

Often referred to as household bleach, sodium hypochlorite (SH) is a widely used anti-microbial ingredient in both consumer and industrial cleaning products. The broad spectrum activity of SH is a result of its ability to denature and aggregate essential proteins in microorganisms which effectively destroys them (Winter et al., 2008). Due to this physical mechanism of action SH has not been linked to anti-microbial resistance.

From an environmental perspective, the most significant concern related to SH is its secondary reactions which create halogenated volatile organic compounds (VOX) (Nazaroff and Weschler, 2004; Kwon et al., 2008; Odabasi, 2008). Emissions of VOX present human health risks, including cancer, and VOX react with other pollutants in the atmosphere to destroy stratospheric ozone (Morello-Frosch et al., 2000; Kerr and Stocker, 1986; Woodruff et al., 2000). The ability of the secondary reactions of SH to create VOX is well documented and studies evaluating SH-containing household cleaners, dishwashing detergents, and laundry additives have reported secondary reaction products including chloroform and carbon tetrachloride (Odabasi, 2008; Olson and Corsi, 2004; Shepherd et al., 1996). In addition to being VOX which contribute to indoor and outdoor air pollution, both of the aforementioned chemicals are probable human carcinogens. However, the contribution of halogenated VOCs produced by SH-containing household products to human and environmental effects has not been fully characterized.

In addition, several studies have evaluated the effects of SH exposure in an occupational setting. Researchers in Europe determined through a series of studies that occupational exposure to SH can result in serious respiratory effects. The first study conducted by the group showed that domestic cleaning women experience a significantly higher risk of asthma and chronic bronchitis than women not working as cleaning personnel (Medina-Ramon et al., 2003). Two subsequent studies with the same population were conducted to identify the specific occupational exposures that resulted in the increase of respiratory problems (Medina-Ramon et al., 2005, 2006). In the first study, frequent use of bleach was independently associated with respiratory symptoms, and most significantly asthma. Exposure to chlorine gas at levels up to 0.7 ppm was recorded during normal use of diluted and undiluted SH by cleaners. In the follow-up study, exposure to SH was shown to aggravate pre-existing obstructive lung disease where those with a history of the disease experienced worsening of respiratory symptoms on days worked as a domestic cleaner and days where more time was spent cleaning. Mean levels of airborne chlorine measured during cleaning with diluted and undiluted SH ranged from 0.4 to 1.3 ppm. In addition to the suggested relationship between adverse respiratory effects and SH use, the concentration of chlorine gas measured during cleaning activity in these studies is especially concerning as the severe inhalation toxicity of chlorine

gas has been described in detail including reports of several fatalities (Agabiti et al., 2001; Bonetto et al., 2006; Parimon et al., 2004). The National Institute for Occupational Safety and Health (NIOSH) has established recommended permissible occupational exposure limits of chlorine gas at 0.5 ppm per day with higher levels requiring personal protective equipment. Based on the established exposure limits of NIOSH it could be suggested that the level of chlorine gas that SH using domestic cleaning personnel are exposed to on a daily basis may increase their risk of respiratory effects secondary to chlorine gas inhalation, although this has not been proven definitively. Inhalation toxicity related to the use of SH has also been reported in avian populations (Wilson et al., 2001). In one case, a psittacine avian colony enclosure was cleaned with a 5% solution of sodium hypochlorite and resulted in a mortality rate of 20% and a respiratory related morbidity rate of 49% of flock members (Wilson et al., 2001). Pathological examinations revealed tracheal and pulmonary lesions similar to those observed in mammalian skin after direct contact with bleach. However, despite the available data, a causal relationship between chronic SH use and long term respiratory sequale has not been established.

In aquatic organisms, the majority of the toxicology work regarding exposure to SH and chlorinated compounds is based on effects of pulp mill effluent on wild aquatic populations. The most commonly described effects are reproductive including decreases in sex steroid hormone levels, gonad size, and fecundity, alterations in secondary sex characteristics, and delayed sexual maturity, all of which significantly decreased when pulp bleaching processes transitioned to elemental chlorine free and total chlorine free processing methods (Hewitt et al., 2008; Valenti et al., 2006). Similar reproductive effects have been described in avian populations, although a definitive relationship between SH exposure and reproductive effects has not been proven in aquatic or terrestrial wildlife (Fry, 2005; Khan et al., 2008).

3. Limitations of risk based analyses

As evidenced, there is a significant body of evidence showing adverse human health and environmental effects related to conventional anti-microbial active ingredients. However, because the true nature of the exposure–effect relationships is unknown, risk assessment is not sufficient to accurately assess the safety of these ingredients. The inability to conduct risk-based assessments is due to a combination of factors including the absence of reliable models or methods to measure an effect, and that many of the effects are chronic and therefore difficult to measure in the absence of extensive longitudinal data.

In order to determine if an anti-microbial active ingredient is appropriate to use, some assessment of safety or hazard must be conducted. When risk cannot be adequately addressed there is no basis for action unless the precautionary principle is applied to assess hazard. As such, in the case of anti-microbial active ingredients, application of the precautionary principle allows for an adequate assessment of ingredient hazard to determine if a safer alternative should be sought out.

4. Categorizing and evaluating uncertainty

Clearly, there are many areas of uncertainty related to common anti-microbial active ingredients. In order to evaluate the level of uncertainty that exists, it is useful to explicitly state what undesirable attributes of a chemical are certain and uncertain based on categories of importance to the reviewer. Table 1 demonstrates the categories used in this evaluation: acute effects, chronic effects, air quality, water quality, wildlife effects, environmental persistence, animal derivative, anti-microbial resistance, and natural resource

Table 1
Negative Attributes of QACs, Sodium Hypochlorite, and Triclosan.

Negative attributes	AE	CE	AQ	WQ	WE	EP	AI	MR	NR
QACs									
Respiratory sensitization & asthma	?	?							
Dermal sensitization	?	?							
Reproductive & developmental effects		?			?				
Microbial resistance								?	
Persists in the environment						?			
Synthetic									✓
Dermal irritation		✓							
Sodium Hypochlorite									
Effects of secondary reactions on health	?	?			?				
Chronic respiratory effects		?							
Reproductive effects in wildlife					?				
Reacts with ozone to produce halogenated VOCs				✓					
Acute respiratory irritant		✓				✓			
Corrosive		✓				✓			
Triclosan									
Effects of degradation products on human health and the environment	?	?	?	?	?				
Endocrine disruption		?			?				
Microbial resistance								?	
Synthetic									✓
Forms dioxin-like compounds when exposed to sunlight	✓	✓		✓	✓				
Persists in the environment									✓

AE = Acute Effects, CE = Chronic Effects, AQ = Air Quality, WQ = Water Quality, WE = Wildlife Effects, EP = Environmental Persistence, AI = Animal Derived Ingredients, MR = Microbial Resistance, NR = Natural Resource Use.

✓ = certainty of negative effect, ? = uncertainty of negative effect.

use. After a thorough literature review, negative attributes are listed and the category in which they fall is marked with either a check mark (representing certainty) or a question mark (representing uncertainty). Using the completed table, the human health and environmental effects of the ingredients are evaluated according to certainty or uncertainty following the process depicted in Fig. 1. Using the precautionary principle, negative attributes of the anti-microbial active that are uncertain result in the exclusion of that ingredient from the formulation development palate. For negative attributes that are well established, through a research and mitigation strategy the ability to remove the negative impacts of an ingredient can be evaluated. For example, if an ingredient has the potential to irritate the skin, prototypes can be developed and tested for *in-vitro* and clinical irritation in formulation. If the negative impact, in this case skin irritation, is removed via the mitigation strategy the ingredient can be used.

Using QACs as an example, in Table 1 there are several attributes that present a potential public health or environmental hazard including the use of natural resources to create the ingredient and the potential to irritate the skin. As previously reviewed in this paper, there is scientific uncertainty around the acute effects, chronic effects, microbial resistance, and environmental persistence of QACs. Although causation has not been established for any of these attributes, because their actual effects are uncertain

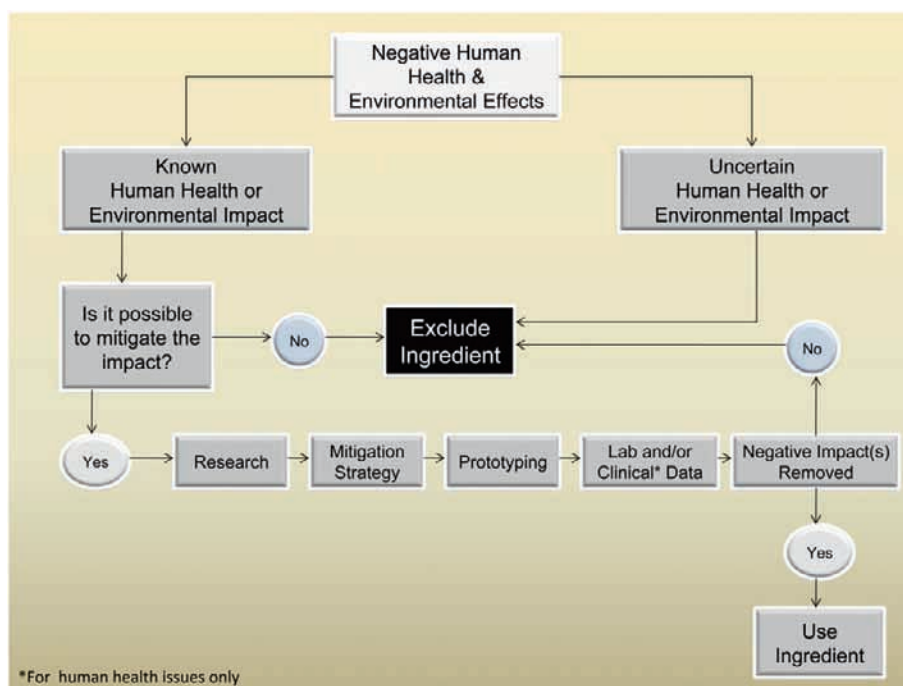


Fig. 1. Process for evaluating ingredients and formulations under the precautionary principle.

a mitigation strategy cannot be developed and validated as parameters for safety have not been established. According to the PP, the inclusion of QACs in a disinfectant formulation raises the threat of human harm and, as such, this ingredient should be avoided and substituted with an alternative active ingredient. A similar assessment can be applied to TCS and SH.

However, this precautionary approach effectively eliminates all conventional anti-microbial active ingredients, which introduces a significant challenge for developing an anti-microbial surface disinfectant. A survey of active ingredients approved for use in EPA-registered products revealed several options for organic acid actives and botanical actives based on essential plant oils. The broad spectrum anti-microbial activity of naturally derived citric and lactic acid is well known and these active ingredients are widely used in both consumer and commercial household and personal care products (Hellstrom et al., 2006; Lopes, 1998; Turner et al., 2004). However, the efficacy of these organic acids is optimal under acidic conditions which can result in products that are irritating to eyes and skin (Berner et al., 1988; Swanson et al., 1995; Mangia et al., 1996). Therefore, despite their minimal environmental and human health impacts, their potential for eye and skin irritation typically precludes them from being utilized as active ingredients in registered disinfectants classified as EPA toxicity category IV; EPA's lowest toxicity category. Due to this limitation, organic acids did not move on to prototyping and botanical active ingredients were evaluated in more detail. Of the essential oils registered as pesticides, thyme oil differentiated itself by virtue of its anti-microbial efficacy and safety profile and was chosen for a more detailed review of authenticity.

4.1. Thymol

Thymol, or 5-methyl-2-isopropyl-1-phenol, is a monoterpene derived from the essential oil of the *Thymus vulgaris* (thyme) plant. The thyme plant is generally recognized as a safe natural seasoning (21 CFR 182.10) and essential oil (21 CFR 182.20) by the US Food and

Drug Administration (FDA) and thus is a common food additive. Historically, thyme has been used for medicinal purposes in many cultures spanning topical to oral routes and is still recommended by Germany's Commission E for treatment of respiratory ailments such as bronchitis and whooping cough. As humans and other living organisms have been exposed to thymol via physical contact and diet on a regular basis for literally thousands of years thymol is known to be well tolerated and its safety profile has been well characterized.

The anti-microbial and pharmaceutical properties of thymol have also been thoroughly described (McOmie et al., 1949; Juven et al., 1994; Mahmoud, 1994; Shapiro and Guggenheim, 1995; Edris, 2007; Xu et al., 2008). The broad spectrum anti-microbial efficacy of thymol results from its ability to disrupt the cytoplasmic membrane of microbes by increasing its permeability and depolarizing its potential resulting in rapid efflux of cellular constituents (Xu et al., 2008). Thymol is recognized by the EPA as a registered pesticide and by the FDA as an allowable active ingredient in several Over the Counter Drug monographs making thymol a common chemical found in US households (Table 2).

Several studies have been conducted to evaluate the potential for thymol to cause antibiotic resistance (Walsh et al., 2003; Shapira and Mimran, 2007; Palaniappan and Holley, 2010; El-Shouny and

Table 2
FDA OTC Monographs listing thymol as an allowable active ingredient.

OTC Monograph	Sub-Category
Acne	N/A
Antifungal	N/A
Cough cold	Nasal decongestant
Dandruff/Suborrheic Dermatitis/Psoriasis	N/A
External analgesic	Anesthetic Fever Blister, Cold sore Poison Ivy/Oak/Sumac
Oral health care	Anesthetic/Analgesic
Relief of oral discomfort	N/A
Skin protectant	Astringent

Magaam, 2009). In one study, clinical and environmental isolates of *Pseudomonas aeruginosa* were found to be resistant to six common antibiotics, however, when these same isolates were exposed to botanical antimicrobials, including thymol, they were completely inactivated (El-Shouny and Magaam, 2009). Another study evaluated the effect of botanical antimicrobials against a selection of antibiotic resistant bacterial strains (Palaniappan and Holley, 2010). Results showed that not only were the resistant strains susceptible to inhibition by thymol, but a combination of thymol and the antibiotic the strain previously showed resistance to resulted in efficacy against the strain. The minimum inhibitory concentrations (MIC) of resistant and non-resistant *Escherichia coli* strains to thymol have also been determined. While the MICs for were heightened for the resistant mutants, resistant mutants were completely inactivated when exposed to higher concentrations of thymol (Walsh et al., 2003). This study also showed that under laboratory conditions bacterial exposure to thymol can lead to reduced susceptibility to chloramphenicol, although this was not deemed to be clinically relevant. Overall, thymol has not been shown to cause antibiotic resistance and has been shown to be effective against a variety of multi-antibiotic resistant strains of bacteria.

Because thymol is delivered as a component of the essential oil of the *T. vulgaris* plant, the safety profile reflects the skin irritation potential common to essential oils. Clinical dermatology studies of thymol show that the ingredient can be irritating and that the irritation is dose dependent. For example, pure thymol (100%) is extremely irritating to the skin (McOmie et al., 1949). However, in studies of lower concentrations, such as a 1% thymol solution, irritation is not seen (Nethercott et al., 1989; Fisher, 1989). The dose dependent nature of thymol's irritation potential suggests that proper formulation could mitigate irritation.

While thymol does not have components that are known or suspected sensitizers, there have been reports of weak sensitization under occlusive conditions at concentrations of 1–5% (Fisher, 1989; Djerassi and Berowa, 1966; Dohn, 1980; Itoh et al., 1988). It has also been reported that thymol can react with formaldehyde and ethanolamine to cause compound allergy (Smeenk et al., 1987). However, the majority of literature reports cases where, under the same conditions, thymol exposure does not result in any sensitization reaction which is consistent with the results of animal toxicology studies (Nethercott et al., 1989; Meneghini et al., 1971; Nishimura et al., 1984; Klecak et al., 1977). In addition, the historical use of thymol in personal care and herbal preparations has established the ingredient's safety for topical applications. As well as this established history of safety, the intensive toxicology reviews undertaken as part of monograph development and pesticide registration by FDA and EPA, respectively, have resulted in thymol being approved for use in eight over the counter drug monographs and as an active ingredient for registered pesticides, including minimum risk pesticides (Table 2). As a result, the evidence supports that thymol is not a sensitizer, although due to the presence of case reports in the literature clinical evaluations of sensitization must be completed for formulations using thymol as part of the standard product safety qualification procedure.

The evaluation of the negative attributes associated with thymol is summarized in Table 3 and identifies acute effects as an area of certainty which requires the research and execution of a mitigation strategy for a formulation using this ingredient. Specifically, skin irritation requires further investigation and mitigation. No areas of uncertainty regarding potentially negative attributes were identified for thymol. Following the process described in Fig. 1, hard surface disinfectant prototypes were developed using a thymol concentration of 0.05%. The inert ingredients included in the prototype formulation were selected based on the Precautionary

Table 3

Negative attributes of thymol.

Negative Attributes	AE	CE	AQ	WQ	WE	EP	AI	MR	NR
Thymol									
Dermal irritation	✓								

AE = Acute Effects, CE = Chronic Effects, AQ = Air Quality, WQ = Water Quality, WE = Wildlife Effects, EP = Environmental Persistence, AI = Animal Derived Ingredients, MR = Microbial Resistance, NR = Natural Resource Use.

✓ = certainty of negative effect.

Principle and are listed in Table 4. The mitigation strategy developed for thymol consisted of three phases: toxicity assessments, performance testing, and skin safety testing.

In the first phase, the acute toxicity of the prototype was calculated using a weighted average of the ingredient toxicities as specified by the UNECE Globally Harmonized System (GHS) Additivity Formula and revealed that the prototype is non-toxic with an LD50 of >431,910 mg/kg (oral, rat). The aquatic toxicity was calculated using the UNECE GHS method and the LC50 for the prototype was calculated as >125 mg/L which shows that the prototype is non-toxic to aquatic life. In phase two, the prototype was tested for anti-microbial efficacy and cleaning performance and met the microbiological requirements for an EPA registered disinfectant and desired cleaning performance standards (data not shown). Having passed the basic safety requirements of the preliminary qualification, to complete the third and final phase of qualification the potential negative effect of thymol was addressed through pre-clinical *in-vitro* and clinical skin irritation and sensitization studies to confirm formula safety and address the area of concern captured in Table 3.

4.2. *In-vitro* irritation[®] assay for dermal irritancy

To determine the acute dermal irritation of the disinfectant prototype with a 0.05% thymol active concentration, the *in-vitro* Dermal Irritation[®] Assay was conducted by a third-party laboratory (*In-Vitro* International, Irvine, California). This assay is a standardized, quantitative acute dermal irritation test that has been described in detail (Mast and Rachui, 1997). In short, test materials are applied to a synthetic biobarrier where conformational changes in macromolecular complexes are used to determine dermal irritation. Dermal irritancy potential is expressed as a Human Irritancy Equivalent (HIE) score, where the classification for a dermal non-irritant is an HIE score of 0.00–0.90, 0.90–1.20 for borderline non-irritant/irritant, and >1.20 for irritant classification. Results show that in a volume-dependent dose-response study HIE values were 0.40, 0.46, 0.72, 0.86 and 1.02 for volumes of 25 μ L, 50 μ L, 75 μ L, 100 μ L, and 125 μ L respectively. Although one dose's HIE score was in the lower limit of the borderline non-irritant/irritant category (HIE = 1.02 for 125 μ L dose) this material was classified as a dermal non-irritant. As such, the next step in the eradication strategy,

Table 4

Ingredient list for 0.05% thymol disinfectant.

Ingredients
Thymol as a component of Thyme Oil (0.05% anti-microbial active)
Sodium Lauryl Sulfate
Copper Sulfate Pentahydrate
Citric acid
Essential oils and Botanical extracts for fragrance including: Oregano oil, lemongrass oil, blue atlas cedar bark oil, lemon peel oil, lemon fruit extract, orange bergamot mint leaf extract.

clinical dermatology testing, was conducted to establish a clinical correlation.

4.3. Human repeat insult patch test for dermal irritation and skin sensitization

The Human Repeat Insult Patch Test (HRIPT) was conducted under Good Clinical Practice according to standardized methods at a third-party laboratory to evaluate if repeated dermal contact could induce primary or cumulative irritation and/or allergic contact sensitization (Consumer Product Testing Company, Fairfield, New Jersey)(McNamee et al., 2008). Briefly, subjects were semi-occlusively patched on the upper back between the scapulae with 0.2 mL of the 0.05% thymol disinfectant prototype after the volatilization period. The induction phase consisted of patch application and clinical grading three times per week for three weeks followed by a rest period. At the conclusion of the two week rest period the challenge phase began where a patch was applied to a virgin test site adjacent to the original induction patch site. The patch was removed and clinically graded at twenty-four and 72 h post-application. Fifty-four subjects completed the study. Results showed only one reaction during the course of the study where prior to application eight of induction one subject experienced level one erythema and slight edema at the test site which completely resolved by application nine. No other visible skin reactions occurred. These results did not indicate potential for dermal irritation or contact sensitization for the disinfectant prototype with an active concentration of 0.05% thymol.

The three phase mitigation strategy demonstrated that the disinfectant prototype containing 0.05% thymol did not exhibit the negative human health effect of concern (irritation) and that thymol was appropriate for inclusion in this disinfectant formula. The microbiological, cleaning performance, ocular irritation (data not shown), and skin safety data lead to the selection of this 0.05% thymol prototype as the final formula, which was fully qualified and launched in January 2010 as the first botanical disinfectant available from Seventh Generation.

5. Conclusions

Toxics reduction efforts such as the Massachusetts Toxics Use Reduction Act (TURA) in conjunction with increasing awareness about the impact of consumer products on human health and the environment have driven the greening of the cleaning products industry. Consumer concerns about these risks are now driving change in the marketplace at the same time that innovative regulatory strategies such as the Massachusetts TURA are evolving to develop safer and more sustainable products. It is these trends which support the use of a PP based model to account for the potential for harm from chemicals that may achieve widespread use. By factoring these uncertainties into the product development equation from the outset, the PP presents a more complete set of design parameters. Rather than stifle innovation, the example of thyme oil based disinfectants illustrates that the PP can actually drive innovation and result in safe and sustainable products and solutions.

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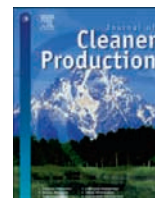
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Toxics use reduction in the home: lessons learned from household exposure studies

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ABSTRACT

Workers and fence-line communities have been the first to benefit from the substantial reductions in toxic chemical use and byproducts in industrial production resulting from the Massachusetts Toxics Use Reduction Act (TURA). As TURA motivates reformulation of products as well as retooling of production processes, benefits could extend more broadly to large-scale reductions in everyday exposures for the general population. Household exposure studies, including those conducted by Silent Spring Institute, show that people are exposed to complex mixtures of indoor toxics from building materials and a myriad of consumer products. Pollutants in homes are likely to have multiple health effects because many are classified as endocrine disrupting compounds (EDCs), with the ability to interfere with the body's hormone system. Product-related EDCs measured in homes include phthalates, halogenated flame retardants, and alkylphenols. Silent Spring Institute's chemical analysis of personal care and cleaning products confirms many are potential sources of EDCs, highlighting the need for a more comprehensive toxics use reduction (TUR) approach to reduce those exposures. Toxics use reduction targeted at EDCs in consumer products has the potential to substantially reduce occupational and residential exposures. The lessons that have emerged from household exposure research can inform improved chemicals management policies at the state and national levels, leading to safer products and widespread health and environmental benefits.

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1. Introduction

In response to growing concern about the effects of industrial pollution in the 1980s, particularly from industrial disasters such as in Love Canal, New York, and Bhopal, India, the federal government passed the Emergency Planning and Community Right-to-Know Act (EPCRA 1986), which led to the establishment of the Toxics Release Inventory (TRI) and gave workers and citizens unprecedented access to information about releases of toxic chemicals from industrial facilities (U.S. EPA, a). Growing out of this “right-to-know” legislation were a series of pollution prevention laws passed by a dozen states in the late 1980s and early 1990s, which reflected a shift in environmental policy from a focus on waste management toward pollution prevention (Geiser, 1993).

The Massachusetts Toxics Use Reduction Act (TURA 1989)—the first comprehensive pollution prevention law in the country—specifically focuses on reducing toxics use and emissions in the manufacturing process (TURI, 2009; TURA, 1989). While the

dramatic reductions in chemical use and releases that have resulted from TURA have widespread benefits (MA DEP, 2005), particularly for the health of workers and nearby communities, there may be an opportunity to expand TURA's benefits to consumer health by targeting use of toxics in commercial goods such as consumer products and building materials.

Indoor environments are increasingly understood as important contributors to exposures for a wide range of pollutants (Rudel and Perovich, 2009; Rudel et al., 2003; U.S. GAO, 1999; Mitchell et al., 2007). During the past fifty years, changing patterns in consumer product and building material use have resulted in corresponding changes in chemical emissions indoors, including increases in the variety and levels of some chemicals (Weschler, 2009). Chemical concentrations are often greater indoors than outdoors due to multiple indoor sources and limited chemicals degradation and ventilation indoors (Rudel et al., in press; U.S. EPA, 2010a). Indoor exposures may be more relevant to health than ambient exposures given that people spend an estimated 90% of their time indoors (Klepeis et al., 2001). Furthermore, recent trends in green building, which have focused on improving energy efficiency, have resulted in increasingly airtight homes. While these changes have been successful in decreasing energy loss, they may have the unintended

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consequence of trapping pollution inside, and thus increasing indoor exposures to some pollutants (Spengler and Adamkiewicz, 2009).

Indoor exposures to a few pollutants, such as lead, radon, tobacco smoke, and asbestos, have been extensively studied. However, some classes of chemicals commonly used in consumer products and building materials have received insufficient attention, including endocrine disrupting compounds (EDCs)—chemicals that can mimic or otherwise disrupt endogenous hormones. Although research on the health effects of EDCs is still developing, studies with animals and cell lines, as well as limited human studies, suggest EDCs may contribute to breast and other hormonal cancer risk, and adverse developmental and reproductive effects (Brody et al., 2007; Colborn et al., 1996; Lau et al., 2007; Diamanti-Kandarakis et al., 2009; Swan, 2008). Examples of EDCs with consumer product sources include pesticides; polybrominated diphenyl ethers (PBDEs) and other flame retardants found in fabrics, polyurethane foam, plastics, and electronics; polychlorinated biphenyls (PCBs), persistent organic compounds widely used in electrical equipment, plastics, and caulk, and banned in 1979 due to concerns about their toxicity and persistence; phthalates, industrial chemicals used in plastics and personal care products; alkylphenols, surfactants used in detergents, pesticide formulations, and polystyrene plastics; and parabens, preservatives used in personal care products such as lotions (Rudel and Perovich, 2009).

Silent Spring Institute's research has focused on studying exposures to EDCs and mammary gland carcinogens—chemicals that cause mammary gland tumors in animal studies—and identifying potential sources of these compounds in the indoor environment. The Institute's Household Exposure Study (HES) has documented widespread exposure to a mixture of EDCs and mammary gland carcinogens in household air and dust (Rudel et al., 2003, in press; Brody et al., 2009). To identify specific indoor sources of chemicals measured, Silent Spring Institute is evaluating and testing consumer products for a suite of EDCs and other chemicals of concern. The results of this research will be used to develop evidence-based guidelines for exposure reduction. In this article, we review the key findings from Silent Spring Institute's Household Exposure Study and product testing research. We examine the lessons that have emerged from this research and discuss the implications for chemicals management policies at the state and national levels.

2. Household Exposure Study

2.1. Cape Cod Household Exposure Study

In the Cape Cod Household Exposure Study, indoor air and house dust samples from 120 Cape Cod, MA, homes were analyzed for 89 EDCs, including phthalates, flame retardants, parabens, pesticides, alkylphenols, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) (Rudel et al., 2003). We surveyed participants about product use and housing characteristics, and interviewed a subset ($n = 25$) of participants about their response to learning results for their own home (Altman et al., 2008). For two homes with elevated levels of PCBs, we re-sampled air and dust, tested residents' blood, inspected the homes, and interviewed residents to investigate the source of the elevated levels (Rudel et al., 2008).

The study documented widespread exposure to EDCs, with 67 compounds detected and an average of 24 compounds per home. Our findings likely underestimate the range of EDCs present in homes because we measured a limited set of compounds previously identified as EDCs, and most chemicals in commerce have not

been screened for endocrine activity. Several EDCs were detected in all homes sampled, including bis(2-ethylhexyl)phthalate (DEHP, a common plasticizer used in polyvinyl chloride and personal care products) and 4-nonylphenol (a surfactant used in some laundry detergents, cleaning products, and plastics). The study provided the first reported indoor measurements for over 30 of the compounds, including the first measurements in U.S. household dust of polybrominated diphenyl ethers (PBDEs, flame retardants found in fabrics, polyurethane foam, plastics, and electronics).

Because indoor air and dust are not currently regulated, we compared concentrations of chemicals detected in homes with EPA's risk-based guidelines for outdoor air and residential soil where available. In all homes, the concentration of at least one compound exceeded the EPA risk-based guideline for air or soil; however, there are no guidelines for 28 of the compounds measured (Rudel et al., 2003; Zota et al., 2009). Moreover, the existing federal guidelines do not consider endocrine effects or the effects of complex mixtures of chemicals to which people are exposed. Characterizing risk based on exposures to single chemicals likely underestimates actual risk as studies have shown that mixtures of EDCs may have additive or other interactive effects when combined (Kortenkamp, 2007). Overall, our results highlight the need to consider mixtures of chemicals when assessing risk.

2.2. Northern California Household Exposure Study

To assess how exposures to EDCs vary across geographic regions and socioeconomic status, we expanded the Cape Cod HES to include homes in Richmond, CA, an urban community bordering a Chevron oil refinery, transportation corridors, and other industry, and Bolinas, CA, a nonindustrial comparison community (Brody et al., 2009). We collected paired indoor-outdoor air samples, as well as household dust samples, from 50 homes. Samples were analyzed for over 150 compounds, including metals and particulate matter (PM_{2.5}), which are associated with industry and transportation, and EDCs, including phthalates, PBDEs, parabens, pesticides, alkylphenols, PAHs, PCBs, and other estrogenic phenols. We observed housing characteristics and interviewed participants about product use, demographics, and their response to study findings.

We detected 104 compounds in indoor air in Richmond and 69 in Bolinas. In outdoor air, we detected 80 compounds in Richmond and 60 in Bolinas, including many EDCs that had not been measured previously in outdoor air. We found higher concentrations of EDCs in indoor air compared to outdoor air, and lack of correlation between indoor and outdoor concentrations for most of the chemicals, which suggests that they have primarily indoor sources. Indoor concentrations of the most ubiquitous EDCs were generally correlated with each other, underscoring the importance of considering exposure to mixtures of chemicals when developing chemical screening and exposure reduction strategies. For many PAHs, which are products of combustion, outdoor and indoor air levels were correlated, demonstrating the influence of outdoor sources on indoor concentrations.

3. Lessons from the Household Exposure Study

3.1. Residential exposures to EDCs are widespread

Our household exposure research provides evidence that residential exposures to EDCs and other chemicals of concern are widespread. In the HES, we documented exposure to over 80 EDCs in household air and dust. Paired indoor-outdoor measurements provide evidence that consumer products and building materials play a significant role in indoor environmental quality. Given that

exposure to chemicals with evidence of potential health effects in homes is substantial, we should be concerned about putting these chemicals into products and building materials, which can migrate into household air and dust.

3.2. Banning a chemical does not necessarily eliminate it

Residential exposures to pesticides and other chemicals from consumer products can persist even after the chemicals are banned. Persistence indoors is expected because many of these chemicals are semivolatile organic compounds (SVOCs), which are slowly released from sources over time and also have a tendency to partition onto surfaces throughout the home (Weschler and Nazaroff, 2008). We detected the pesticide 4,4'-DDT, which was banned in 1972, in 65% of Cape Cod dust samples in 1999–2001 and 86% of California dust samples collected in 2006. Other banned and restricted pesticides frequently detected include chlordane, heptachlor, methoxychlor, dieldrin, and pentachlorophenol. Furthermore, many pesticides were detected at levels above EPA risk-based guidelines. The presence of these pesticides above health guidelines years after their use was prohibited or restricted illustrates that these chemicals do not easily degrade in the protected indoor environment and that banning chemicals is not always effective at removing exposure.

Unlike pesticides, which often display warning labels and include labeling for active ingredients, many chemicals of concern with consumer product sources enter homes unrecognized. For example, we found PCBs in nearly a third of the Cape Cod homes despite their being banned in the 1970s and having a reputation as industrial pollutants that did not have significant consumer uses. Follow-up testing of two Cape Cod homes with unusually high concentrations revealed that levels of PCBs in air and dust remained elevated five years after the initial sampling; and blood levels of long term residents of these homes were higher than the 95th percentile of those reported in the *Third National Report on Human Exposure to Environmental Chemicals* (Rudel et al., 2008). During an interview, one participant recalled using the wood floor finish Fabulon. By consulting an out-of-print reference book, researchers discovered that Fabulon Bowling Alley Finish, which was used in the 1950s and 1960s, contained PCBs during this period (Fig. 1). Thus, persistent chemicals used legally in consumer products in the past have created lingering health risks that are often difficult to identify without expensive testing. Evaluating the safety of chemicals before they are widely used in consumer products could avoid introducing this type of long-lasting risk in the future.

3.3. Consumer product standards influence household exposure

Residential exposures to EDCs may be influenced by specific standards related to consumer products and building materials. In our Household Exposure Study, we found penta-PBDE levels in California house dust were 10 times higher than other levels reported in the US and 200 times higher than in Europe, where the compound has been phased out (Zota et al., 2008). The homes with the maximum concentrations were the highest ever reported in indoor dust. Blood levels of California residents in the National Health and Nutrition Examination Survey (NHANES) were nearly two-fold higher compared to residents of other states. These results show elevated exposure to penta-PBDEs in California, which is likely an unintended consequence of the state's stringent furniture flammability standard. The unique standard, which requires furniture to be resistant to an open flame for 12 seconds, spurred manufacturers to add penta-PBDE to household products such as polyurethane furniture foam to meet the requirements.

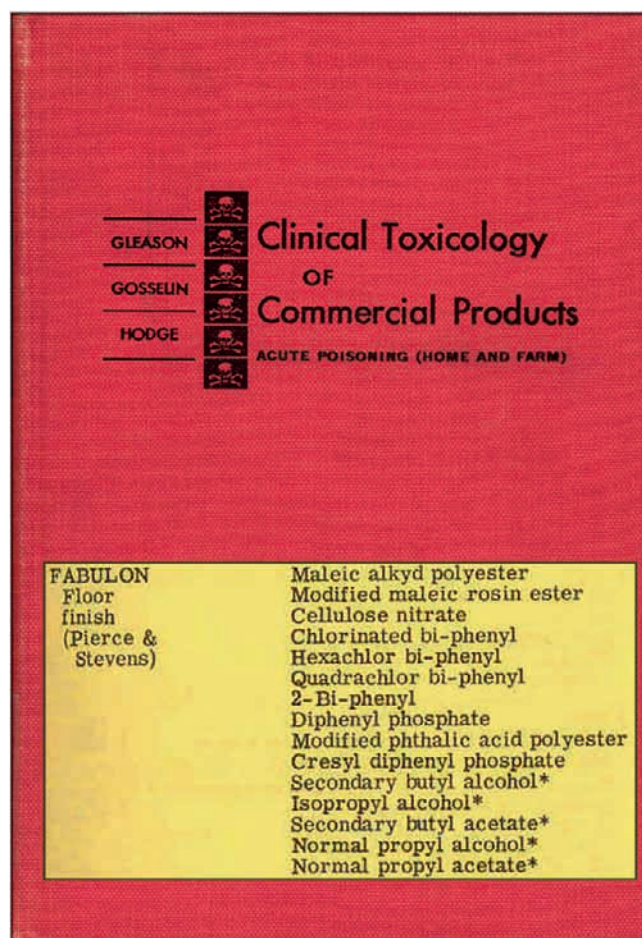


Fig. 1. Entry for Fabulon floor finish from 1957 edition of Gleason et al. *Clinical Toxicology of Commercial Products* lists PCBs among the ingredients.

In 2004, penta-BDE was banned in California and some other states; however, the persistent chemical lingers in many household furnishings. Furthermore, because manufacturers are still required to comply with the safety standard, they have replaced penta-BDE with alternative flame retardants that may not have been thoroughly tested for safety. Rather than substituting one harmful ingredient for another, we need a comprehensive framework for identifying safer alternatives for use in commercial products.

Other well-intentioned product standards may also have unintended exposure implications. For example, Leadership in Energy and Environmental Design (LEED)—the internationally recognized green building certification system (U.S. Green Building Council)—provides rating incentives that encourage the use of some materials that may be sources of indoor pollution such as flame retardants from insulation and recycled carpet backing. Implications of LEED for indoor air quality have not yet been empirically evaluated.

3.4. Outdoor pollutants penetrate indoors

In addition to indoor sources, outdoor sources of some chemicals contribute to residential exposures. In our Northern California HES, we found exposures were generally higher in Richmond compared to Bolinas for compounds associated with industry and transportation. In nearly half of Richmond homes, PM_{2.5} levels exceeded California's annual ambient air quality standard. Paired indoor-outdoor correlations indicate outdoor air is an important source of indoor concentrations of some compounds, including

PM_{2.5}, PAHs, and metals. Levels of vanadium and nickel in Richmond outdoor air were among the highest in the state, implicating heavy oil combustion from the nearby refinery and marine port (Brody et al., 2009). As with other compounds from industry and transportation sources, vanadium and nickel were migrating into homes. Other studies, which have focused on volatile organic compounds (e.g. Sax et al., 2004) and PM_{2.5} (e.g. Meng et al., 2009), have also observed the impact of outdoor sources on indoor exposures. Taken together, these results illustrate the cumulative impacts of pollution from indoor and outdoor sources on indoor air quality. In order to address indoor exposures, TUR approaches need to target the combined effects of indoor and outdoor sources.

4. Developing evidence-based exposure reduction strategies

Many consumers seek guidance on how to reduce exposure to EDCs and other pollutants indoors. Although household exposure studies can document the presence of pollutants indoors, they often provide limited information about chemicals' specific sources and thus exposure reduction strategies. Moreover, source identification is hampered by a lack of information about product ingredients because some chemicals may not be listed on product labels, some may arise from product packaging materials rather than ingredients, and others may be present as byproducts. In some cases, manufacturers may not know the identity of chemicals in the components they purchase from manufacturers upstream (Massey et al., 2008).

While new initiatives, such as Good Guide™, that rate products based on safety can provide some direction to consumers navigating product labels, the rating systems are restricted to information disclosed by manufacturers. Green Seal™, EPA's Design for the Environment (DfE) program, and other third party certifiers also can help inform consumer product choices; however, they are limited in the scope of products and chemicals analyzed.

To help guide consumer product choices and potentially reduce indoor exposure to EDCs, Silent Spring Institute is seeking to develop evidence-based recommendations. These guidelines will also inform an intervention study designed to determine how much residential exposures can be reduced through product replacement.

4.1. Product selection

As a first step to inform exposure reduction, we selected household and personal care products for analysis. We chose individual products based on information about market share and availability and classified them as either "alternative" or "conventional" according to criteria related to product ingredients and marketing. We designated as "alternative" those products that we expected would contain minimal quantities of specific chemicals of concern, including suspected EDCs and mammary carcinogens (Table 1). Products that did not meet the criteria for alternative products were designated as conventional. Our criteria list is not intended to be exhaustive; that is, it does not consider all indoor pollution concerns such as irritants, asthmagens, and neurotoxins, but rather reflects EDCs in indoor air and dust in our Household Exposure Study.

4.2. Request for information on product ingredients

Product labels provide a preliminary but incomplete picture of product ingredients since the multitude of federal labeling laws—including the Federal Food, Drug, and Cosmetic Act (FD&C Act), the Federal Insecticide, Fungicide, and Rodenticide Act

Table 1

Selection criteria used to identify "alternative" consumer products.

<i>Products should contain/be</i>
Primarily plant-based ingredients
Paraben-free
Fragrance-free (allow botanical extracts, except tea tree oil and lavender)
<i>Products should not contain</i>
Ethanolamines
Organofluorines (including labeled as being stain resistant)
Anti-microbials (e.g. triclosan)
Alkylphenol-based surfactants (i.e. nonionic surfactants)
Dichlorobenzene
Phthalates (including labeled as containing vinyl)

(FIFRA), and the OSHA Hazard Communication Standard (HCS)—do not require full disclosure. Because analytical testing of products is expensive, we first attempted to obtain information about ingredients from manufacturers. We contacted 34 manufacturers of conventional ($n = 24$) and alternative ($n = 10$) products to inquire about specific ingredients, including requests for information beyond what appeared on product labels and material safety data sheets (MSDSs).

Most manufacturers we contacted did not provide complete responses. Of the 24 conventional product manufacturers we contacted, 70% provided no information (of those, 17% stated the information was proprietary), 13% provided only MSDSs even after we stated that was insufficient, and 17% provided some or all of the additional information we requested. Manufacturers of alternative products were slightly more willing to share product information. Of the alternative product manufacturers contacted, 20% provided no information, 20% provided only MSDSs, and 60% provided some or all of the additional information we requested.

4.3. Product testing

Because we were able to obtain only partial information on product ingredients from labels and manufacturers, we tested 214 conventional and alternative household and personal care products for over 65 chemicals, including phthalates, fragrances, parabens, and anti-microbials. Products were purchased from local area stores and analyzed for a suite of neutral compounds and a suite of phenolic compounds.

A composite sampling scheme for conventional products was used to minimize analytical costs. Specifically, 2–7 products within a product type category (e.g. bar soap, toothpaste, surface cleaner) were combined and analyzed as one sample. Our goal was to represent "typical" exposure using conventional products and to identify specific alternative products without our chemicals of concern. A total of 170 conventional products (mean = 4 per product type category) and 44 alternative products were analyzed.

All conventional samples had at least one detect; eleven alternative products contained no detectable amounts of targeted compounds. The average number of detected compounds was up to 8.7 in conventional products (uncertainty due to composite sampling) and 2.9 in alternative products. These results indicate that it is possible to select products with fewer compounds of concern based on inspection of product labels; however, the efficacy of the selection process varies by product category.

4.4. Evaluating consumer product labels

One of the goals of developing criteria for selecting products is to help consumers make more informed product choices, so we evaluated the average consumer's experience trying to utilize the guidelines. With training from Silent Spring Institute researchers,

student interns studied the labels of over 180 alternative and conventional cleaning and personal care products in two local area stores (Table 2). Products were chosen based on information about market prominence and availability. For each item, interns documented information about product price, environmental and health claims, ingredients, and any difficulty following the criteria for selecting alternative products (Table 1).

The exercise revealed a number of challenges for shoppers. As the research team expected, some products did not list ingredients on their labels; and products with labels often did not indicate if all ingredients were disclosed. This made it impossible to determine which ingredients were present in or absent from many products. Helpful product labels advertised specifically that they were “phthalate-free” or “paraben-free.” Likewise, other products announced that they “disclose all ingredients” or were “EU compliant.”

In general, environmental and health claims were common, particularly on alternative product labels. Examples of frequently encountered claims include “natural,” “non-toxic,” and “safe.” These claims were not restricted to alternative products. For example, one conventional antimicrobial soap was advertised as “eco-smart.” Many of these claims are potentially misleading because the use of the terms in product labeling is not adequately regulated in the US: the US Federal Trade Commission has created some guidelines for environmental marketing, but they are rarely enforced (Torrie et al., 2009). Lengthy claims also contributed to making label-reading time consuming; the interns took an average of five minutes per product to wade through ingredient lists and environmental and health claims. Interpreting the labels was challenging because ingredients could be listed under multiple names (e.g., surfactants), with abbreviations (e.g., monoethanolamine could be listed as MEA), in small print, or on the inside of the label. In sum, we found that although the criteria were useful for avoiding some chemicals of concern in some products, the lack of transparency about consumer product ingredients hinders consumers’ ability to reduce their exposures.

5. Implementing lessons learned

Our household exposure study and product testing research illustrates the multiple challenges faced by consumers, researchers,

public officials, manufacturers, retailers, and others who wish to identify and reduce exposure to EDCs and other chemicals of concern in commercial products. Household exposure studies have documented widespread exposure to EDCs in homes; however, it remains challenging to identify and reduce sources of exposure. Our analysis of household and personal care products reveals that this difficulty stems in part from inadequate labeling requirements and some manufacturers’ reluctance to provide information about product ingredients. Although product testing can provide some useful information about selected chemicals of concern, it is a resource-intensive process that affords only a narrow snapshot of potential consumer product exposures.

While we continue to support individual efforts to reduce exposure, we recognize the need for a more comprehensive toxics use reduction approach that targets upstream sources of exposure and stimulates development of safer alternatives. The lessons that have emerged from our research can inform exposure reduction strategies at both the state and national levels. Our findings support the following goals for chemicals policy reform:

- Create a framework for evaluating the safety—including for endocrine effects—of new and existing chemicals, and alternatives to hazardous chemicals. This framework should include: (1) new toxicity testing requirements for commercial chemicals; (2) research and development of new techniques for rapid screening and prioritization of chemicals based on toxicity (e.g. EPA’s ToxCast program); and (3) novel decision theory approaches that rely on available data to select the least toxic chemicals for particular uses.
- Shift the burden of proof. Instead of requiring government and the public to demonstrate a chemical’s harm, require manufacturers to test for safety.
- Provide incentives and technical support to manufacturers for consumer product reformulation.
- Consider exposures to mixtures of chemicals, which can produce interactive effects, when assessing risk.
- Consider the impact of chemicals on human health through the full product lifecycle, including indoor exposure from product use.
- Promote public right-to-know by increasing transparency about product ingredients through labeling requirements.
- Build capacity for green chemistry—the design and manufacture of chemical products and processes that reduce or eliminate the use and generation of hazardous substances (U.S. EPA, b)—by supporting research and education.

5.1. State level

States can play an important role in achieving objectives for toxics use reduction. In addition to benefits at the local level, novel state chemicals policies can help catalyze reforms at the federal level. There are many options for state participation in chemicals management, including collecting data on chemical use, requiring manufacturers to label ingredients, creating incentives for information sharing, restricting what can be sold in the state, and providing technical assistance to manufacturers with product reformulation (Lowell Center for Sustainable Production, 2008a, b).

In the absence of an integrated federal approach, several states have already taken steps to address chemicals policy reform (Tickner et al., 2005). For example, California’s new Green Chemistry Initiative provides a framework for chemicals policy reform in the state, which includes: promoting pollution prevention, increasing transparency about product ingredients, providing publicly available information about chemical safety, and improving consumer product safety and sustainability. Two state

Table 2
Products evaluated in label-reading exercise.

	Count
<i>Store</i>	
Alternative	108
Conventional	81
<i>Product type</i>	
Alternative	114
Conventional	75
<i>Product category</i>	
Air freshener	7
All purpose cleaner	14
Conditioner	9
Deodorant	10
Dishwashing soap	15
Dryer sheets	9
Laundry detergent	14
Lip care	15
Lotion	21
Shampoo	7
Shaving	8
Soap	40
Sunscreen	9
Toothpaste	11
Total	189

laws have already been passed that work toward these goals (Cal EPA, 2008). Other examples at the state level include recent laws targeting toxics in children's products in Maine and Washington, which incorporate TUR principles (Lowell Center for Sustainable Production).

In Massachusetts, TURA has been successful in reducing toxics use and emissions in the state and has served as a model for other states and nationally. Building on this success, TURA has the potential to extend these benefits to include further reductions in exposure from consumer product use. Possible opportunities to expand TURA within its existing framework to achieve this goal may include: (1) focusing on opportunities for reductions in EDC use in consumer products during the TUR planning process; (2) expanding TURI's trainings to include information about indoor exposure to EDCs from commercial products; (3) supporting research on alternatives assessment for EDCs in consumer products; and (4) including additional EDCs and other emerging contaminants on the list of reported chemicals.

TURI has already demonstrated success in assisting with product reformulation. For example, electronics manufacturers, with TURI's help, have applied concepts from product lifecycle assessment (LCA) to reduce the use of lead in their products (TURI). Recent grants administered by TURI will support research on alternatives to bisphenol-A in epoxy can linings and brominated flame retardants in textiles. In addition, the state is considering a bill, H. No. 757 (2009) An Act for a Competitive Economy Through Safer Alternatives to Toxic Chemicals, which has the potential to expand the TURA program's ability to promote substitution of hazardous chemicals with safer alternatives in consumer products.

Although these opportunities and developments are promising, the TURA program is limited in the extent to which it can affect consumer product exposures. First, TURA generally only applies to companies that use large quantities of toxics; that is, companies that either manufacture or process 25,000 pounds or more of a reportable chemical per year or otherwise use 10,000 pounds (TURA §9A), and 1,000 pounds for a short list of "higher hazard substances" (TURA §9B). Confidential business information (CBI) claims, which prevent manufacturers from having to report product ingredients that they consider to be trade secrets, provide another limitation to TURA's scope (TURA §20). Some of the most promising methods for addressing consumer product exposure, such as product testing and labeling requirements, are not covered by TURA. Finally, TURA does not address some types of products such as cosmetics and pesticides, or imported products used in Massachusetts homes. These limitations underscore the need for more comprehensive chemicals policies.

5.2. National level

While state level strategies will continue to be important, ultimately, a coordinated national approach to chemicals management is needed. Currently, a patchwork of laws comprises the fabric of U.S. chemicals regulation. The primary federal statute regulating industrial chemicals in the U.S., the Toxic Substances Control Act (TSCA 1976), is recognized by many as outdated and inadequate (U.S. GAO; NAS, 1984; U.S. EPA, 2007). Wilson and Schwarzman have identified three main gaps in the framework for chemicals management in the U.S., including a lack information about chemical risk required from manufacturers (data gap); a lack of tools for government to take action to reduce exposures to hazardous chemicals (safety gap); and a lack of investment in green chemistry research and education (technology gap) (Wilson and Schwarzman, 2009). Closing these gaps, the authors argue, will require fundamental chemicals policy

reform that increases transparency and accountability, and promotes the development of green chemistry.

Responding to similar gaps, the European Union recently overhauled its chemicals management program by enacting the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH 2006) (European Commission, 2006), which provides a unique opportunity to motivate chemicals policy reform in the U.S. (Lowell Center for Sustainable Production, 2008a; Wilson and Schwarzman, 2009; Ackerman et al., 2006). Furthermore, the 2008–2009 President's Cancer Panel Report, "Reducing Environmental Cancer Risk, What We Can Do Now," calls for adopting a precautionary approach to chemicals management in the U.S. (President's Cancer Panel, 2010).

Some promising steps toward chemicals policy reform have already been taken at the federal level. The EPA recently expressed a commitment to rethinking chemicals management, including developing action plans and increasing public access to safety information for existing chemicals of concern (U.S. EPA, c, d, e). The Endocrine Disruption Prevention Act of 2009 proposes to develop methods to identify EDCs with the goal of informing regulation, while the Safe Chemicals Act of 2010, the most comprehensive chemicals policy bill to date, aims to overhaul TSCA.

Looking forward, implementing a comprehensive chemicals management policy that addresses EDCs and other chemicals of concern in commercial products and stimulates the development of safer alternatives has the potential to substantially reduce indoor exposures that affect health. Just as Massachusetts was a leader in passing the nation's first TUR law, it could lead the way in initiating policies at the state level that reduce exposures and promote changes at the federal level.

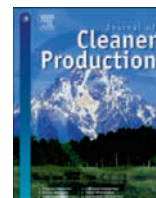
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Environmental assessment of green hardboard production coupled with a laccase activated system

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ABSTRACT

European consumption of wood-based panels reached record levels in recent years driven mostly by demand from end-use sectors: residential construction, furniture, cabinets, flooring and mouldings. The main panel types are composite boards such as particleboard, high density fiberboard (HDF), medium-density fiberboard (MDF) and other adhesively bonded composites such as plywood and wet-process fiberboard (hardboard). The synthetic resins used in their manufacture come from non-renewable resources, such as oil and gas. Several consequences are associated to this type of adhesives: variation in the availability and cost of these wood adhesives depends on raw materials, the formaldehyde emissions as well as the limited recyclability of the final product. Hence, in the search for alternatives to petroleum-based wood adhesives, efforts are being devoted to develop adhesives by using phenolic substitutes based on lignin, tannin or starch. In this context, the forest industry is increasingly approaching to enzyme technology in the search of solutions. The main goal of this study was to assess the environmental impacts during the life cycle of a new process for the manufacture of hardboards manufacture, considering the use of a two-component bio-adhesive formulated with a wood-based phenolic material and a phenol-oxidizing enzyme. This new product was compared to the one manufactured with the conventional phenol-formaldehyde resin. The study covers the life cycle of green hardboards production from a cradle-to-gate perspective, analysing in detail the hardboard plant and dividing the process chain in three subsystems: Fibers Preparation, Board Forming and Board Finishing.

Auxiliary activities such as chemicals, bio-adhesive, wood chips, thermal energy and electricity production and transport were included within the system boundaries.

Global warming (GW), photochemical oxidant formation (PO), acidification (AC) and eutrophication (EP) were the impact categories analysed in this study. Additionally, the cumulative energy demand was evaluated as another impact category. According to the results, four stages significantly influenced the environmental burdens of the production system: laccase production, on-site thermal energy and electricity production as well as wood chipping stage. Due to the environmental impact associated to the production of green bonding agents, a sensitivity analysis with special focus on the eutrophying emissions was carried out by evaluating the amount of laccase and lignin based phenolic material used. The combined reduction in both bonding agents may slightly reduce the contributions to this impact category. In addition, a hypothetical scenario with no laccase and with a higher concentration of the lignin based material (25% more) could improve the environmental profile in all impact categories with a reduction of 1.5% in EP.

Further research should focus mainly on laccase production, in order to reduce its energy demand as well as on the amount of green adhesive required to obtain mechanical and swelling properties similar to those of conventional hardboard.

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1. Background, aim, and scope

The European Union (EU) is one of the largest producers, traders and consumers of forest products worldwide (European Commission, 2010). Forest-based industries and other related industries make up

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one of the most important and dynamic industrial sectors in the EU, representing up to 10% of the total European manufacturing industries. In 2005, these industries employed roughly 3 million people in 350,000 companies with an economic turnover of about 380 billion €, producing an added value of around 116 billion € (European Commission, 2010).

The forest sector (forestry, forest-based and related industries) comprises the following industrial sectors: i) woodworking; ii) cork and other forest-based materials; iii) pulp, paper and paper-board manufacturing; iv) paper and paper-board converting and; v) printing industries. Specifically, wood processing involves the conversion of trees into useful consumer products and/or building materials such as wood boards. The woodworking industries supply basic products such as sawn goods, wood panels and builders' carpentry for construction, internal decoration and packaging (pallets) (European Commission, 2010). In general, the European consumption of panels reached record levels in 2006 (~ 64.7 million m³), driven mainly by demand from end-use sectors: residential construction, furniture, cabinets, flooring and mouldings (UNECE, 2006/FAO).

Wood panels are characterized by their variable physical and mechanical properties. The main panel types in Europe are composite boards such as particleboard, high density fiberboard (HDF) and medium-density fiberboard (MDF), and other adhesively bonded composites such as plywood and wet-process fiberboard (hardboard). Fiberboard is an engineered product made from compressed wood or non-wood lignocellulosic fibers. Because of their high resistance and strength, fiberboards can be used as a raw material for laminate flooring, exterior siding and trim, garage doors, furniture, wall panelling, interior trim and perforated boards. Nowadays, the consumer market is conscious of the environmental problems derived from the industrial sector. Important amounts of petroleum based adhesives (such as urea or phenol formaldehyde) are required for the manufacture of panels. Therefore, formaldehyde emissions during production and end-use are a relevant consequence with negative environmental impacts on ecosystem quality (Imam et al., 1999; US. EPA, 2002). Therefore, special attention is focused on the reduction of this type of adhesives as well as on their replacement by more environmentally-friendly, natural and safer alternatives such as lignin based materials (Moubarik et al., 2009): lignosulfonates (a lignin co-product of sulfite pulping), organosolved lignin, kraft lignin, flavonoid-based tannins from certain trees (Widsten et al., 2009), starch from renewable sources or glues derived from animal tissues casein (Imam et al., 1999). In this context, non-conventional processes based on the treatment of lignin with enzymes have been investigated for fiberboards production at laboratory and pilot scale (Widsten and Kandelbauer, 2008). Moubarik et al. (2009) demonstrated the performance of cornstarch–quebracho tannin-based resins used as adhesives in the plywood production to partially substitute phenol-formaldehyde resin (PF). The new plywood panels showed better mechanical properties and water resistance when compared to conventional PF panels, as well as lower formaldehyde emissions. Moreover, starch has been used as a wood adhesive not only for interior but also for external applications with other polymers such as PF and urea-formaldehyde (UF) (Imam et al., 1999).

Life Cycle Assessment (LCA) has proved to be a valuable methodology for evaluating the environmental impacts of products and service systems, and should be part of the decision-making process toward sustainability (Baumann and Tillman, 2004). Several studies have focused on the production of conventional wood-based products such as load boxes (Echevengua Teixeira et al., 2010), wood floor coverings (Nebel et al., 2006; Petersen and Solberg, 2003), particleboards (Rivela et al., 2006), MDF (Rivela et al.,

2007), hardboards (González-García et al., 2009a) and related wood items such as window frames (Asif et al., 2002; Richter and Gugerli, 1996), walls (Werner, 2001) and furniture (Taylor and van Langenberg, 2003). Furthermore, wood products tend to have a more favourable environmental profile compared to functionally equivalent products obtained from other materials such as plastics, aluminium or steel (Werner and Richter, 2007). To date, LCA studies for green production of boards are not available. The objective of this paper is to environmentally analyse the industrial process of green hardboard manufacture considering the substitution of the phenol-formaldehyde resin by a two-component adhesive with a wood-based phenolic material and a phenol-oxidizing enzyme (i.e. laccase). Additionally, this new product will be compared to the one manufactured with the conventional PF resin used as the main bonding agent (González-García et al., 2009a).

2. Goal and scope definition

2.1. Objectives

This study aimed at analysing the manufacture of green hardboard from an LCA perspective in order to detect the environmental 'hot spots' throughout the production life cycle. Furthermore, a comparison of these environmental results with the conventional production of hardboard was also discussed. An Austrian hardboard plant, which has implemented the biotechnological process of green hardboards production, was selected to study the process in detail. The study covers the whole life cycle of green hardboard manufacture from raw material production to plant gate.

2.2. Functional unit

The functional unit provides a reference point for inputs and outputs (ISO 14040, 2006). In this paper, it is defined as 1 m³ of finished green hardboard (for interior applications). The board density is approximately 900 kg m⁻³ and its moisture content ~7%.

2.3. Description of the system under study

Conventional hardboards (HB) are composite panel products consisting of lignocellulosic fibers manufactured under heat and pressure in a wet process with a small dose of phenolic binder (Widsten et al., 2009). Additives such as paraffin wax can be used to improve certain characteristics such as abrasion and moisture resistance. A panel of this kind has homogeneous thickness, density, appearance and no grain. Phenol-formaldehyde (PF) resin is commonly used in the production of these panels but the presence of synthetic resins limits the recycling and final disposal of used hardboards (Smith, 2004). An alternative process is the substitution of these synthetic resins by bio-based phenolic materials in combination with phenol-oxidizing enzymes. This process has been named as a "green strategy". Examples of bio-based phenolic materials could be lignosulfonates (co-product from dissolving pulp mills) or flavonoid-based tannins (chestnut tannin, tara tannin, mimosa tannin or quebracho tannin). The main phenol-oxidizing enzymes is laccase, which is already commercially produced by a genetically modified fungus in submerged fermentation. In the presence of oxygen, laccase catalyzes the oxidation of phenolic substrates (e.g. certain lignin phenylpropane units) to phenoxy radicals.

The studied HB plant uses a smooth-one-side type production process, which renders good natural fiber to fiber interfelting and bonding with minimum added binder required and provides a moist surface of high plasticity giving the desired embossing sensitivity. The hardboards were produced according to a large

Table 1
Main features of green HB.

Nominal width	1220–1524 m
Moisture content	2–9%
Board thickness	3.0–3.6 mm
MoR	38–60 N mm ⁻²
MoE	3200–3900 N mm ⁻²
Internal bond (IB) ^a	0.8–2.2 N mm ⁻²

^a with a 24 h water swelling (20 °C) of 29–57%.

range of properties. The boards are produced with a two-component adhesive based on laccase activated tannin system instead of PF resin. The main features of green HB vary according to the brand but standard quality boards are shown in Table 1.

According to our previous LCA study of conventional HB production (González-García et al., 2009a), the process chain was divided into three main subsystems: Fibers Preparation, Board Forming and Board Finishing. Auxiliary activities included chemicals, laccase, lignin based phenolic material, thermal energy and electricity production, transport activities and wood chips production. Concerning the production of the lignin based phenolic component, several materials can be used. The innovative nature of this process gives rise to some problems when collecting data for an LCA study, since it is difficult to find quality data, as well as detailed descriptions of the production processes of these alternative materials. Fortunately, the production of lignosulfonates has been reported in literature (Widsten et al., 2009). Therefore, the use of lignosulfonates derived from dissolving pulping as a bio-based phenolic component was considered and included within the system boundaries. The system investigated is illustrated in Fig. 1.

2.3.1. Subsystem of fibers preparation

The main raw materials are green wood chips obtained from Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*). This material is delivered by truck from Austrian wood-based industries such as sawmills, satellite chip mills, etc. Initially, wood chips are washed to remove dirt and other debris.

Clean chips and additional raw material from the plant (sanding dust, sawdust, trimmings, rejected hardboard etc.) are pre-heated to soften lignin and enable subsequent fiber separation. The following step consists of their reduction into fibers, followed by an enzymatic treatment and placement in a storage bin. The enzymatic treatment is carried out by immersing the fibers in the aqueous laccase containing solution for a 20 min incubation time. Enzyme dose may be reduced by applying longer incubation time and/or recirculation. Spectrophotometric assays of laccase activity were carried out with 10 mM 2,2'-azino-bis-(3-ethylbenzthiazolinesulphonate) (ABTS) as substrate in 100 mM sodium acetate buffer (pH 5.0). The absorbance was monitored at 436 nm (extinction coefficient = 29,300 M⁻¹ cm⁻¹). One U of enzyme activity is defined as the amount of enzyme releasing 1 μmol min⁻¹ oxidized product at 25 °C. Regarding the dose of the green bonding agent, 10.5 kg of laccase and 40 kg of lignin based phenolic material are used in the green HB production process, instead of 34 kg of PF used in the conventional process. A fraction of the wood material is burnt in biomass boilers to produce thermal energy for plant activities.

2.3.2. Subsystem of board forming

Fibers with the two-component adhesive are transported from the storage bin to the forming machine where they are placed onto a moving conveyor belt to form a mat. The mat is pre-pressed and trimmed before being loaded into the hot press. This press applies heat and pressure to cure the adhesive and bond the fibers for 4 min. The press uses a multi-opening batch system and is heated (~170–180 °C, above the normal industrial level) by the steam produced at the thermal energy plant.

2.3.3. Subsystem of board finishing

After the pressing process, the boards are placed in a conditioning room and then sanded and sawed into final size. Finally, the boards are packaged and sent to the warehouse. Trimming residues are recycled back to board production or used for on-site energy production.

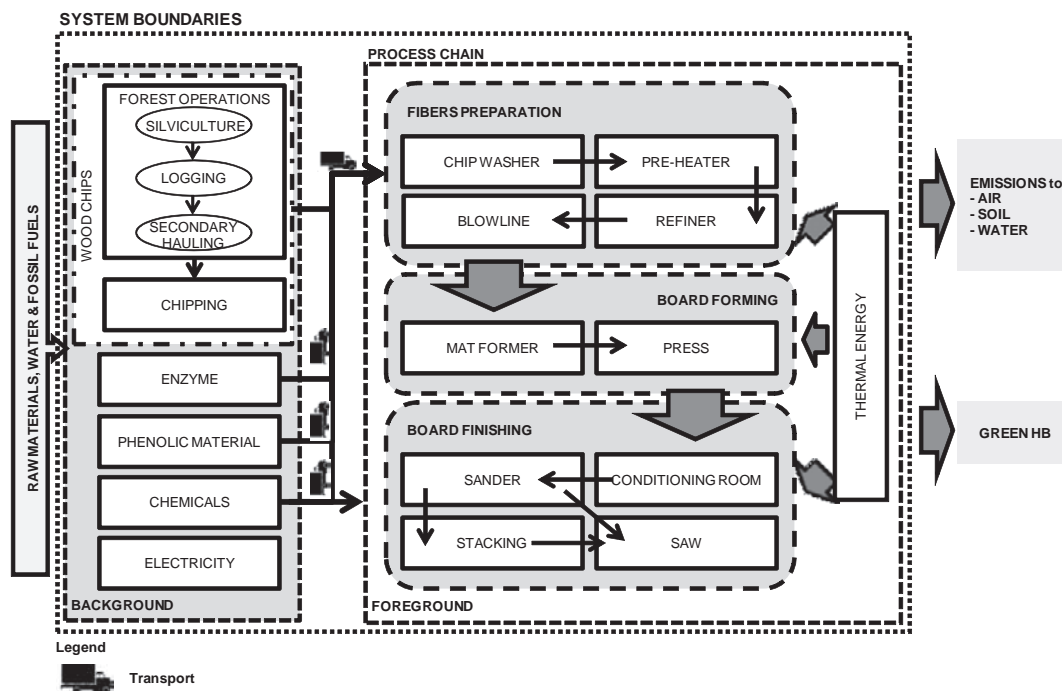


Fig. 1. System boundaries and process chain under study.

2.3.4. Ancillary activities

Several auxiliary activities were included within the system boundaries. Laccase, paraffin emulsion and other chemicals were part of the Fibers Preparation subsystem. In addition, their transport by truck from wholesaler to plant gate (roughly 300 km) was included in the study.

Softwood chips production (the main raw material) was included, considering from softwood plantation to roundwood chipping and delivery to fiberboard plant (Fig. 1). Although not specifically present in the figure, both silviculture, logging operations and transport of roundwood to sawmill (100 km by truck) were considered. All the wood produced in the plantations is assumed to be used in chips manufacture since this kind of wood can be considered as raw material for other forest-based industries (e.g. paper pulp production). Moreover, transport of workers, machinery and materials (fertilizers, pesticides and fuels) to and from forest plantations were also included. Seedling production was excluded due to lack of data. A more detailed description of these activities can be found in González-García et al. (2009b). Roundwood is then processed into green chips, which will be delivered to the plant by truck (an estimated distance of 100 km).

Austrian electricity generation was taken into account with the following profile: 79.7% from hydroelectric plants, 20.2% from fossil fuels, mainly hard coal and lignite, and 0.1% from renewable resources. Finished HB delivery was not included within the system boundaries because its production is carried out at pilot scale at present and green HBs are mainly used for R&D activities.

Finally, all the thermal energy consumed in the HB manufacturing process (steam, hot oil and hot gas) is obtained from the biomass and is produced at the plant as described above. Wood waste from wood-based mills is used as fuel and its transport to plant gate (100 km) was included within the system boundaries.

2.4. Data quality and simplifications

Inventory data for the foreground system (green HB manufacturing process) consisted of average data obtained by on-site measurements. When possible, typical process-specific data were collected to avoid anomalous conditions.

The key emission sources identified were dryers, presses, mat formers, biomass boilers and finishing operations (sanding and sawing). All the emission data corresponded to field data. Other inventory data for the background system such as electricity, paraffin and aluminium sulphate production were obtained from the Ecoinvent database (Althaus et al., 2007; Dones et al., 2007). Regarding chemicals and green chips requirements and wood waste transportation routes were supplied by plant workers, while emission factors were obtained from the Ecoinvent database (Spielmann et al., 2007). Inventory data for forest operations related to softwood production were taken from González-García et al. (2009b), where softwood plantations were assessed. In addition, inventory data for the wood chipping stage were taken from the literature (ETH-ESU 96, 2004). With regard to laccase production, life cycle data for a representative industrial process were found in Nielsen et al. (2007).

Inventory data for the lignin based phenolic material production were taken from González-García et al. (Submitted for publication). In this study, an LCA analysis was performed in order to analyse the environmental burdens in a Swedish biorefinery where dissolving cellulose is produced as the main product, together with ethanol and lignosulfonates as co-products. In addition, extra steam is produced from the biorefinery waste which avoids fossil fuel consumption. A summarized inventory table for the lignin based phenolic material considered is shown in Table 2.

Table 2

Global inventory data per 1 kg of lignin based phenolic material.

INPUTS from TECHNOSPHERE			
Materials		Energy	
Biomass		Electricity from grid	40.2 kWh
Green logs (50% moisture)	0.26 m ³	Steam from biomass ^a	208.4 kWh
Chemicals		Transport	
Hydrogen Peroxide	2.7 kg	20–28 t truck	0.77 t km
Sodium hydroxide	4.5 kg	16 t truck	0.07 t km
Sulfurous acid	0.14 kg		
Chelant	0.10 kg		
OUTPUTS			
To TECHNOSPHERE		To ENVIRONMENT	
Materials		Emissions to air	
Lignosulfonate	1 kg	CO ₂ biogenic	0.11 kg
Ethanol	2.5 kg	CO ₂ fossil	4.2 kg
Dissolving pulp	42.0 kg	Emissions to water	
		COD	1.8 kg
		BOD ₅	0.40 kg

In contrast to the conventional process where fiber drying and mat forming contribute to the environmental impact due to the uncontrolled formaldehyde emissions derived from the PF adhesive, the use of this green adhesive avoids these harmful emissions.

The production and maintenance of capital goods in both conventional and green HB systems were excluded from the analysis, as environmental data were assumed to be comparable in both scenarios (González-García et al., 2009a). Additionally, several industrial LCA studies have shown that the environmental load from the production of capital goods is insignificant when compared to their operation stage (Rivela et al., 2006,2007). Hence, the exclusion of such processes is also justified. Table 3 summarises the data sources handled in this paper.

2.5. Allocation procedure

An important feature of the wood-based industry is the simultaneous production of several products. For the panel industry, the main product is the panel, while residual wood is obtained as a by-product. An allocation procedure is only necessary for the panels, since the residual wood is used for on-site generation of thermal energy. Forest waste was taken into account to complete the energy balance of the biomass plant. No environmental burden allocation was assumed to forest waste from previous processes and only their transport and later processing were computed.

3. Environmental impact assessment

A retrospective LCA for green HB manufacture was carried out according to the CML 2 baseline 2000 V2.1 biogenic method to quantify the environmental impact (Guinée et al., 2001). This method results in the definition of an environmental profile for the

Table 3

Summary of data sources.

Energy	Electricity	Ecoinvent database (Dones et al., 2007)
Transport	Truck 16 t and 40 t	Ecoinvent database (Spielmann et al., 2007)
Chemicals	Paraffin and aluminium sulphate	Ecoinvent database (Althaus et al., 2007)
Enzyme	Laccase	Nielsen et al. (2007)
Phenolic compound	Lignin based material	González-García et al. (Submitted for publication)
Raw materials	Wood chips	ETH-ESU 96 database (ETH-ESU 96, 2004); González-García et al. (2009a)

Table 4

Impact assessment results (Characterization step) of green hardboard manufacture for 1 m³ of finished green hardboard.

Impact category	Unit	Value
Global Warming (GW)	kg CO ₂ eq	346.8
Photochemical Oxidation (PO)	kg C ₂ H ₂ eq	0.126
Acidification (AC)	kg SO ₂ eq	3.93
Eutrophication (EP)	kg PO ₄ ³⁻ eq	0.849
Cumulative Energy Demand (CED)	MJ low heat value	6233.4

assessed production by quantifying the environmental effects on different categories, while only indirect or intermediate effects on humans can be assessed. The impact categories analysed in this study were: global warming (GW), photochemical oxidants formation (PO), acidification (AC) and eutrophication (EP). In addition, the application of the cumulative energy demand method (CED) was also included, in order to evaluate this indicator (VDI-Richtlinien, 1997) as another impact category (in terms of MJ equivalent) as the production of enzymes is likely to be energy intensive (Nielsen et al., 2007). The CED states the entire demand, valued as primary energy, which arises in connection with production, use and disposal of an economic good. LCA software SimaPro 7.10 developed by PRé Consultants (PRé Consultants, 2008) was used for the impact assessment. The results for the characterisation step are shown in Table 4.

Fig. 2 shows the relative contributions of the green HB production process to each impact category under study. The Fibers Preparation subsystem presented the highest contribution (more than 54%) to all categories, followed by Board Forming and Board Finishing. This result was mainly due to the higher electricity consumption compared to the remaining subsystems and also to the laccase requirement. Fig. 3 shows a more detailed study with the relative contribution of the main processes to each impact category.

3.1. Global warming potential

The Fibers Preparation subsystem was responsible for most of the GW contributions (83%). Electricity and laccase production were responsible for 39% and 31% of total CO₂ equivalent emissions (Fig. 3). Fossil fuel consumption (mainly natural gas and hard coal) for electricity production accounted for more than 39% of the total contribution followed by the diesel requirement in wood chipping stage (17%). It is important to highlight that the combustion of biomass (wood waste) in biomass boilers to produce thermal energy requirements, gave rise to biogenic CO₂ emissions. This

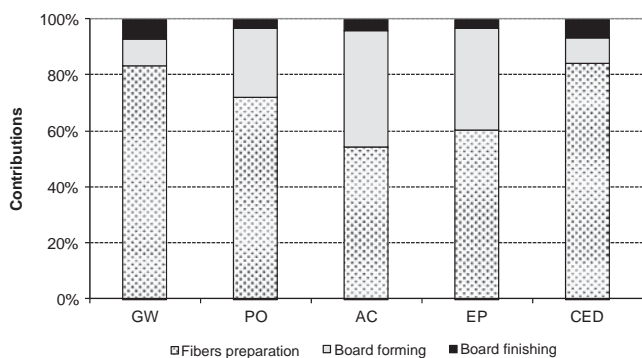


Fig. 2. Relative contributions per subsystems (in %) to each impact category. Impact category acronyms: GW = Global Warming, PO = Photo-Oxidant formation, AC = Acidification, EP = Eutrophication and CED = Cumulative Energy Demand.

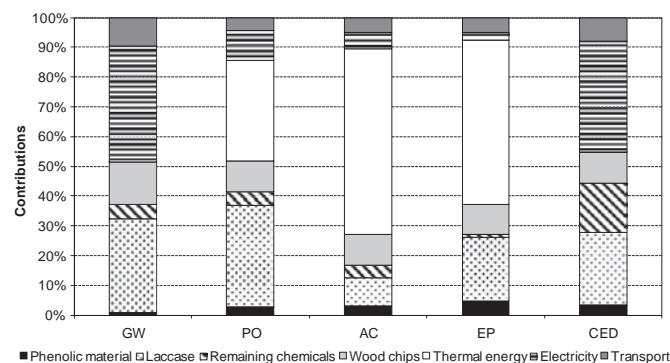


Fig. 3. Relative contributions per processes (in %) to each impact category. "Wood chips" includes not only the roundwood chipping step but also, all forest activities focused on roundwood production.

amount of CO₂ could be considered equal to that uptaken by photosynthesis during the biomass growth. Consequently, biomass burning is CO₂-neutral but not CO₂-free. Fossil CO₂ emissions gave the greatest contribution (~97%) to this impact category, followed by N₂O and CH₄.

3.2. Photochemical oxidants formation potential

The subsystem of Fibers Preparation had the largest contribution to the potential impact of photochemical oxidant formation (PO): 72%. Board forming and board finishing are responsible for 24% and 3%, respectively (Fig. 2). Both laccase and on-site thermal energy production showed the highest contributions to this impact category (34% each). The PO of the system studied was mainly caused by SO₂ and CO emissions which were strongly related to energy use.

3.3. Acidification potential

The Fibers Preparation and Board Forming subsystems were the most important contributors to AC: 54% and 42%, respectively, followed by the subsystem of Board Finishing (Fig. 2). This result agrees with those of related studies (González-García et al., 2009a; Rivela et al., 2006,2007). Specifically, on-site thermal energy production was the main hot spot (63% of total contributions) due to the emissions of NO_x and SO₂ from the biomass boilers. It is important to mention the contributing emissions from fossil fuel combustion during green chips production as well as the production of energy requirements in the laccase production process (Fig. 3).

Lignin based phenolic material production shows a small contribution (~3%) caused by the cogeneration unit where black liquor and fuel oil (used in the start-up of the boilers) are burnt to recover the cooking chemicals and to fulfill the steam requirements in the biorefinery.

3.4. Eutrophication potential

Once again, the Fibers Preparation subsystem had the largest contribution to this impact category (~61%) followed by Board Forming (36%) and Board Finishing (3%) (Fig. 2). The thermal energy plant was the main contributor to this impact category (55% of total) according to Fig. 3, followed by laccase production (22%) and chipping stage (10%). The production of the phenolic compound contributed to 5% of total eutrophying emissions mainly due to COD emissions derived from the wastewater treatment plant in the biorefinery. Airborne NO_x emissions showed the greatest

contribution to EP (~95%), followed by those of NH_4^+ and COD (~3%). Specifically, it is important to point out the NO_x emissions from the biomass energy converters and electricity production (Fig. 3).

3.5. Cumulative energy demand

According to the results, the Fibers Preparation subsystem shows the largest contribution to the environmental profile (~84%). If it is analysed in detail, electricity production was the main hot spot in terms of MJ (low heat value) equivalent (37%) followed by the laccase production (24%) and the production of the remaining chemicals (17%). Once again, phenolic material production shows a small contribution to this indicator (3% of total). Specifically, it is interesting to remark two aspects: 1) the contribution derived from fossil fuel consumption (non-renewable energy) in processes such as chemicals and electricity production and 2) the production of a green adhesive (laccase and lignin based material) requires up to 58% less energy in comparison with the production of PF.

4. Discussion

In this study, the green HB production process was analysed in detail with the purpose of identifying the environmental burdens and hot spots of a wood-based product: green HB. This production process is an example of the industrial use of the enzyme laccase for the production of green adhesives in substitution of conventional petrochemical adhesives. According to Fig. 3, four stages considerably influenced the environmental burdens of the production system: laccase production, on-site thermal energy production from wood waste, electricity production and finally, to a lesser extent, the wood chipping stage. Previous studies on conventional fiberboards manufacture (MDF, particleboards and HB) have also identified that some of these processes such as electricity and chemicals production are the main contributors to the environmental impact (González-García et al., 2009a; Rivela et al., 2006,2007).

The HB plant presented an important use of renewable energy since all heat requirements (steam for defibrator, hot oil for pressing and hot gas for drying) were fulfilled by on-site biomass waste burning. Approximately 98% of the energy required was obtained from internal recycling (e.g. rejected HBs, sanding dust, sawdust or trimmings) and barely 2% from external biomass (wood waste from other factories and forest operations). For this reason, the biomass boilers showed high contribution in impact categories such as AC, EP and PO due to the emission of NO_x and SO_2 (Jawjit et al., 2007; González-García et al., 2009c).

In contrast with other studies on conventional fiberboards production where petrochemical resins (UF and PF) are used as adhesives, a two-component adhesive based on laccase activated lignin was considered instead of PF resin. Laccase acts as a catalyst for the oxidation of phenolic hydroxyls to phenoxy radicals by molecular oxygen, which is reduced to water (Widsten et al., 2004). If phenoxy radicals located on different fibers are brought into close contact, the formation of covalent interfiber bonds could occur by radical coupling. An adhesive effect equal to that obtained with synthetic resins could be obtained if the frequency of interfiber linkages is high enough (Widsten et al., 2004). The effect from the lignin based phenolic production was really small in all impact categories under study (less than 5%). Furthermore, in the HB production process, it was reported that some phenolic compounds, such as condensed tannins (e.g. mimosin tannin), do not improve mechanical properties of the HB more than the laccase treatment alone (Widsten et al., 2009). Therefore, a sensibility

analysis was carried out and several alternative scenarios were proposed in order to assess the influence of the two-component bio-adhesive production on the environmental profile:

- **Scenario A** is the current conventional HB production process, considering the use of 34 kg of PF as bonding agent (González-García et al., 2009a).
- **Scenario B** is the current green process of the HB plant under study considering as bonding agent 10.5 kg of laccase and 40 kg of lignin based phenolic material. It is interesting to underline that the cost of this scenario is 12 fold the value corresponded to the conventional process due to the huge dose of enzyme.
- **Scenario C** is characterized by the use of 10.5 kg of laccase (hypothetical alternative)
- **Scenario D** is characterized by the reduction of 10% in the two-component bio-adhesive dose required (9.45 kg of laccase and 36 kg of lignin based material).
- **Scenario E** is characterized by the exclusion of the laccase (the enzyme production is a hot spot in the current process) and increasing by 25% the dose of lignin based material, that is 50 kg. In fact, this scenario was carried out at pilot scale and HBs with similar properties were obtained. From an economic point of view, this scenario may be an interesting alternative, since the related costs are considerably lower as it did not require the the enzyme.

Fig. 4 shows the comparative environmental profile between conventional HB using PF as a resin (scenario A) and alternative scenarios of green HB production (scenarios B, C, D and E). The values were indexed using Scenario A as the baseline (index = 100 for each impact category under study). As expected, the highest reduction in the environmental profile was achieved with a reduction in the laccase dose (Scenario E, removal of laccase dose from the adhesive). More research should be carried out in this issue as the use of this enzyme as biocatalyst in board production is very recent (Widsten et al., 2009) and the definition of optimum dose should require further study.

The exclusion or dose reduction of the lignin based component also causes an environmental benefit in some impact categories. Scenario C, where only laccase is considered, entails a reduction up to 55% of contributions to PO, and up to 30% the consumption of primary energy in comparison with the conventional HB production process. In addition, the mechanical properties of the wood composite board could be similar to the current green HB properties (Widsten et al., 2009).

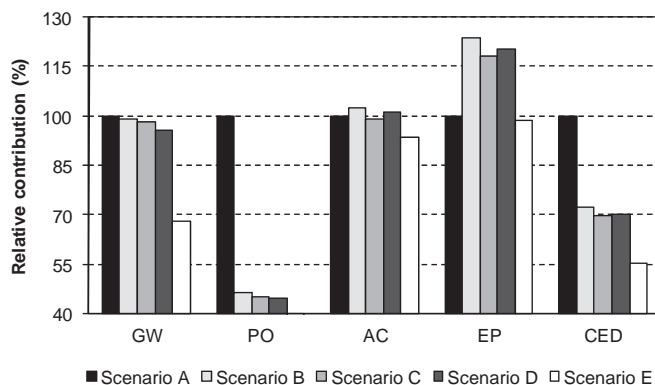


Fig. 4. Relative environmental profile of the different hardboard production processes according to the blending agents, the conventional process serving as the baseline (Index = 100).

In Scenario D (with a reduction of only 10% in the dose of green adhesive) it was possible to obtain reductions up to 4%, 55% and 30% in GW, PO and CED, respectively. In contrast, for the remaining impact categories the contributions increased.

On the contrary, Scenario E showed reductions in all impact categories: 32% for GW, 69% for PO, 6% for AC, 1.5% for EP and 45% for CED. This potential scenario is the only one which achieved improvement in the environmental profile in terms of AC and EP in comparison with the conventional one, specifically due to the non-utilization of laccase and the subsequent reduction of associated energy.

Therefore, and according to these results (Fig. 4), the change from conventional HB to green HBs can reduce the contributions to almost all impact categories under study excluding EP, where the enzyme manufacture shows an important role. The large use of energy, as well as the carbohydrates (sugar and starch) and protein consumption in the laccase production process (Nielsen et al., 2007) and the emissions of COD in the lignin based material production process (González-García et al., Submitted for publication) are the main responsible for this increase of nutrient enrichment in comparison with the conventional process. The removal of the laccase from the adhesive is the only possible option to reduce the eutrophying emissions.

With regard to CED, the entire energy demand could be reduced by 45% since almost 30% of energy required in the subsystem of Wood preparation is associated to the production of laccase.

Important reductions can be achieved regarding PO (it is possible to reduce the environmental profile up to 55% changing conventional HB to green HBs), in particular due to the avoidance of the emission of formaldehyde by means of the production and use of green bonding agents instead of PF.

4.1. Sensitivity analysis

In order to make substantial improvements in the environmental performance of green HB production process, it should be necessary to address the scenarios of major contribution to environmental impact. The normalization phase allows us to compare all environmental impacts using the same scale as well as to add the normalization values of impact categories in order to obtain a unique value per scenario. The dose of green bonding agent was analysed in more detail and reductions of 10%, 20% and 25% in the dose of laccase, lignin based material and both were proposed and analysed. Fig. 5 shows the normalization index per scenario only taking into account the normalization values of the four impact

categories under analysis: GW, PO, AC and EP. The situation in Western Europe has been taken as the reference for all impact categories (data from year 1995) as this is the most complete list available (Guinée et al., 2001). Regarding the energy requirements (CED), the CML methodology does not include it, therefore this flow indicator has been only considered at the characterisation step. According to these outcomes, the categories can be arranged in the following order:

1. Highly significant: AC
2. Significant: EP
3. Lightly significant: GW and PO

According to the results shown in Fig. 5, the current green HB production process (0% of reduction) improves the environmental profile up to 18% in comparison with the conventional process using PF. The reduction in the dose of green adhesive (up to 25%) only improves the environmental profile by 19%. However, both reductions of 100% in the laccase and increases of 25% in the lignin material dose were also performed, taking into account that this scenario was just assessed at pilot scale and there is no large difference on the HBs properties. According to its results, the normalization index could be reduced by 93% in comparison with the conventional process.

If we assess the results in more detail, two impact categories were identified as the most significant in terms of normalization values: AC and EP. According to our previous results (Fig. 4), the EP is the impact category with greatest increase (up to 25%) when green HBs are produced instead of conventional HBs with PF as bonding agent. Moreover, this result is already known since the application of enzymes to other industrial processes such as paper pulp bleaching also gives off more eutrophication in comparison with the conventional process (Fu et al., 2003) as the industrial production of enzymes requires energy and raw materials (Nielsen et al., 2007) and there may be processes in which the enzyme application is environmentally advantageous and there may be others, where they are not (Nielsen and Wenzel, 2007). The other impact category which is influenced by the laccase production (due to the energy requirement) is AC (Fu et al., 2003). Hence, a more detailed assessment is shown for both impact categories in Fig. 6 and Fig. 7.

4.1.1. Sensitivity analysis of EP and AC

As expected, the only reduction in the lignin based material dose (Fig. 6, Green HB-Li) supposes minimum influence on the

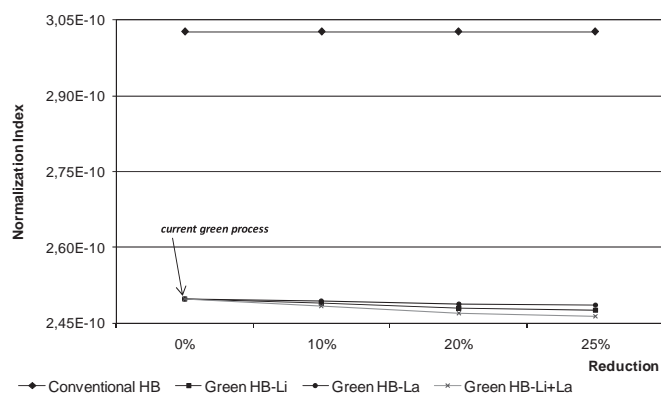


Fig. 5. Sensitivity analysis of the normalization index (per functional unit) taking into account normalization values of GW, AC, EP and PO for the scenarios under study. Acronyms: HB-Li = reductions of lignin based material, HB-La = reductions of laccase and HB-Li+La = reductions of lignin and laccase amount.

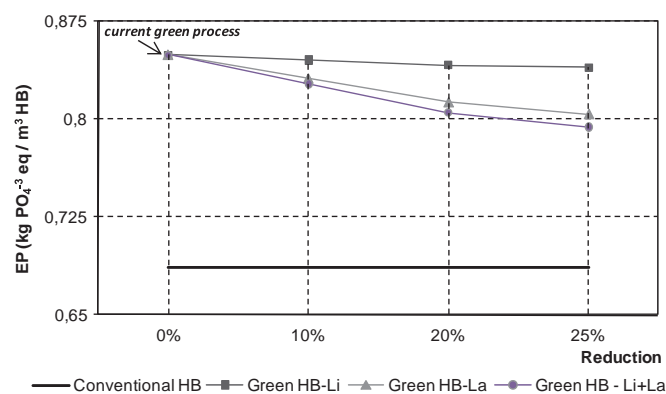


Fig. 6. Sensitivity analysis of equivalent PO_4^{3-} emissions as a result of the reduction on the dose of green blending agents. Acronyms: HB-Li = reductions of lignin based material, HB-La = reductions of laccase and HB-Li+La = reductions of lignin and laccase amount.

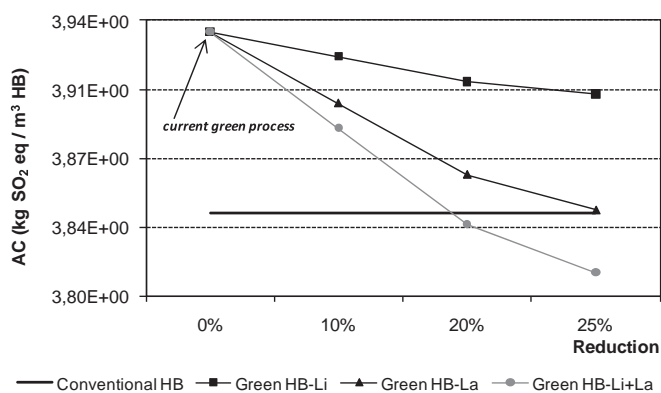


Fig. 7. Sensitivity analysis of equivalent SO₂ emissions as a result of the reduction on the dose of green blending agents. Acronyms: HB-Li = reductions of lignin based material, HB-La = reductions of laccase and HB-Li + La = reductions of lignin and laccase amount.

contributions to EP in comparison with the current green process (up to 1.2% with reduction of 25% in the dose) since in the current green production, it represents 5% of total contributions. However, the reduction of the laccase dose should produce increased effects on the eutrophying emissions. If the dose of lignin based material is maintained but the dose of laccase is modified and reduced by 25% (Fig. 6, Green HB-La), it is possible to achieve a reduction of 5.6% in the eutrophying emissions. Moreover, the combined reduction in both bonding agent means the highest reductions (Fig. 6, Green HB-Li + La): up to 7% with a decrease in the amount of both bonding agents. Although it is not presented in the figure, the removal of laccase (100%) with an increase in the lignin material by 25% shows the best environmental profile in terms of eutrophying emissions given that it is possible to reduce the equivalent PO₄³⁻ emissions up to 1.5% in comparison with the conventional process with PF.

As regards the results in terms of AC, the reduction of 20% and 25% in the dose of both bonding agents (Fig. 7, Green HB-Li + La) would allow reducing the equivalent SO₂ emissions below the result obtained for the conventional process. Reductions in lignin based material dose lightly reduce the acidifying emissions.

Furthermore, other aspects should be taken into account when conventional and green HBs are compared such as i) preventing the health-hazardous formaldehyde emissions during board production, ii) the non-toxicity application conditions of laccase technology, iii) biodegradability of generated wastewaters, iv) the possibility to increase the options of reusing of discarded boards, v) boards burning for energy without the generation of harmful emissions and vi) generating and usage of residuals from composite panel products, not only environmental but also economical and health benefits could thus be obtained from binderless (synthetic resin-free) boards production processes.

5. Conclusions

This work focused on the assessment of a wet-process green hardboard manufacture by means of a two-component adhesive based on laccase activated phenolic system was considered instead of PF resin. The relative environmental improvement potential of the green hardboard production in terms of several impact categories (GW, AC, EP, PO and FF) was assessed in detail in this paper in order to provide valuable information that can assist the forest-based industry, specifically the wood panel industry, to incorporate more environmentally-friendly adhesives and to improve their environmental performance and sustainability. Laccase, on-site

thermal energy and electricity production as well as chipping stage considerably influenced the environmental impacts.

6. Recommendations and perspectives

The results indicate the production of green hardboards using a two-component bio-adhesive based on both a wood phenolic material and a phenol-oxidizing enzyme is industrially viable, meeting the specification of hardboards produced with the conventional phenolic resin. Further research should focus on the laccase production process in order to reduce its energy demand, as well as on the amount of green adhesive required and application conditions to obtain the same mechanical properties as the conventional hardboard.

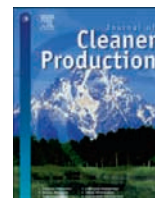
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A renewable waste material for the synthesis of a novel non-halogenated flame retardant polymer

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ABSTRACT

The recognition of toxicity and environmental persistence of halogenated flame retardant (FR) materials has prompted the reduction in their usage across the globe. There is an immediate need for new types of non-toxic and effective FR produced preferably through sustainable routes. Here we report the synthesis and characterization of a new polyphenolic FR material based on a renewable and biodegradable starting material, cardanol (a byproduct of cashew nut processing). Cardanol was polymerized in aqueous media using various types of oxidants. The thermal properties of the resulting polymers were investigated. Polycardanol synthesized using a specific type of oxidant exhibited good thermal stability and low heat release capacity. Preliminary results obtained from this study are quite promising and indicate the possibility of synthesizing new types of FR materials from bio-based phenols.

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1. Introduction

1.1. Polymers and flame retardants (FR)

Polymeric materials have become an indispensable part of our daily life. The production and consumption of plastics is continuously increasing, due to their ability to conform to numerous applications. One of the major disadvantage of most polymeric materials is their intrinsic flammability (Lyon and Walters, 2004). This necessitates the use of external additives to ensure fire safety in most applications. Most polymeric formulations contain FR additives that decrease the rate of flame propagation through the material thus creating a less flammable product.

1.2. Toxicity of FR materials

Most FR materials used in polymeric applications are based on halocarbons, organophosphonates or metal oxides. Though some of

these compounds impart excellent flame retardancy, they tend to be toxic (D'Silva et al., 2004) and persistent, having a significant long term impact on the environment (de Wit, 2002). It has been shown that some of the FR additives also emit toxic and corrosive gases during combustion. These FR additives and the products of their combustion threaten both air and water ecosystems (Alaee and Wenning, 2002). The presence of trace amounts of polybrominated diphenylether (PBDE), (one of the widely used halogenated flame retardant) in sperm whales, seals, dolphins and even human beings (Birnbaum and Staskal, 2004), poses enormous environmental threats and health related issues throughout the world (Zarker and Kerr, 2008; Gutowski et al., 2005). While small molecule-based FR materials are effective in reducing flammability of polymers, they often leach out of polymeric products during use. This is one of the leading causes for the environmental toxicity and bioaccumulation of these FR materials (Grand and Wilkie, 2000).

1.3. Need for alternative FR materials through 'green' initiatives

With the European Union banning the use of halogenated FR (The European Parliament and the European Council, 2003; Gerrard and Kandlikar, 2007), there has been a tremendous need for new

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environmentally friendly, non-toxic, low-leaching alternative halogen-free FR polymers and additives. It is also important to establish 'benign' processing pathways in accordance with the principles of green chemistry, to produce cleaner products. Previous efforts dedicated for the synthesis of non-halogenated FRs were primarily on compounds containing phosphorus (Weil et al., 1999), silicon (Zaikov and Lomakin, 1998) and boron (Armitage et al., 1996). Simple co-polymerization of epoxies (Lin et al., 2000), vinyls (Liu et al., 1996) and acrylics (Banks et al., 1994) with phosphate monomers, linear polyphosphazenes and aromatic cyclic phosphazenes (Allen, 1994) are the broad categories of phosphorous containing non-halogenated FRs. Among silicon containing compounds, polymers based on linear silanes/siloxanes (Masatoshi and Serizawa, 1998) and silsesquioxanes (Provatas and Matisons, 1997) are being extensively investigated. Recently, polymers incorporating boric acid/borates (Morgan et al., 2000) and carboranes (Grimes, 1970) have been found to be very good non-halogenated FR materials. However, the starting materials and synthetic method used were toxic and the final product is also not environmentally benign (Lu and Hamerton, 2002). Hence, development of non-toxic alternatives to halogenated FR materials has been a priority for several organizations including the Toxic Use Reduction Institute (TURI).

1.4. Characteristics of FR materials

In polymers, flame retardancy is usually achieved by incorporating an additive that prevents flame propagation by physical (char forming or intumescent) and chemical (radical scavenging) action. On the other hand, polymers with excellent thermal stability such as Nomex™ can also be used directly in challenging fire-proofing applications.

1.5. Alternative phenolic FR materials

Phenols have been known to be very efficient radical quenchers and have been used extensively in the antioxidant industry. Polymers based on phenols (especially thermosets) have very high thermal stability and excellent char forming characteristics. These are important requirements for a good FR material (Bruno et al., 2001; Samuelson et al., 2000). Bio-derived and biodegradable phenols can serve as good, sustainable starting materials for the synthesis of FR polymers.

1.6. Cardanol

Cardanol (see Fig. 1) is a phenol with a meta-substituted C₁₅ aliphatic chain and one of the main components of Cashew nut shell liquid (CNSL), a waste product from the cashew nut industry. Other important components of CNSL are also shown in Fig. 1. Biodegradability studies show that cardanol degrades to 96% of its original weight within 28 days (Evaluation Report on CNSL by Toxic Use Reduction Institute). Cardanol and its derivatives have been investigated for use in a variety of applications (Façanha et al., 2007). It has been reported that cardanol can also be used along with lignin-based compounds for the synthesis of polyurethanes that exhibit good thermal and mechanical properties (Minh Tan, 1996). The unsaturated chains of cardanol have been grafted with natural rubber to increase heat stability and the resulting compounds were reported to exhibit much better thermo-oxidative stability (Vikram and Nando, 2007). Derivatives of cardanol have also shown promise as anti-oxidants in the stabilization of gasoline (Dantas et al., 2003). CNSL derivatives have been brominated and the resulting products have been found to possess good FR behavior; however the inherent

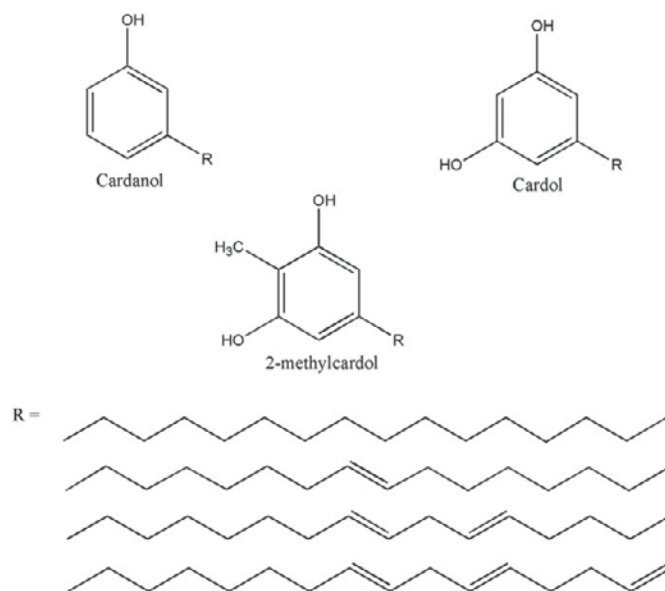


Fig. 1. Structures of the components in Cashew Nut Shell Liquid.

toxicity of brominated compounds limits the use of these materials in FR applications (Pillai, 2000).

There have been several reports on the use of oxidative catalysts such as iron salen for the polymerization of cardanol (Ikeda et al., 2002). The reaction involved the use of a toxic biphasic organic reaction media (dioxane, dimethylformamide) (Kim et al., 2003; Won et al., 2004) to prevent the hydrocarbon tails from interfering with the polymerization reaction. The yields reported were also quite poor. One of the principles of green chemistry emphasizes the use of 'renewable feedstock' (Anastas and Warner, 1998; Uihlein et al., 2008). Another important aspect of greener chemical reactions is the utilization of water as the reaction media, especially for large-scale synthesis. In an attempt to adopt these principles in the design of new FR materials, oxidative polymerization of a renewable material (cardanol) has been explored in aqueous media.

2. Materials and methods

2.1. Materials

Cardanol and hydrogenated cardanol were obtained from Palmer International Inc (Skipack, PA). Potassium ferricyanide, ferric chloride, ammonium persulfate and sodium hydroxide were purchased from Sigma Chemicals Co. (St. Louis, MO).

2.2. Methods

In a typical reaction, cardanol (0.3 g, 1 mmol) was dissolved in 100 ml of water containing sodium hydroxide (2 g, 50 mmol) maintained at 50 °C. An oxidant such as potassium ferricyanide (0.658 g, 2 mmol) was then added to the solution and the mixture was stirred at 1100 rpm for 6 h. The polymer (brown solid) was filtered after salting out with sodium chloride (5.84 g, 0.25 mol) followed by extensive washing with water to remove any residual sodium chloride. The filtered product was then washed with hexanes in a Soxhlet extractor for 24 h to remove unreacted monomer. The reactions with hydrogenated cardanol were also carried out using the above described procedure. Control reactions were carried out at neutral pH or in the absence of oxidant. In

Table 1

Oxidative polymerization of cardanol in water. [All reactions were carried out under oxygen].

S.NO	Cardanol (mmol)	Oxidant (mmol)	NaOH (mmol)	Yield (%)
1	1	$K_3[Fe(CN)_6]$	5	0
2	1	$K_3[Fe(CN)_6]$	5	78
3	1	$K_3[Fe(CN)_6]$	2	74
4	0.1	$K_3[Fe(CN)_6]$	2	50
5	1	$(NH_4)_2S_2O_8$	2	50
6	1	$FeCl_3$	2	50

addition the type of oxidant and the oxidant to monomer ratio was varied (as shown in Table 1) to optimize product yield.

3. Results and discussions

The oxidative polymerization of phenolic monomers at high pH proceeds as shown in Fig. 2. The reaction can either proceed through a C–O–C coupling and/or through aromatic C–C linkages. High pH conditions are required for complete ionization of the phenol. The monomer can subsequently be polymerized using a strong oxidant. Alkaline pH is known to significantly decrease the oxidation potential of phenols (Saito et al., 2004). The polymerization of 2,6-dimethylphenol in water using oxidative catalysts has been previously reported (Saito et al., 2004).

Cardanol when dissolved in high pH water forms a dark pink colored solution. This solution can be oxidatively polymerized to a dark brown insoluble polymeric product using potassium ferricyanide. The polymer was isolated and characterized using Fourier Transform Infrared-Attenuated Total Reflectance (FTIR-ATR) spectroscopy. The FTIR-ATR spectra of (a) cardanol and (b) poly(cardanol) are shown in Fig. 3.

The FTIR spectrum of the polymer shows characteristic peaks at 1240 and 1190 cm^{-1} which is attributed to vibrations of C(Ar)–O–C (Ar). The 1155 cm^{-1} peaks are attributed to C(Ar)–OH linkage. In comparison with the monomer spectra, there is also a large decrease in the intensity of the peak at 3400 cm^{-1} which corresponds to O–H vibrations. This may indicate the possibility of extensive C–O–C coupling. The spectrum of the polymer correlates very well with the IR spectra reported for poly(cardanol) (Ikeda et al., 2000). The use of hydrogenated cardanol in place of cardanol did not significantly change the spectroscopic properties of the final product formed. The use of other oxidants/catalysts such as ferric chloride [entry 5, Table 1] and ammonium persulfate [entry 6, Table 1] did not produce a polymer.

(The use of strong oxidants is not favorable from the environmental and toxicity standpoint, but this is a preliminary effort

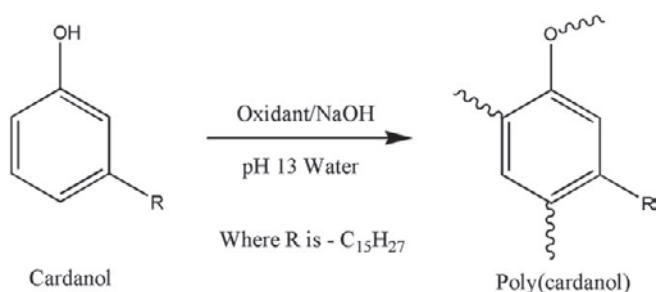


Fig. 2. Proposed reaction scheme for poly(cardanol) synthesis.

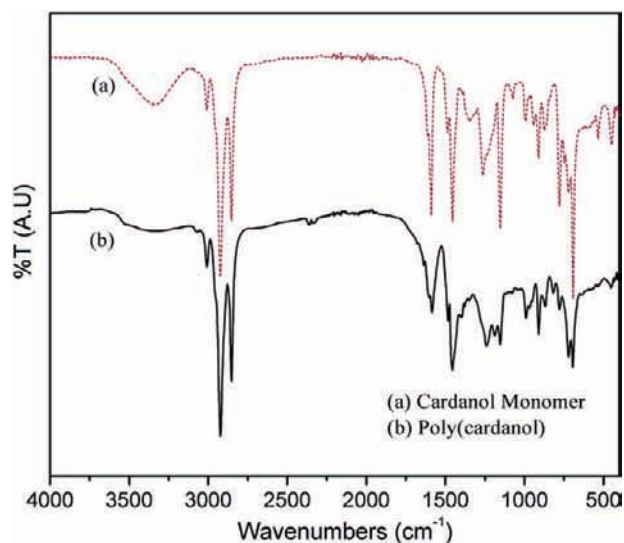


Fig. 3. FTIR-ATR analysis of cardanol monomer and poly(cardanol) synthesized using $K_3[Fe(CN)_6]$.

demonstrating the polymerization of a renewable starting material in an aqueous environment. With the success of this effort in producing a polymeric FR material based on cardanol, other greener, non-toxic oxidants or catalysts can also be explored for the synthesis.)

3.1. Thermal characterization

3.1.1. Thermogravimetric Analysis (TGA)

TGA studies were carried to assess the thermal stability and char forming capability of the synthesized poly(cardanol). TGA spectra of the monomer and the polymer were carried out in air at a heating rate of 20 $^{\circ}C\ min^{-1}$. Fig. 4 clearly shows that the poly(cardanol) has better thermal stability when compared to the cardanol monomer. In addition, the polymer forms reasonable amount of char after thermal degradation. The char accounts for about 25%

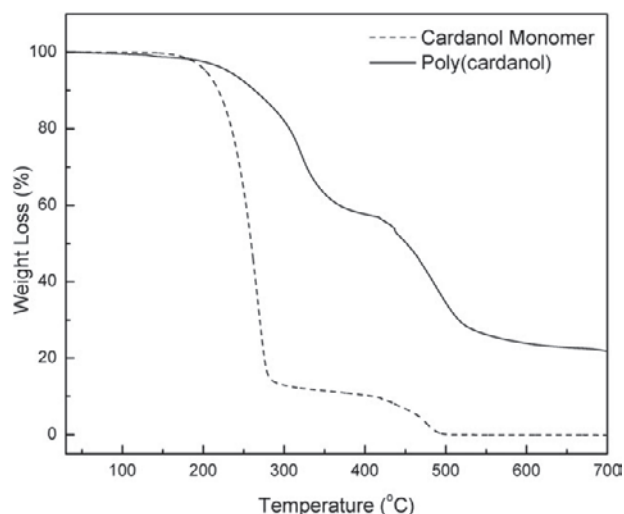


Fig. 4. TGA analysis of cardanol monomer and poly(cardanol) synthesized using $K_3[Fe(CN)_6]$.

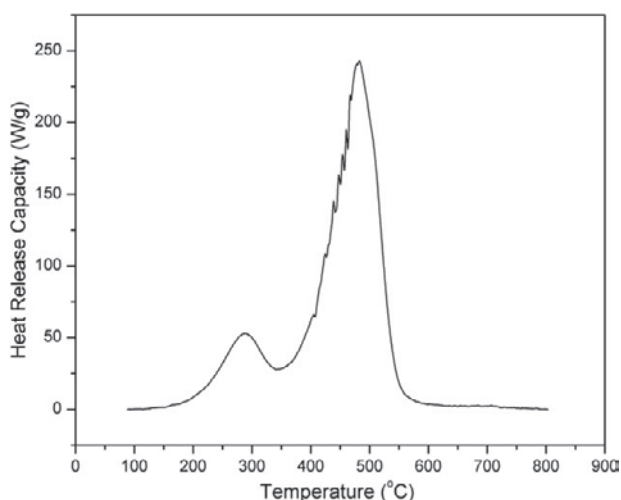


Fig. 5. PCFC analysis of poly(cardanol) synthesized using $K_3 [Fe(CN)_6]$.

of the initial weight of the polymer at temperatures as high as 700 °C. For a good FR material, formation of reasonable amounts of char (upon thermal degradation/burning) is beneficial. The char can potentially inhibit flame propagation through the substrate by forming a physical barrier that cuts off the supply of oxygen required for combustion. Further, char layer also helps prevent diffusion of combustible polymer degradation products to the flame. The phenolic groups in the polymer can also act as radical traps and further prevent flame propagation. The insolubility of the final poly(cardanol) has impeded further detailed structural characterization.

3.1.2. Pyrolysis flow combustion calorimetry (PCFC)

PCFC is a technique that provides information about the rate of combustion of a material through heat release capacity (HRC) values. HRC is an important parameter useful in assessing the fire hazard of a material. PCFC analysis was done with 5 mg of the polymer sample with highest yields of the reaction product. The polymer was flash-pyrolyzed at 5 °C/sec to 1200 °C. Pyrolysis products (gaseous) were swept by an inert gas (nitrogen) into a combustion chamber containing oxygen. In the chamber, the ratio

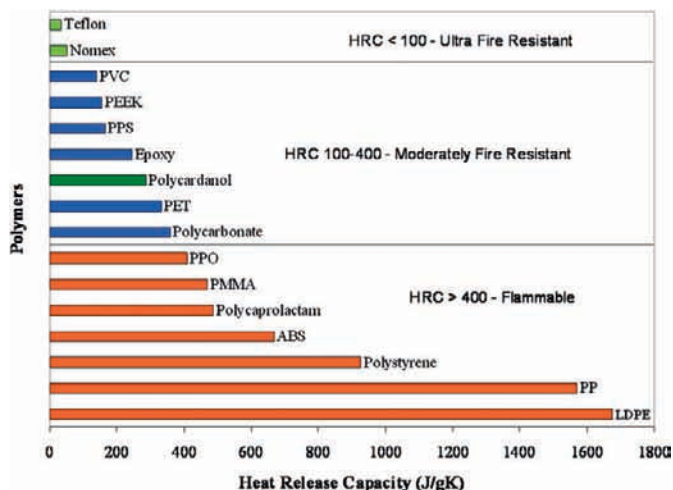


Fig. 6. PCFC Analysis of poly(cardanol) in comparison with commercial used polymers.

of N_2 to O_2 in the mixture was comparable to that present in atmospheric air. Heat release rate was calculated from the rate of consumption of oxygen. The percentage char at 760 °C was also calculated. Poly(cardanol) synthesized using potassium ferricyanide exhibited maximum heat release at a temperature of about 480 °C (Fig. 5) with reasonable char yields (22.6%) as shown in Fig. 4. The polymer also exhibited low HRC (285 J/g K) (Fig. 6).

Fig. 6 shows the comparison of the HRC of poly(cardanol) with other commercially used polymers. These materials can be classified as moderately fire resistant according to classification of FR materials based on their HRCs as described by Walters and Lyon (2003).

4. Conclusions

The synthesis of a novel non-halogenated FR polymer based on a renewable and biodegradable starting material (cardanol) is reported. The reactions were carried out in aqueous media, without the use of organic solvents. The polycardanol clearly exhibited reasonable thermal stability and fairly low heat release capacity as substantiated by the TGA and PCFC results respectively. The use of a sustainably sourced starting material combined with a polymerization reaction that is carried out in aqueous media; provide opportunities for producing FR additives using cleaner processes. The amphiphilic nature of cardanol could also be utilized to design polymerization reactions in organized media and obtain well-ordered and perhaps more processable polymers. More efforts are underway to understand the mechanism of the polymerization and the nature of the product that can provide superior thermal and FR properties.

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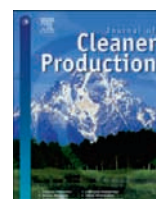
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Selecting safer building products in practice

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ABSTRACT

In recent years the green building movement has focused increased attention on chemical hazards in building products and the need to select safer alternatives. This paper describes a number of tools available to architects and other building professionals and explores the product evaluation process behind one resource, BuildingGreen's GreenSpec directory, as a window into the imperfect reality of alternatives assessment in the building design field.

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1. Introduction

The modern “green building” movement dates back to the energy crisis of the 1970s, but it wasn't until the late 1980s that human health aspects of the built environment became a major consideration. In 1973 the American Institute of Architects (AIA) formed a Committee on Energy and many in the building industry began to focus on making buildings more energy efficient (Building Design and Construction, 2003). This single-minded focus on energy backfired, as reduced air exchange from tighter seals worsened indoor air quality resulting in “sick building syndrome.” After chemical offgassing from building products was implicated in a prominent case at EPA headquarters in 1988 (Malin, 2006), concern over harmful volatile organic compound (VOC) emissions became a part of the green building movement. Since its first pilot version in 1998, The US Green Building Council (USGBC)'s LEED rating system has included indoor environmental quality as one of its categories of impact, with credit available for selecting products with low VOC emissions.

Over time the US green building movement has taken an increasingly broad view of what concerns are included in the designer's purview. However, despite other well-established material-based hazards in buildings such as lead and asbestos (Campbell et al., 2010; Rabin, 2008), and emerging concerns such as

phthalates, halogenated flame retardants, and others (Hotchkiss, 2008; Spengler and Adamkiewicz, 2009; Weschler, 2009) more comprehensive attention to chemical hazards in building materials is a relatively recent phenomenon and not yet widespread within the green building movement. The healthcare sector was the first to focus more broadly on chemical hazards in the built environment. The efforts of Healthcare Without Harm, The Global Health and Safety Network, Kaiser Permanente, and many others (Horrihan, 2005; Kaplan et al., 2009), raised the level of awareness about these issues among building professionals, owners, and product manufacturers. Chemical hazard concerns are now becoming part of the wider green building movement as evidenced by the materials red list within the Living Building Challenge (Went, 2009). This deeper attention is not yet the norm. LEED2009 still does not include a credit for reducing chemicals of concern, although there is now a pilot credit for eliminating Persistent Bioaccumulative Toxins (PBTs) from products (USGBC, 2010).

Building professionals who take on the task of reducing health concerns from buildings, face many challenges in actually selecting safer building materials. Among those challenges:

- Choosing what level of priority and attention to give to minimizing chemical hazards relative to other life-cycle impacts of buildings and building materials.
- Determining what is in a product (let alone what hazards may be emitted during a product's full life-cycle),
- Determining what chemicals are to be avoided, possibly by establishing a “red-list.”

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- Finding safer (red-list chemical free) products—that work, and are available, and are affordable
- Assessing whether a product free of a red-listed chemical may simply contain a lesser-known hazard.

While some building professionals are making an effort to seek out products with the lowest life-cycle environmental impact, life-cycle information is frequently unavailable. Also, LCA tools have elicited criticism (Henrik et al., 2007) for not adequately accounting for chemical hazards (Niederl-Schmidinger and Narodoslawsky, 2008). There is a growing array of information available on chemical hazards, and selecting safer alternatives. However much of this target manufacturers or other sectors and are not of practical use for designers and other building professionals. Understanding chemical hazard issues, screening products, selecting, and learning to use alternatives is a complex and time-consuming process. Few architects, interior designers or specifiers have the time or expertise to engage in toxicology debates and the design community has had little guidance for how to practically implement the precautionary principle in addressing emerging chemical concerns.

Until recently, there were few resources available for designers seeking to integrate concerns regarding chemical hazards into their practices. The set of tools described below provide a roadmap for integrating chemical hazard issues into a building professional's product-selection process.

2. Tools for hazard assessment

2.1. Red list approach in use today

Some design firms have taken a minimal-compromise approach for hazards of high concern. For these firms, establishing a Red List of hazards to avoid in product selection is a critical first step in minimizing these hazards. "Red lists," which define a set of chemicals to avoid, are increasingly common and make a bold statement about chemicals that pose concerns regardless of how or where they are used. This approach contrasts with the risk analysis approach used by many manufacturers, which presumes that risk corresponds directly to the level of exposure as well as the nature of the hazard. For PBTs—and for toxins like endocrine disruptors where research shows a nontraditional dose-response (Hotchkiss, 2008)—the extra caution seems warranted.

Red lists should be wielded with care, however. New or lesser-known substitutes for a red-listed chemical are not necessarily safer. In addition, a red-list approach does not consider factors such as available alternatives and any environmental tradeoffs associated with them. Nonetheless, red lists like the Living Building Challenge Red-List and the Perkins+Will Precautionary List, below, can be a useful way to focus effort.

2.1.1. The living building challenge red-list

The Living Building Challenge originally launched in 2006, with v2.0 launched in November 2009 (International Living Building Institute, 2010), challenges design teams to achieve a "deep-green" ideal building, far beyond what is required by the LEED green building rating system (Lee and Burnett, 2008). LBC has seven performance areas with a total of twenty mandatory 'Imperatives,' such as Net Zero Energy, Net Zero Water, and Car Free Living. LBC's imperatives in the Materials performance area include the Red List: avoiding all products that contain any of the 14 red-listed hazardous chemicals (such as lead) or chemical families (such as halogenated flame retardants).

The creators of the LBC list are clear that not all hazards of concern are covered—or implementation would become infeasible. They have focused attention on key known and emerging hazards found in

building products, seeing the LBC as a tool to raise awareness with manufacturers and ultimately transform the market. As it is, many project teams working toward the LBC have found the red-list among the most difficult and time-consuming aspects of the Challenge, particularly in conjunction with another Materials Imperative, "Appropriate Sourcing," that steers design teams toward regionally sourced materials. Numerous exceptions have been made to reflect the realities of the market. Design teams must write a manufacturer about their concerns with a product's constituent hazards before they can be granted an exception in the LBC (Went, 2009).

2.1.2. The Perkins+Will Precautionary List

The design firm Perkins+Will announced their Precautionary List of chemicals in the Fall of 2009 (Perkins+Will, 2010). Perkins+Will has begun using this list internally as a guide to help them remove products with listed chemicals from their material libraries and projects — at least where alternatives are available. Perkins+Will developed the Precautionary List with participation of its specification group, which has now folded the content of the List into its Masterspec requirements.

The Precautionary List Terms of Use make its intent clear: "We believe that it is appropriate to apply the precautionary principle when selecting and specifying products and materials" and that the evolving list is developed "with the understanding that we live in a world without scientific certainty." The list covers emerging concerns like neuro, endocrine, and reproductive toxicants, listing chemicals like Bisphenol-A and phthalates commonly found in building materials.

The online list is freely available and browsable by chemical name, CSI MasterFormat division (a system that categorizes building products), health effect, or environmental category (such as indoor air quality or ozone depletion). Each chemical listing includes where it is found in building products, a general list of alternatives, and a rationale including references for the chemical's appearance on the list. Created by practicing designers for practicing designers, the list is uniquely tailored to industry needs and provides inspiration to other firms. Perkins+Will's perspective is that substantive change requires this kind of sharing between firms.

2.2. Moving beyond the red list to safer chemical properties

The LBC, Perkins+Will, and Pharos red-lists (described below) do not prevent the substitution of red-listed chemicals with lesser-known hazards that are likely to be similarly harmful. By basing the screening on chemical properties, the Green Screen and Basta system described below are taking the next vital step in procuring truly safer products.

2.2.1. The Green Screen

The Green Screen (Cleaner Production Action, 2010) is designed for use by manufacturers, but is included here because it points the way forward from a red-list approach to a green-chemistry approach. The Green Screen evaluates a chemical (and its known and predicted breakdown products) against 11 hazardous properties (e.g., carcinogenicity), and defines detailed hazard criteria for four benchmarks toward safer chemicals. There are other sector-specific (EPEAT, 2010)(Clean Gredients, 2010) efforts along these lines, however the Green Screen is the first general, public, and transparent system. This opens the way for knowledge of safer chemicals evaluated through the Green Screen to be made available to those evaluating products.

2.2.2. The Basta System

The Swedish Basta System (BASTA, 2010) uses a set of criteria for hazardous properties similar to the Green Screen approach, but

goes a step further by listing products that meet safer criteria. Manufacturers with products in the BASTA System self certify by signing an agreement stating that they know the chemical composition of the product, have the competency to determine the properties of constituents, confirm that the product satisfies the requirements – and can provide full documentation if a random audit is performed. The BASTA requirements are based on the EU's REACH (Registration, Evaluation and Authorization of Chemicals) legislation (BASTA, 2010). BASTA provides an example of the kind of system that could be easily applied by designers while providing a degree of assurance that products are actually safer and do not simply contain lesser-known hazards.

Unfortunately BASTA and the GreenScreen are of limited practical use to US designers today because they don't relate directly to evaluation of products available in the US. A large US purchaser could conceivably make use of the BASTA system by developing a trade partnership in Sweden to select and import BASTA products where hazard concerns are considered significant enough to warrant such an approach. Similarly a large purchaser could use the Green Screen as a specification tool, in place of or addition to a chemical red-list, by requiring major suppliers to verify that product constituents have less-hazardous properties as defined by a specific Green Screen level, essentially creating an in-house database like BASTA. Neither of these approaches would be conceivable without significant purchasing power and resources to dedicate. This approach would also be made easier if the US regulatory framework for chemicals were to change to reflect a more precautionary orientation and require increased information on chemicals of concern along the lines of proposed Toxics Substances Control Act (TSCA) reform legislation and the EU's current REACH legislation.

2.3. Balancing toxicity with other concerns

Designers use the materials of a project to tell the 'story' of that project. The needs of a particular building project and the priorities, aesthetic, budget and values of the client drive the product selection process. Even for an environmentally focused client, aesthetics, cost, and performance are not to be compromised, and just within the set of environmental concerns, values and priorities vary by person and project. While an LCA practitioner might suggest a focus on the biggest life-cycle impacts, or a health advocate on high hazard concerns in product areas with the greatest room for improvement or impact, the designer's focus will vary depending on the project needs. For example indoor air quality and toxicity concerns might dominate for a healthcare facility, while embodied energy concerns might dominate for a model zero-energy home.

The LEED green building rating system acknowledges these varying priorities by, after a minimal number of prerequisites, basing the award (certified, silver, gold, platinum) solely on the total number of points achieved. This has led to criticisms that a LEED building, even a Platinum building, could conceivably (if not practically) be achieved without deep treatment of Energy for example, or any treatment of IAQ beyond the prerequisites (Wargo et al., 2010). Designers with a story to tell relating to reduced toxicity for a safe and healthy built environment frequently look beyond LEED to tools listed here for both recognition and guidance.

A few tools, such as the Pharos Project and the GreenSpec Product Guide (2010), provide information and guidance to help designers navigate toxicity in conjunction with other environmental priorities.

2.3.1. Pharos project

The Pharos Chemical and Material Library (Healthy Building Network, 2010) provides a comprehensive and searchable list of

hazards. The library compiles a wide spectrum of government hazard lists, making them accessible to anyone seeking to understand whether a chemical present in a product is of high concern. Pharos does not currently include information on safe or untested chemicals that are not on an existing hazard list. Pharos provides a public and transparent alternative to proprietary lists such as that underlying the McDonough Braungart Design Chemistry Cradle to Cradle Protocol (MBDC, 2010).

Pharos also includes a small but growing list of products evaluated against five sets of criteria, including VOCs, user toxics, and manufacturing toxics. Pharos conducts a level of detailed investigation—even sleuthing out material patents—beyond what other product information resources provide. The Pharos Building Material Library is intended ultimately to provide comprehensive product analysis and ratings. Rather than developing a certification based on the best products in a given category, Pharos tries to define what an environmentally sustainable product should be—and compare existing products to that ideal. Pharos plans to ultimately evaluate materials across an additional 11 impact categories, such as embodied energy and water use, end of life toxicity, social justice, and habitat impact. Pharos does not aggregate impacts, leaving it up to the user to determine how to value (or weight) categories in comparing products.

2.3.2. GreenSpec Product Guide

The GreenSpec Product Guide (BuildingGreen, 2010) includes an independently screened directory of green building products across all product sectors. In selecting products, the GreenSpec editorial team reviews a wide range of life-cycle concerns including constituent chemical hazards. GreenSpec's aim is to balance pragmatism and precaution to create a product guide that is useful to designers who are specifying products today while helping steer the industry toward safer, more environmentally friendly products.

GreenSpec's guidance document "What Makes a Product Green" (Wilson, 2006) lays out the challenge:

"The Holy Grail of the green building movement would be a database in which the life-cycle environmental impacts of different materials were fully quantified and the impacts weighted so that a designer could easily see which material was better from an environmental standpoint. Though efforts are afoot along these lines we are not even close to realizing that goal. Very often, we are comparing apples to oranges. We are trying to weigh, for example, the resource-extraction impacts of one product with the manufacturing impacts of another, and the indoor air quality impacts of a third.

The editorial process GreenSpec uses to evaluate concerns is illustrative of the process firms must go through in assessing products. Like a building professional or design firm librarian, GreenSpec must make product determinations based on available data—regardless of its quality or comprehensiveness—balancing both a wide range of life-cycle concerns (Wilson, 2006) and the availability of preferable alternatives. GreenSpec's treatment of hazards in building products varies along with the widely varying information on both a product and the context in which to evaluate it. Like other tools in this survey, GreenSpec takes a precautionary approach, considering emerging concerns on par with concerns for which the data is thoroughly established.

3. Product evaluation in practice – GreenSpec case study

No single tool yet provides an effective means to balance chemical issues against the wider set of life-cycle issues or adequately deals with the extent of incomplete information and uncertainty that remains. GreenSpec's pragmatic approach provides

a window into how to make reasonable decisions in that imperfect context, using whatever information and tools are available.

GreenSpec works to balance the breadth of concerns with alternatives assessment and a precautionary orientation. This balancing act weighs the need to drive market change by demanding safer and more environmentally responsible products with the immediate need of designers to specify quality products that are available now.

GreenSpec's approach is to:

- Use “life-cycle thinking” to focus attention on primary impacts for the product type;
- Assess constituent materials for special consideration when chemicals of concern are believed to be present;
- Subjectively weigh impacts against availability of alternatives and potential for market improvement to determine selection criteria for each product sector.

3.1. Using life-cycle thinking to focus attention on primary impacts for the product type

GreenSpec uses life-cycle thinking to focus on key criteria that drive impacts for a sector (Table 1), particularly where detailed life-cycle analysis is not available. Life-cycle concerns are categorized as follows (detailed in What Makes a Product Green):

- Products Made with Salvaged, Recycled, or Agricultural Waste Content
- Products That Conserve Natural Resources
- Products That Avoid Toxic or Other Emissions
- Products That Save Energy or Water
- Products That Contribute to a Safe, Healthy Built Environment

As better alternatives come to market and more information becomes available to differentiate individual products and assess environmental impacts across a product sector, the considerations for listing in GreenSpec become increasingly nuanced or may change. For example, in the past GreenSpec listed recycled cast iron effluent pipe as an alternative to PVC effluent pipe. When research came to light showing that cast iron effluent pipe production had more harmful human and environmental health effects than PVC, cast iron was also delisted. Detailed criteria are described in GreenSpec product sector overviews.

3.2. Assessing constituent materials for special consideration of chemicals of concern

In the GreenSpec process special attention is paid to constituents of high concern that can have a significant impact on human

Table 1
Sector Priorities.

Product Type	Focus on	Approach to chemicals
1. Mechanical, Electrical, and Plumbing Systems	Efficient operation	These sectors have other top priorities. Chemical constituent concerns relevant to the product sector are addressed in selection criteria, but chemical constituents may not be reviewed for individual products.
2. Enclosures (windows, insulation, etc.)	Effective moisture and thermal protection	Chemicals and emissions are top priority. Chemical constituents are reviewed for each product.
3. Massive, Structural (concrete, steel, etc)	Embodied impact	
4. Interior Finish Non-structural Materials (plastics, composites)	Indoor emissions Embodied impact	

and environmental health, even at minute quantities (such as those slated for phase out by the EU or with characteristics of a chemical to “Avoid” according to the Green Screen). The challenge for both the GreenSpec review team and building professionals selecting products is that:

- (a) many constituents are not listed on MSD sheets, particularly minor constituents or those with emerging hazard concerns not yet on the government's radar;
- (b) little is known about impacts of the vast majority of chemicals; and
- (c) viable product alternatives do not always exist.

Thus, GreenSpec focuses first on concerns that arise across a product sector (such as the use of the halogenated flame retardant HBCD in polystyrene)(Wilson, 2009), for which more investigative time can be spent, and secondarily on the composition of individual products where data are available and other life-cycle concerns are not an overriding consideration (such as for nonstructural interior finish). Depending on priorities for the category, GreenSpec may review MSD sheets; ask manufacturers for specific information about additives, binders, and finishes; request disclosure about “red-list” ingredients; or place on indefinite hold a borderline product until a manufacturer is able to provide adequate proof of the safety of constituent materials. In short, the depth of the investigation into chemical concerns depends on available information, what other environmental concerns are significant, and what product alternatives exist.

3.3. Weigh impacts of concern with availability of alternatives and potential for market improvement to determine selection criteria for each product sector

GreenSpec uses qualitative editorial judgment to weigh the level of concern from constituents with the availability of alternatives and other environmental and health criteria that distinguish products within the category, to determine a balanced approach to the product sector and/or individual product selection. This “balance” can vary dramatically sector to sector (See Table 2 for examples).

3.3.1. Include most preferable alternatives

GreenSpec excludes individual products containing high hazard chemicals where feasible alternatives exist. Where there are available substitute products that are cost-effective and of comparable performance, only these alternatives are included in GreenSpec.

GreenSpec is also likely to describe or list “stretch alternatives,” which are alternative materials, products, building designs, or code approaches, that may not be easily adopted, but can point industry

Table 2
Examples of GreenSpec's listing decision for specific sectors.

Listing Decision	Product Sectors
Include most preferable alternatives	Textiles (the product line from OEcotextiles has significantly reduced impact relative to the sector norm)
Include preferable alternatives, with caveats	Commercial Carpet (virtually all products on the market include fluorochemical treatments for stain resistance, raising health and environmental concerns)
Exclude all products, take an editorial stand	Electrical Wire (halogenated flame retardants and heavy metals) Polystyrene Insulation (HBCD flame retardant)

leaders and innovators toward products and practices that dramatically reduce environmental impact.

3.3.2. Include most preferable alternatives – with caveats

There are frequently no impact-free products or easy alternatives for a product sector. Thus, GreenSpec often includes products that, while environmentally preferable to the majority of products in the sector, contain chemicals of concern or other clear negative attributes. In these cases, GreenSpec uses section and product description to highlight both the benefits relative to standard practice and any remaining concerns—with the intent of driving change within the industry.

3.3.3. Take an editorial stand – exclude all products

In special cases, GreenSpec sets high standards that exclude all or nearly all products in a sector, taking an editorial stand designed to push the market toward safer products. This typically takes place when it is believed that a key concern (usually a chemical constituent) is not being adequately considered by the industry, and that designers can be supported in selecting the best option without GreenSpec actually listing products. This may be because there is no other key differentiating factors or because the best alternatives are easily obtained commodity products.

For example, after research into the hazards of building wire (Malin, 2006), GreenSpec announced that it would only list electrical wire and cable that was free of halogens and heavy metals. While products that meet this requirement are now available, at the time there was no wiring available to the US commercial building industry that met these criteria. GreenSpec's judgment was that there was no other key environmentally differentiating factor for building wire and that it was important to raise awareness about the issue by making a bold statement about what was needed from the industry.

4. Conclusion

In the absence of a regulatory structure for chemicals that is adequately protective of human and environmental health, the green building community is increasingly addressing chemical hazards in building products directly through their product procurement.

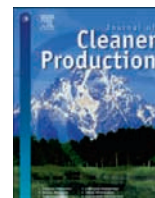
A set of new tools is emerging that helps building professionals make more informed decisions regarding chemical hazards. While not yet widely adopted, these tools provide a palette of options to facilitate decision making and outline the path for future development. For many in the industry, the first major step on the path to safer building products has been the establishment and use of a red-list of chemical constituents to avoid when making product selections. This red-list approach, used by the Living Building Challenge and the Perkins+Will Precautionary List, signals to product manufacturers that there is demand for safer products. However, the absence of comprehensive information on chemical properties and chemical safety can lead to substitution of widely recognized hazards with related, but lesser-known hazards. The Green Screen and the BASTA system go beyond this red-list approach to ensure that any constituent chemicals exhibit safer properties.

Advances in chemical assessment are vital, as are advances in life-cycle analysis—and efforts to better integrate hazard assessment into LCA are still needed. In practice, however, the building industry is still a long way from having adequate information to be able to make use of the best available assessment methodologies, and even where *information* is available, truly preferable (safe, high-performing, and cost-effective) alternatives may not be

Pharos, in its fully developed form, could shine a beacon toward those truly preferable alternatives, and provide a platform for comprehensive review for each area of concern. Ultimately, however, a decision must be made balancing impacts. Aggregated LCA scores are based on a predetermined weighting of environmental impacts. Pharos refuses to aggregate impacts. GreenSpec's approach is to use the best available data, a life-cycle approach, and educated subjective judgment to weigh considerations. GreenSpec's process provides insight for balancing pragmatism and precaution in making product selection decisions despite inevitably limited time and information. This involves the following: using life-cycle thinking to prioritize the research effort and weigh impacts of concern; asking for key information even if you aren't likely to get it; always remaining aware of what could not be factored into the analysis and update thinking based on new information; making one's priorities clear to the market through whatever means possible; and always remembering that ultimately a selection must be made from the available options. In the end, it comes down to the human ability to weigh dissimilar attributes and establish a preference—comparing apples to oranges. This is a weakness, but also a strength; most of all it is a window into the messy reality of product selection in practice in the inevitable absence of perfect information.

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An abbreviated alternatives assessment process for product designers: a children's furniture manufacturing case study

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ABSTRACT

Alternatives assessment is becoming increasingly popular to evaluate the potential environmental and human health hazards of materials. A three step process was used to identify and evaluate alternative products for a children's furniture manufacturer. An alternatives assessment framework was developed to analyze alternative mattresses. The framework specifically addresses those environmental and safety attributes applicable to the product and the product components in accordance with the product's intended use. The result of the assessment allowed the manufacturer to select the most environmentally friendly alternative and eliminate polyvinyl chloride from their product.

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1. Introduction

The safety of children's products has come under increased scrutiny due to the prevalence of product recalls caused by products not meeting requirements for lead and other toxic material content requirements set forth by the U.S. Consumer Product Safety Commission (CPSC). In response, the Consumer Product Safety Improvement Act (CPSIA) was signed into law in August 2008 and went into effect February 10, 2009. The Act places more stringent lead content restrictions and for the first time restricts certain phthalate content in products and articles intended for children under the age of twelve, including cribs, to 0.1%.

A combination of the Consumer Product Safety Improvement Act restrictions on phthalate content of children's products, increased awareness of the health and environmental concerns associated with polyvinyl chloride (PVC), and dedication to the environment led a New York State manufacturer of furniture and spaces designed for children to eliminate or greatly reduce the PVC content of its children's cribs. These cribs are used in daycare facilities across the United States and must meet stringent flammability and cleaning requirements. The manufacturer identified a selection of potential alternative materials but was uncertain if there were additional options and which alternative

materials meet performance, regulatory, and company environmental criteria.

In response, a review of existing alternatives assessment methodologies was performed and a unique alternatives assessment methodology was developed. Potential alternatives were identified and assessed according to the methodology. The numerical and descriptor data points were translated into results that the manufacturer interpreted. As a result, the manufacturer has replaced all of its crib PVC-based components.

2. Alternatives assessment review

2.1. Background

Alternatives assessment is a tool used to compare and contrast the viability and attributes of potential replacements. Alternatives assessment can be used in the design phase to drive innovation and to evaluate identified alternatives. A significant amount of data must be collected to comprehensively evaluate alternatives. A number of human health and environmental data points are incorporated in the assessment process resulting in the generation of a significant amount of data. It can be difficult and cumbersome for product design teams to sort through the data, determine and apply their priorities to the data, and conclude the process with a viable alternative. Displaying the results in a simplified, easy to interpret manner designed for the user, is key to a successful alternatives assessment process.

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Table 1
Summary of attributes included in select alternatives assessment processes.

Attributes Assessed	Environmental Effects	Human Health Effects	Other Effects
TURI 5 Chemicals Study ^a	<p><i>Environmental Effects:</i> Hazardous Air Pollutant Water Solubility Density Specific Gravity Vapor Pressure Henry's Law Coefficient Kd (soil sorption coefficient) Koc (adsorption coefficient) Log Kow (octanol/water partition coefficient) Persistence: Water, Soil, Sediment, Air Bioaccumulation Aquatic Toxicity Drinking Water Quality <i>Other Environmental Hazards:</i> Degradation Products Ozone Depleting (ODC) Greenhouse Gas <i>Environmental Fate:</i> Persistence Bioaccumulation Potential <i>Ecotoxicity:</i> Acute Aquatic Toxicity Chronic Aquatic Toxicity</p>	<p><i>Acute Human Health Effects:</i> Metabolites Dermal Absorption Lethal Dose concentration: Inhalation LC 50, Oral LD50, Dermal LD50 Occupational Exposure Limits: IDLH, PEL, REL, TLV, Ceiling/ST Irritation: Dermal, Ocular, Respiratory <i>Chronic Human Health Effects:</i> Reference Dose Mutagenicity Carcinogenicity Skin Sensitization Reproductive & Developmental Toxicity Target Organ</p>	<p><i>Other Hazards:</i> Flammability Reactivity Corrosivity Flash Point</p>
GreenScreen ^b	<p>Environmental hazards</p>	<p><i>Human Health:</i> Carcinogenicity Mutagenicity/Genotoxicity Reproductive Toxicity Developmental Toxicity Endocrine Disruption Neurotoxicity Acute Toxicity (oral, dermal, or inhalation) Corrosion/Irritation of the skin or eye Sensitization of the skin or respiratory system Immune system effects Systemic toxicity/organ effects (via single or repeated exposure) Acute health hazards Chronic health hazards Exposure potential</p>	<p><i>Physical/Chemical Properties:</i> Explosive Flammable</p>
Column Model	<p>Environmental hazards</p>	<p>Acute or chronic toxicity: Impacts that may result from single, intermittent or chronic use of, or contact with, the product, considering opportunities for dermal, oral and inhalation exposures during product use or other stages in the lifecycle of the product. Carcinogenicity Genotoxicity Teratogenicity Reproductive toxicity Developmental toxicity Neurotoxicity Immunotoxicity Endocrine disruption Organ or tissue system toxicity Respiratory effects Epigenetic effects Persistence Bioaccumulation Synergistic potential Any other hazard traits, as defined in Section 2, that related to adverse impacts on public health</p>	<p>Fire and explosion hazards Hazards caused by procedures</p>
Safer Consumer Product Alternatives ^c	<p><i>Materials and resource consumption:</i> Amount of raw materials used - renewable and non-renewable Water consumption and conservation Production, in-use, and transportation energy inputs Energy consumption and efficiency Reusability and recyclability <i>Environmental impacts:</i> Water quality impacts including BOD, COD and TSS Air emissions including NOx's, Sox's, Toxic Air Contaminants Greenhouse gas emissions Stratosphere ozone depletion Waste and end-of-life disposal including solid waste, wastewater releases, liquid waste Other emissions: Noise, radiation, vibration, odor, waste heat Ecotoxicity (including both aquatic and terrestrial ecosystems) Any other hazard traits that relate to adverse impacts on the environment</p>	<p><i>Public and occupational health impacts, including potential impacts to sensitive subpopulations. Toxicity and toxicological endpoints addressed shall include, but not be limited to all of the following:</i> Acute or chronic toxicity: Impacts that may result from single, intermittent or chronic use of, or contact with, the product, considering opportunities for dermal, oral and inhalation exposures during product use or other stages in the lifecycle of the product. Carcinogenicity Genotoxicity Teratogenicity Reproductive toxicity Developmental toxicity Neurotoxicity Immunotoxicity Endocrine disruption Organ or tissue system toxicity Respiratory effects Epigenetic effects Persistence Bioaccumulation Synergistic potential Any other hazard traits, as defined in Section 2, that related to adverse impacts on public health</p>	<p><i>Economic impacts:</i> Capital investment Operations and maintenance cost Cost for resources Energy costs Waste disposal and treatment cost Non-compliance liability</p>

(continued on next page)

Table 1 (continued).

Attributes Assessed	Environmental Effects	Human Health Effects	Other Effects
Cradle to Cradle TM ^d	<i>Environmental health criteria:</i> Fish toxicity Daphnia toxicity Algae toxicity Persistence/biodegradation Bioaccumulation Climatic Relevance Other	<i>Human health criteria:</i> <i>A. Priority:</i> Carcinogenicity Endocrine disruption Mutagenicity Teratogenicity Reproductive Toxicity <i>B. Additional:</i> Acute toxicity Chronic toxicity Irritation of skin and mucous membranes Sensitization Other	<i>Material Class:</i> Organohalogen content Heavy metal content

^a Table 2.5.3: EH&S Parameters Considered in Assessing Alternative, Massachusetts Toxics Use Reduction Institute, Five chemicals alternatives assessment study, University of Massachusetts Lowell, 2006.

^b Table 1 Threshold Values for Each Chemical Hazard Included in the Green Screen v 1.0, Clean Production Action, 2009, The GreenScreen for Safer Chemicals, Version 1.

^c VI. Alternatives Assessments in California Environmental Protection Agency Department of Toxics Substances Control, 2010, Outline of Draft Regulations for Safer Products, <http://www.dtsc.ca.gov>, 1 May 2010.

^d 4.3 Ingredient Characterization in McDonough Braungart Design Chemistry, LLC., 2008, Cradle to Cradle Certification Program, Version 2.1.1.

In the past decade, a number of alternative assessment processes have been developed and used to assess alternatives at the product, material, and chemical level. The Massachusetts Toxics Use Reduction Institute surveyed nine methods and tools that are available for alternatives assessment developed by government and private organizations in the US and Europe in 2005. Tools were divided into two categories – hazard data display methods where data on a range of chemical hazards is presented and the user must apply decision methods to the data and screening/decision methods which have decision rules built into the method, prioritize risk, and recommend alternatives (Civie et al., 2005).

2.2. Five chemicals alternatives assessment study, Massachusetts Toxics Use Reduction Institute, June 2006

In July 2005, the Commonwealth of Massachusetts requested that TURI assess safer alternatives for lead, formaldehyde, perchloroethylene, hexavalent chromium, and di(2-ethylhexyl) phthalate (DEHP). TURI developed an alternatives assessment process to identify alternatives and their associated environmental impacts, human health impacts, technical feasibility, and economic feasibility. TURI used three phases to achieve the goal. First, the uses of chemicals in Massachusetts were identified and subsets of uses were prioritized for in-depth analysis. Second, TURI identified alternatives for chemical use and chose priority alternatives for further study. Once alternatives and uses were prioritized, TURI researched the health, environmental, technical, and economic aspects of each alternative using information from publically available sources and industry experts. An important distinction of the TURI process is that it does not rank alternatives, but “provides information that will allow users to make informed decisions and in some cases, to design additional research to fill remaining information gaps” (TURI, 2006). The study chemical is used as a baseline that the alternative chemical is compared against. The process is not intended to assess the relative aspects of one alternative over another. The results are also difficult to sort through and interpret due to the sheer volume of data included as well as the presentation method. Large, multiple page tables present the data. Categorizing the data or assigning risk values may help to make the data easier to interpret and draw conclusions.

2.3. GreenScreen for safer chemicals, Clean Production Action, March 2007

The GreenScreen is a scientific way to analyze alternative chemicals for human health, environment, and safety aspects and also presents the results in a more easy to interpret manner. A set of four benchmarks are used. A set of environment, safety, and human health criteria exists at each benchmark and an alternative must pass all criteria at a given benchmark in order to move up to the next benchmark. Benchmark's start at the bottom with 1 (red) Avoid – chemical of high concern, and move up to 2 (orange) Use but search for safer substitutes, 3 (yellow) Use but still opportunity for improvement, and 4 (green) Prefer – safer chemical.

Whereas the TURI Five Chemicals Study presents a plethora of information that is not ranked or benchmarked, GreenScreen uses color coding and target values to benchmark alternatives against. This allows the decision maker to quickly identify the alternative with the least safety, health, and environmental concern and those areas which present concern, preventing the alternative from moving to a higher benchmark value.

2.4. *Column model, the Institute for Occupational Safety (BIA), German federation institute for statutory accident insurance and prevention, September 2009*

The Column Model is used to evaluate chemicals for their potential hazards. It is unique in that the data used to populate the alternatives assessment comes from the chemical's material safety data sheet and is based on the R-phrase. In Europe, R-phrases are used to indicate a specific hazard associated with a chemical or product, and are presented as a number. For example, R23 corresponds to "toxic by inhalation" (European Union, 1967). A table format is used with the potential risks along the top row with established criteria based on R-phrases established for five risk levels: very high risk, high risk, medium risk, low risk, and negligible risk. Each alternative is evaluated for the following hazards: acute health hazards, chronic health hazards, environmental hazards, fire and explosion hazards, exposure potential, and hazards caused by procedures. Each alternative is evaluated for each of the six hazards. The results of the assessment are not presented as a single score but rather a score in each of the six hazards. The user determines which hazard is most important and can base their decision on specific criteria important to the user.

2.5. *Safer consumer product alternatives, draft outline for regulations, California Department of Toxic Substances Control (DTSC), April 2010*

California has developed the draft outline in response to Senate Bill Number 509, which requires the department to "establish the Toxics Information Clearinghouse, which shall provide a decentralized, Web-based system for the collection, maintenance, and distribution of specific chemical hazard trait and environmental and toxicological end-point data" for consumer products sold in California. There is a six step process DTSC must follow to identify chemicals of concern, map those chemicals to the consumer products which use them, the manufacturer is required to perform an alternatives assessment for the chemical and submit the action plan to DTSC based on the results. As part of the Draft Outline for Regulations, DTSC has outlined the requirements for the alternatives assessment process, including the attributes which must be included in the evaluation. DTSC is taking a life cycle approach to

the alternatives assessment, including impacts at the various stages of the product: raw materials mining; intermediary material processing; manufacturing and packaging; distribution, transportation and marketing; use; product end of life; and reuse and recycle. There are a total of thirty six indicators which must be included in the alternatives assessment. The indicators are organized into the following four categories: materials and resource consumption; public and occupational health impacts, including potential impacts to sensitive subpopulations; environmental impacts; and economic impacts. The decision to implement an alternative is left to the manufacturer, as the DTSC does not outline a prioritization or decision making scheme. The manufacturer must submit their action plan based on the results of the alternatives assessment for the approval of DTSC before moving forward.

2.6. *Cradle to cradle certification program version 2.1.1, McDonough Braungart Design Chemistry (MBDC), LLC, September 2008*

Cradle to Cradle is a voluntary, third party US based environmental product certification. Part of the certification assessment is an assessment of the product's ingredients. Assessment criteria are established for human health, environmental health, and material class. In order to receive certification, the manufacturer submits their list of ingredients to MBDC who then evaluates them against the criteria. The results are color coded and categorized from (green) little to no risk, (yellow) low to moderate risk, (red) high hazard and risk, and (grey) incomplete data. Color coding the results simplifies communication with product designers and managers who are not regularly versed in environmental and toxicity terminology. Criteria for each impact category have been developed at each risk level and remains proprietary information, making it difficult to evaluate the assessment process. (Table 1)

2.7. *Alternatives assessment frameworks*

2.7.1. *Alternatives assessment framework of the Lowell center for sustainable production, University of Massachusetts Lowell, July 2006*

In addition to the alternatives assessment processes summarized above, the Lowell Center for Sustainable Production at University of

Table 2
Product level analysis metrics.

Attribute	Pass	Fail
Critical Parameters		
Aesthetic	Attractive look and feel, "baby friendly", neutral color	Unattractive, harsh colors
Allergens	Does not contain known allergens or contains known allergens that are wrapped and sealed in the mattress	Contains known allergen exposed to surface of the mattress
Dimension	Available mattress sizes meet the crib dimensional requirements	Available mattress sizes do not meet the crib dimensional requirements
Firmness	Firm	Soft
Flammability	Meets CAL117 fabric standard	Does not meet CAL117 fabric standard
Cover material	Does not contain heavy metals, organohalogens, halogenated hydrocarbons, or polyvinyl chloride	Contains heavy metals, organohalogens, halogenated hydrocarbons, or polyvinyl chloride
Material Disclosure	Manufacture willing to disclose all materials used	Manufacture not willing to disclose all materials used
Smell	No smell; smell more benign than urethane foam	Definite unappealing smell
Preferential Parameters		
Cleanability	Water resistant; able to withstand daily cleaning with 10% bleach solution, green cleaners, and other popular cleaners and disinfectants daily	Water resistant; cannot withstand daily cleaning with 10% bleach, green cleaners, or other popular cleaners and disinfectants daily
Durability	Able to withstand daily cleaning for at least 5 years with no degradation	Product degrades due to cleaning within the first 5 years
Mattress Material	Mattress is made mostly of natural materials Mattress does not contain heavy metals, organohalogens, and halogenated hydrocarbons	Mattress is made from 100% man made materials Mattress does contain heavy metals, organohalogens, and halogenated hydrocarbons
Price	Costs no more than 20% more than current mattress	Costs over 20% more than current mattress

Table 3
Results of the product level analysis.

Attribute	Option A	Option B	Option C	Option D	Option E	Option F	Option G	Option H
Analysis result	Pass	Fail	Fail	Fail	Pass	Pass	Pass	Fail
Critical parameters								
Aesthetic	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Allergens	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Dimension	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Fail
Firmness	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Flammability	Pass	Unsure	Pass	Unsure	Pass	Pass	Pass	Pass
Cover MATERIAL	Pass	Fail	Fail	Unsure	Pass	Pass	Pass	Pass
Material Disclosure	Pass	Fail	Fail	Fail	Pass	Pass	Pass	Pass
Smell	Pass	Fail	Fail	Pass	Pass	Pass	Pass	Pass
Preferential parameters								
Cleanability	Fail	Pass	Pass	Unsure	Pass	Pass	Fail	Fail
Durability	Fail	Pass	Pass	Unsure	Pass	Pass	Fail	Fail
Mattress material	Pass	Fail	Pass	Unsure	Pass	Pass	Pass	Pass
Price	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail

Massachusetts, Lowell has developed a framework for developing an alternatives assessment process (Rossi et al., 2006). The goal is to develop an open source framework for quick “assessment of safer and more socially just alternatives to chemicals, materials, and products”. The Comparative Assessment process is used to compare two existing alternatives and consists of the following steps: (1) identify target for replacement, (2) characterize and prioritize the end use of the replacement, (3) identify potential alternatives, (4) evaluate and compare alternatives, (5) select the preferred alternative, and (6) revisit and review the selected alternative to ensure it remains the preferred alternative. During the evaluation step, the Framework recommends incorporating human health, environment, and social justice impacts; economic feasibility; and technical performance. The Framework emphasizes using the assessment process by public policy and regulatory decision makers rather than product designers and industry.

2.7.2. States Alternatives Assessment Protocol Wiki, in process

A number of alternatives assessment experts throughout the United States have joined forces to create the States Alternatives Assessment Protocol Wiki. The Wiki was spearheaded by the Toxics Use Reduction Institute at University of Massachusetts Lowell with a goal to create a skeleton that states can use to perform an alternatives assessment and serve as a resource portal. The process evolves in real time, as the Wiki is Internet based, allowing the public to view information as it is created and edited and allowing experts to create and edit information in real time. The Wiki is a joint effort between a number of governmental and non-governmental bodies to work together to develop a scientifically acceptable method for performing alternatives assessment.

3. Using alternatives assessment to fulfill CPSIA requirements: children’s furniture manufacturer case study

3.1. Problem

A children’s crib produced by a New YorkState manufacturer uses a mattress consisting of a polyurethane foam core wrapped in polyvinyl chloride fabric. Polyvinyl chloride, commonly referred to as PVC, contains potentially toxic phthalates, used as plasticizers to make plastic soft and pliable. Phthalates are commonly found in toys, vinyl upholstery, shower curtains, inks, pesticides, and cosmetics (European Council for Plasticisers and Intermediates, 2010a). Di-2-ethyl hexyl phthalate (DEHP), diisodecyl phthalate (DIDP) and diisononyl phthalate (DINP) are the most commonly used phthalates, with DEHP dominating others due to its low cost (European Council for Plasticisers and Intermediates, 2010a). Animal studies have shown that high doses of phthalates cause endocrine disruption and can lead to birth defects (CDC, 2005). Children are more susceptible to potential effects due to their small size and development (Sathyanarayana et al., 2008).

The Silent Spring Institute analyzed indoor air and house dust samples from 120 Cape Cod Massachusetts homes and 50 Northern California homes for more than 89 different endocrine disrupting compounds. Sixty seven compounds were found in the Cape Cod homes, with an average of 24 per home while 104 compounds were found in the California homes. DEHP was detected in all Cape Cod homes sampled. Outdoor air samples were also taken in the California homes and higher concentrations of endocrine disrupting chemicals were found in indoor air than outdoor air (Dunagan et al., 2010).

Table 4
Hazard score definitions.

Number Assigned	Color Assigned	Hazard value
4	Red	Very high hazard
3	Red	High hazard
2	Orange	Moderate hazard
1	Yellow	Low hazard
0	Green	No or very low hazard
NA	Gray	Not applicable at product level
NP	White	Information is not provided by the data source
NE	White	Value is not established by the data source

Table 5
Definitions of ingredient level metrics.

Attribute	0 No or Very Low Hazard	1 Low Hazard	2 Moderate Hazard	3 High Hazard	4 Very High Hazard
<i>Bioaccumulation & Persistence</i>					
Fish Chv	Greater than 10 mg L Chemically inert	Not established	Between 0.1 and 10 mg L	Not established	Less than 0.1 mg L
Bioaccumulation Factor (BCF)	Not bioaccumulative Chemically inert BCF less than 1000	Not established	Bioaccumulative BCF between 1000 & 5000	Not established	Very bioaccumulative BCF greater than 5000
Water Persistence	Not persistent Chemically inert Less than 60 days	Not established	Persistent Between 60 & 180 days	Not established	Very persistent Greater than 180 days
Soil Persistence	Not persistent Chemically inert Less than 60 days	Not established	Persistent Between 60 & 180 days	Not established	Very persistent Greater than 180 days
Sediment Persistence	Not persistent Chemically inert Less than 60 days	Not established	Persistent Between 60 & 180 days	Not established	Very persistent Greater than 180 days
Air Persistence	Not persistent Chemically inert Less than or equal to 2 days	Not established	Not established	Not established	Very persistent Greater than 2 days
Dangerous for the Environment	Not listed	Not established	Not established	Not established	Listed
Greenhouse Gases	Not listed	Not established	Not established	Not established	Listed
Ozone Depleting Substance (ODS)	Not on EPA's Class I or Class II ODS lists	Not established	Not established	Not established	On EPA's Class I or Class II ODS lists
<i>Regulatory Coverage</i>					
FDA Food Additive Status	GRAS under any condition	Not established	Concentration restrictions in specific food groups	Not established	Not listed
EPA Hazardous Air Pollutant	Not listed	Not established	Not established	Not established	Listed
US National Drinking Water Regulations	Not listed	Listed & Maximum Contaminant Level of 0	Not established	Not established	Listed & Maximum Contaminant Level above 0
Federal or State Regulatory Program Lists or Other Chemical Blacklists	Not listed	Not established	Not established	Not established	Listed
<i>Acute Toxicity</i>					
Inhalation LC50	Not established	Minimal Toxicity Greater than 20 mg L	Low Toxicity Between 2 & 20 mg L	Moderate Toxicity Between 0.2 & 2 mg L	High Toxicity Less than 0.2 mg L
Oral LD50	Not established	Minimal Toxicity Greater than 5000 mg kg	Low Toxicity Between 500 & 5000 mg kg	Moderate Toxicity Between 50 & 500 mg kg	High Toxicity Less than 50 mg kg
Dermal LD50	Not established	Minimal Toxicity Greater than 20,000 mg kg	Low Toxicity Between 2000 & 20,000 mg kg	Moderate Toxicity Between 200 & 2000 mg kg	High Toxicity Less than 200 mg kg
<i>Health Hazard</i>					
EWG Hazard Rating	0 or 1	2 or 3	4 or 5	6 or 7	8, 9, or 10
Endocrine Disruption	Not recognized nor suspect	Not established	Not established	Suspected	Recognized
Symptoms	None	Irritation of eyes and skin	Irritation of respiratory tract	Difficulty breathing, weakness, dizziness	Unconsciousness or death
Allergies/Immunotoxicity	No evidence	Not established	Not established	Moderate evidence	Strong evidence
Recognized Health Hazard	No negative health effect	Skin and/or eye irritation	Not established	More than skin and/or eye irritation and less than a toxicant or carcinogen	Toxicant and/or carcinogen
Suspected Health Hazard	No negative health effect	Skin and/or eye irritation	Not established	More than skin and/or eye irritation and less than a toxicant or carcinogen	Toxicant and/or carcinogen
Carcinogenicity	Not recognized or suspect ACGIH A5 IARC Group 4	Not classifiable as a human carcinogen ACGIH A4 IARC Group 3	Possibly carcinogenic to humans ACGIH A3 IARC Group 2B	Probably carcinogenic to humans ACGIH A2 NTP B IARC Group 2A	Confirmed human carcinogen ACGIH A1 NTP A IARC Group 1

In addition to human health effects, PVC has a negative effect on the environment throughout its life cycle. Dioxin, a toxic persistent organic pollutant that bioaccumulates, is released into the environment during PVC production. PVC is both costly and difficult to recycle, so it typically ends up in a landfill or is incinerated for energy production. Both disposal scenarios release dioxin to the environment (Strutt, 1997 and Belliveau and Lester, 2004).

The CPSIA limits DEHP, DBP, and benzyl butyl phthalate (BBP) content to 0.1 percent or less by weight for any children's toy or article. Studies have shown that the phthalate content of PVC toys can range from 10 to 40% by weight with DINP and DEHP being the dominant phthalates detected (Stringer et al., 2000). In a June 2008 study performed by the Center for Health, Environment, and Justice, five vinyl shower curtains – similar to vinyl mattress covers – were evaluated for phthalate content (Lester et al., 2008). Of the curtains tested, DEHP was the primary phthalate in three curtains and ranged from 16% to 25% by weight while DINP was the primary phthalate in two curtains and was approximately 40% by weight.

To ensure that the children's crib product meets the CPSIA phthalate limits, the mattress' PVC-based cover must be replaced. In order to adequately find a replacement, an alternatives assessment method was developed to evaluate mattresses currently existing in the marketplace. The mattress was scheduled for replacement within one year and identifying viable alternatives had to be done quickly and efficiently to meet the implementation deadline.

In order to determine the technical feasibility and environmental attributes of the alternatives, a three step assessment process was developed incorporating aspects from a number of established alternatives assessment processes. Alternative mattresses were identified through research, the mattresses were assessed against priority attributes and screened at the product level, and the remaining mattresses were further evaluated according to attributes of the mattress components.

3.2. Identifying potential alternatives

In order to ensure the largest group of potential alternatives were assessed, mattresses that were not available from a manufacturer with a waterproof cover were not immediately rejected. Standalone waterproof covers are available in the marketplace for use with any mattress so the mattress system as a whole was evaluated. The system may be composed of a single piece mattress with attached waterproof cover or a non-waterproof mattress with a standalone waterproof cover.

The identification of alternative mattresses and covers were limited to commercially available models due to the manufacturer's quick implementation schedule. Potential alternative mattresses and cover materials were identified through brainstorming, Internet research, and discussions with children's furniture experts. Manufacturer websites were a useful source of information. Most alternative mattress manufacturers were contacted in order to obtain additional details about the mattress that were not readily available or to verify information on their website.

3.3. Product level analysis

3.3.1. Methodology

The product level analysis provides a method to quickly reduce a large number of potential alternative products to a smaller group of more appropriate and feasible alternatives that warrant further analysis. Critical parameters and preferential parameters and "pass" and "fail" criteria for each parameter are developed and the alternatives are analyzed against them. Parameters include product performance metrics and priority human health and environmental attributes. The Massachusetts Toxics Use

Reduction Institute used a similar approach to prescreen alternatives when performing their Five Chemicals Alternatives Study (Eliason and Morose, 2010).

The prioritization of the human health and environmental parameters are dependent on a number of factors. The manufacturer had a number of specific requirements they wish to follow, such as eliminating the use of PVC. The parameters were also behavioral, such as the willingness of the mattress manufacturer to disclose the product components and share internal testing results. The critical parameters are those that alternatives must meet in order to be considered for use. In contrast, preferential parameters are those which are not required, but are preferred by the manufacturer.

Information to complete the product level analysis was retrieved from the manufacturer. Material safety data sheets and technical data sheets for mattress components, results of performance and environmental tests, and information available to the public from the furniture manufacturer was used to complete the assessment. Table 2 outlines the critical and preferential parameters used to assess the alternative mattresses at the product level.

3.3.2. Product level analysis results

Eight mattresses were identified as potential alternatives. Four mattresses passed the product level analysis. Two mattresses were unable to meet the dimensional parameters in addition to others, another mattress had a vinyl cover, and the manufacturer of the fourth mattress that failed the analysis was not willing to disclose information about the components of the mattress. The four remaining mattresses were evaluated at the component level. Results of the product level analysis are shown in Table 3.

3.4. Component level analysis

3.4.1. Methodology

Alternative mattresses that pass the product level analysis were screened at the component level. Each mattress was broken down into its successive components, including the core materials, wrapping or cover material, adhesives, and other small components, such as thread used to sew the cover.

The mattress' material safety data sheets, technical data sheets, and communication with the mattress manufacturers were used to identify individual components that comprise the product. The individual components of the alternative mattresses were evaluated independently of each other. This is an important distinction as the potentially additive and synergistic effects of the components were not evaluated. Previous research has shown that the effect of multiple chemical exposure may be synergistic (Christiansen et al., 2009) meaning exposure to the mixture is more hazardous than exposure to individual components of the mixture. This was taken into consideration by the research team and the crib manufacturer and decided that evaluating components of the alternatives as well as any laboratory test results would suffice at this time due to the time constraint and limited information available on the synergistic effects of chemical exposure. Future analysis of the alternative products would include an evaluation of potential synergistic effects.

In contrast to the product level metrics, those at the component level do not contain performance metrics. Component level metrics are based on environmental and human health impacts, are influenced by those included in other alternatives assessment processes, and are organized in four categories: bioaccumulation and persistence, regulatory coverage, acute toxicity, and the potential hazard to human health.

Transparency is key to the alternatives assessment and it is imperative that publically available data sources are used for each of

Table 6
Coded results of the component level analysis.

		Bioaccumulation & Persistence									Regulatory Status
		Fish ChV	Bioaccumulation Factor	Water Persistence	Soil Persistence	Sediment Persistence	Air Persistence	Dangerous for the Environment	Greenhouse Gases	Ozone Depleting Substance	FDA Food Additive Status
Mattress and Cover (All in One) Options											
Mattress 1	Component 1A	0	0	0	0	0	0	0	0	0	2
	Component 1B	0	0	0	0	0	0	0	0	0	4
	Component 1C	0	0	0	0	0	0	0	0	0	2
	Component 1D	0	0	0	0	2	4	0	0	0	0
	Component 1E	0	0	0	0	0	0	0	0	0	2
	Component 1F	NP	NP	NP	NP	NP	NP	0	0	0	0
Mattress 2	Component 2A	NP	NP	NP	NP	NP	NP	0	0	0	4
	Component 2B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Component 2C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Component 2D	0	0	0	0	0	0	0	0	0	0
	Component 2E	NP	NP	NP	NP	NP	NP	4	0	0	4
	Component 2F	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
	Component 2G	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Component 2H	NP	NP	NP	NP	NP	NP	0	0	0	4
	Component 2I	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
	Component 2J	4	3	3	3	3	3	0	0	0	4
	Component 2K	NP	NP	NP	NP	NP	NP	NP	NP	NP	4
	Component 2L	3	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Component 2M	4	NP	NP	NP	NP	NP	0	0	0	4
	Mattress Only Options										
Mattress 3	Component 3A	NP	NP	NP	NP	NP	NP	0	0	0	2
	Component 3B	0	0	0	0	0	0	0	0	0	4
	Component 3C	0	0	0	0	0	0	0	0	0	4
Mattress 4	Component 4A	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
	Component 4B	NP	NP	NP	NP	NP	NP	0	0	0	4
	Component 4C	0	0	0	0	0	0	0	0	0	4
Cover Only Options											
Cover 1	Component 5A	0	0	0	0	0	0	0	0	0	2
	Component 6A	NP	NP	NP	NP	NP	NP	0	0	0	4

the twenty-three attributes included in the analysis. Data points for five hazard levels, ranging from very high hazard to no or very low hazard, were established for each attribute and can be seen in Table 4. Each component of the mattress was evaluated in each of the twenty-three attributes. The evaluation results were then mapped to the established criteria at each hazard level as seen in Table 5.

In order for the results to be more easily understood by non experts, corresponding numerical values were established for each hazard level. The hazard levels were also color coded to further increase the visibility of the results. The results are presented in a table format, with a color and number assigned to each of the twenty-three attributes assessed for each component of the mattress.

Regulatory Status			Acute Toxicity			Health Hazard						
EPA Hazardous Air Pollutant	National Drinking Water Regulations	Federal or State Regulatory Program Lists or Other Chemical Blacklists	Inhalation LC50	Oral LD50	Dermal LD50	EWG Hazard Rating	Endocrine Disruption	Symptoms	Allergies/ Immunotoxicity	Recognized Health Hazard	Suspected Health Hazard	Carcinogenicity
Mattress and Cover (All in One) Options												
0	0	0	NE	2	NE	4	0	0	3	0	4	1
0	0	0	0	0	0	NE	0	0	0	0	0	0
0	0	0	NE	2	NE	3	0	0	4	0	4	1
0	0	4	0	2	0	1	2	0	0	0	4	0
0	0	4	NP	NP	NP	1	0	0	0	0	0	1
0	0	4	NE	NE	NE	0	0	1	0	0	0	0
0	0	0	NP	NP	NP	0	0	1	2	0	0	1
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	1	NA	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	4	NP	NP	NP	NE	NP	2	NP	0	0	0
NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
0	0	0	NP	NP	NP	0	0	0	0	0	0	0
NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	0
0	0	4	0	1	0	1	0	2	0	4	4	2
NP	NP	NP	NP	NP	NP	0	0	2	0	0	0	0
NA	NA	NA	0	3	2	NA	3	4	3	0	0	0
0	0	0	NP	NP	NP	NE	3	NP	NP	0	4	0
Mattress Only Options												
0	0	0	0	0	0	2	0	1	4	3	0	0
0	0	0	0	0	0	0	0	1	3	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
0	0	0	NP	NP	NP	0	0	1	2	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0
Cover Only Options												
0	0	0	0	2	0	4	0	0	3	0	4	1
0	0	0	0	0	0	2	0	0	4	0	4	1

3.4.2. Component level analysis results

In addition to the four mattresses that passed the product level analysis, two standalone mattress covers were also included in the component analysis. The mattresses were broken down into their components based on information available from the manufacturer. Manufacturers were contacted and additional information was requested where it was not immediately available. Material safety data sheets for adhesives and fire barriers were obtained where possible and their components were included in the analysis.

The vast majority of chemicals available in the marketplace have not been evaluated or studied for potential environmental or human health concerns. When a significant amount of information is not available, it is up to the decision maker to determine how those null or not available data points will be evaluated while making comparisons. The lack of information for an attribute can be viewed as detrimental as a “high risk” attribute or it may simply not be included in the analysis. In this case, the lack of data was noted in the matrix and left to the furniture manufacturer to interpret as they see fit.

Color coding and assigning numerical values to the results allow the non-expert decision maker to view a short summary of the results and evaluate how the alternatives rank against each other. Rather than sorting through technical data that may not mean much to a decision maker, the color coded matrix in Table 6 shows that Mattress 2 is both missing a significant amount of data and has a significant number of high risk data points as compared to the other mattresses. Presenting the data in this manner instead of a single score system allows the user to make value decisions based on what is important to them and compare alternatives based on the value decisions.

As a result of the alternatives assessment, the manufacturer has replaced their vinyl covered mattress with a waterproof cotton

mattress. The use of PVC has been eliminated and the alternative mattress is less hazardous to the environment and human health.

4. Conclusion

An alternatives assessment process is a valuable tool to systematically assess potential options and assist with the decision making process. The usability of the model is based on how rapidly and accurately the alternatives assessment process can be completed and how useful the results are. The alternatives assessment process was completed in approximately six months, allowing the manufacturer ample time to work with the alternative mattress manufacturer to ensure their transition deadline was met. The clarity and conciseness with which the results are reported ensures their usability. Detailed tables containing scientific information are useful for technical experts, but provide little to no value to product designers or other decision makers who are also interested in the results. Translating the results to easily identifiable ranks, such as colors or numbers, allows them to be understood by a larger group of readers, thus making them more useful.

4.1. Benefits of the alternatives assessment model

Developing a two step method allows those alternatives that don't meet critical design parameters to be screened out of the assessment early on, reducing time and energy needed to complete the assessment. Building critical parameters such as cost and dimension into the product level assessment ensures those evaluated at the component level are all technically and financially feasible.

Color coding and assigning numerical values to the component results allows them to be understood by personnel with differing backgrounds. Product designers, marketing professionals, and others

that do not have a strong understanding of toxicology and environmental hazards can identify preferable alternatives and pinpoint potential concerns with considered alternatives. Presenting details behind the numerical values for each characteristic is overwhelming to the reader and technical jargon can be difficult to navigate.

Other alternatives assessment and environmental impact calculations combine attributes into one single, numerical score. On the outside, single score methods make it easy to compare multiple alternatives based on their scores. The concern is that single score methods do not allow the reader the flexibility to dig into the score and identify the areas of concern. The component level analysis in this alternatives assessment process allows the reader to see how an alternative performs in each individual attribute. The reader has the ability to make decisions based on components of the single score, rather than the single score itself.

Analyzing products at the component level allows the user to define what attribute is more important to them and evaluate alternatives as they wish. For example, if carcinogenicity and aquatic toxicity are important to the user, those attributes can be highlighted and assessed separate from the others.

4.2. Limitations of the alternatives assessment model

The assessment results do not determine a clear “best” alternative. Instead, the user is forced to look at all results and make

a value judgment to determine which attributes are more important and weigh the pros and cons of each alternative. This is both a benefit and limitation of the model. One reader may accept a certain level of risk while another reader may not, making it difficult to agree on the best alternative.

The assessment model does not take into account the potential additive and synergistic effects of the components of the products evaluated. Research has shown that the effect of multiple chemical exposures may be synergistic. Because very limited information currently exists on the synergistic effects of chemicals, it is difficult to consider at this time. In the future, as more information and more accurate information becomes available, it can easily be incorporated into the model.

Role of the funding source

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Appendix A.

Glossary of hazards.

Bioaccumulation and Persistence	
Fish ChV (fish chronic value)	This value is used to estimate a chemical's relative toxicity. The value is estimated using EPA's ECOSAR (Ecological Structure Activity Relationship) program. The PBT Profiler compares the ChV of each chemical to its water solubility. If the solubility is less than the ChV, then there are no effects at saturation. ^a
BCF (bioconcentration factor)	The measure of the ability for a water-borne chemical substance to concentrate in fatty tissue of fish and aquatic organisms relative to its surroundings. EPA defines bioconcentration as the net accumulation of a substance by an aquatic organism as a result of uptake directly from the ambient water through gill membranes or other external body surfaces. ^a
Water, Soil, Sediment, Air Persistence	Ability of a chemical substance to remain in an environment in an unchanged form. The longer a chemical persists, the higher the potential for human or environmental exposure to it. ^a
Dangerous for the Environment	The European Economic Community first created a List of Dangerous Substances in 1967, classifying substances according to health hazards and physico-chemical properties. The list has subsequently been expanded, and the Nordic Council of Ministers conducted a special project to review available toxicity data in order to identify substances that should be classified as dangerous to the environment. The EEC assigns “risk phrases” to compounds depending on their adverse environmental effects, to support product labeling and risk reduction efforts. The risk phrases currently used to define dangerous to the environment emphasize hazards to the aquatic environment, because of the lack of data on other target ecosystems. ^b
Greenhouse Gases	A gas, such as carbon dioxide or methane, which contributes to potential climate change. ^c List of greenhouse gases comes from Annex A of the Kyoto Protocol. ^d Carbon dioxide (CO ₂) Methane (CH ₄) Nitrous oxide (N ₂ O) Hydrofluorocarbons (HFCs) Perfluorocarbons (PFCs) Sulphur hexafluoride (SF ₆)
ODS (Ozone Depleting Substances)	Compounds that contribute to stratospheric ozone depletion. ^c
Regulatory Coverage	
FDA Food Additive Status	Any substance the intended use which results or may reasonably be expected to result – directly or indirectly – in its becoming a component or otherwise affecting the characteristics of any food. This definition includes any substance used in the production, processing, treatment, packaging, transportation or storage of food. The status indicates any use limitations for an additive. ^e

(continued on next page)

Appendix A. (continued).

Bioaccumulation and Persistence	
EPA Hazardous Air Pollutant	Air pollutants which are not covered by ambient air quality standards but which, as defined in the Clean Air Act, may present a threat of adverse human health effects or adverse environmental effects. Such pollutants include asbestos, beryllium, mercury, benzene, coke oven emissions, radionuclides, and vinyl chloride. ^c
US National Drinking Water Regulations	Legally enforceable standards that apply to public water system that protect public health by limiting the levels of contaminants in drinking water. Maximum Contaminant Levels are the maximum permissible level of a contaminant in water delivered to any user of a public system. MCLs are enforceable standards. ^c
Federal or State Regulatory Program Lists or Other Chemical Blacklists	Federal Regulatory Lists include: Air Contaminants (Occupational and Safety Health Act) Regulated Toxic, Explosive, or Flammable Substances (Clean Air Act) Criteria Air Pollutants (Clean Air Act) Extremely Hazardous Substances (Superfund) Hazardous Air Pollutants (Clean Air Act) Hazardous Constituents (Resource Conservation and Recovery Act) Hazardous Substances (Superfund) Inhalation Hazard Chemicals (Department of Transportation) Maximum Contaminant Levels (Safe Drinking Water Act) Priority Pollutants (Clean Water Act) State Regulatory Lists include: California Air Toxics "Hot Spots" Chemicals (Assembly Bill 2588) Air Contaminants (California Occupational and Safety Health Act) Maximum Contaminant Levels (California Safe Drinking Water Act) Public Health Goals and Action Levels (California Safe Drinking Water Act) Known Carcinogens and Reproductive Toxicants (California Proposition 65) California Toxic Air Contaminants (Assembly Bill, 1807) Other Chemical Blacklists include: Bioaccumulative Chemicals of Concern (U.S. Environmental Protection Agency) Dangerous for the Environment (Nordic Council of Ministers) Greenhouse Gases (Intergovernmental Panel on Climate Change) Ozone Depleting Substances (Montreal Protocol) Persistent, Bioaccumulative, and Toxic Chemicals (U.S. Environmental Protection Agency)
Acute Toxicity Inhalation LC50 (lethal concentration)	Median level concentration, a standard measure of toxicity. It tells how much of a substance is needed to kill half of a group of experimental organisms in a given time via inhalation. ^c
Oral LD50 (lethal dose)	The dose of a toxicant or microbe that will kill 50 percent of the test organisms within a designated period. The lower the LD 50, the more toxic the compound. ^c
Dermal LD50 (lethal dose)	The dose of a toxicant or microbe that will kill 50 percent of the test organisms within a designated period. The lower the LD 50, the more toxic the compound. ^c
Health Hazard EWG Hazard Rating (Environmental Working Group)	Represents a synthesis of known and suspected hazards associated with ingredients and products. Hazard ratings are shown as low, moderate, or higher concern categories, with numeric rankings spanning those categories that range from 0 (low concern) to 10 (higher concern). ^f
Endocrine Disruption Symptoms Allergies/Immunotoxicity	Exposure to chemical substances which causes adverse effects on the endocrine system. Negative health effects which result from exposure. Sensitivity to a substance which causes an inflammatory reaction or adverse effects on the functioning of the immune system that result from exposure to chemical substances.
Recognized Health Hazard	Recognized toxicants possess evidence that they do cause specific adverse health effects and are identified as recognized toxicants based on the hazard identification efforts of authoritative national and international scientific and regulatory agencies. ^b
Suspected Health Hazard	Suspected toxicants possess evidence that they can cause specific adverse health effects, but no authoritative hazard identification is currently conducted by regulatory agencies or scientific organizations for that health effect. Inclusion of a chemical on a "suspected" list should be viewed as a preliminary indication that the chemical <i>may</i> cause this effect, rather than a definitive finding that it does. ^b
Carcinogenicity	The ability of a material to cause cancer.

^a United States Environmental Protection Agency, PBT Profiler, <http://www.pbtprofiler.net/>, 10 Jun. 2010.

^b Scorecard, www.scorecard.org, 1 May 2010.

^c US EPA, Terms of Environment: Glossary, Abbreviations, and Acronyms <http://www.epa.gov/OCEPAt/terms/>, 8 Jun. 2010.

^d United Nations Framework Convention on Climate Change. Kyoto Protocol, <http://www.unfccc.int/>, 10 Jun. 2010.

^e United States Food and Drug Administration.

^f Environmental Working Group, SkinDeep Cosmetic Safety Database, <http://www.cosmeticsdatabase.com/>, 10 Jun. 2010.

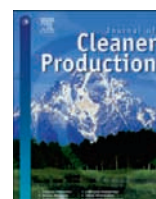
Appendix B.**Hazard data sources.**

Bioaccumulation and Persistence	
Fish ChV (fish chronic value)	US Environmental Protection Agency, PBT Profiler, http://www.pbtprofiler.net , Ver 1.203.
BCF (bioconcentration factor)	US Environmental Protection Agency, PBT Profiler, http://www.pbtprofiler.net , Ver 1.203.
Water, Soil, Sediment, Air Persistence Dangerous for the Environment	US Environmental Protection Agency, PBT Profiler, http://www.pbtprofiler.net , Ver 1.203. Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006. Nordic Council of Ministers, April 2002, N-CLASS Database on Environmental Hazard Classification, accessed via Scorecard, http://www.scorecard.org
Greenhouse Gases	Annex A, Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1997, accessed via Scorecard http://www.scorecard.org .
ODS (Ozone Depleting Substances)	United States Environmental Protection Agency, Class I Ozone Depleting Substances, http://www.epa.gov/ozone/ods.html . United States Environmental Protection Agency, Class II Ozone Depleting Substances, http://www.epa.gov/ozone/ods2.html .
Regulatory Coverage	
FDA Food Additive Status	United States Food and Drug Administration, Food Additive Status List, http://www.cfsan.fda.gov/~dms/opa-appa.htm .
EPA Hazardous Air Pollutant	United States Environmental Protection Agency, List of Hazardous Air Pollutants, http://www.epa.gov/ttn/atw/188polls.html .
US National Drinking Water Regulations	United States Environmental Protection Agency, National Primary Drinking Water Regulations & National Secondary Drinking Water Regulations, http://www.epa.gov/safewater/contaminants/index.html#mcls .
Federal or State Regulatory Program Lists or Other Chemical Blacklists	Accessed via Scorecard, http://www.scorecard.org .
Acute Toxicity	
Inhalation LC50 (lethal concentration)	National Library of Medicine's Hazardous Substances Data Bank, http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB . NIOSH Pocket Guide to Chemical Hazards, http://www.cdc.gov/niosh .
Oral LD50 (lethal dose)	National Library of Medicine's Hazardous Substances Data Bank, http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB . NIOSH Pocket Guide to Chemical Hazards, http://www.cdc.gov/niosh .
Dermal LD50 (lethal dose)	National Library of Medicine's Hazardous Substances Data Bank, http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB .
Health Hazard	
EWG Hazard Rating (Environmental Working Group)	Environmental Working Group, Skin Deep ingredient profiles, http://www.cosmeticsdatabase.com .
Endocrine Disruption	The following sources were accessed via Scorecard, http://www.scorecard.org Agency for Toxic Substances and Disease Registry. Minimal risk Levels for Hazardous Substances. January 2004. http://www.atsdr.cdc.gov/mrls.html BKH/European Commission. <i>Towards the establishment of a priority list of substances for further evaluation of their role in endocrine disruption: - preparation of a candidate list of substances as a basis for priority setting. Final report-November 2000.</i> http://europa.eu.int/comm/environment/docum/01262_en.htm#bkh . Category 1 chemicals from Annex 1: Candidate list of 553 substances. http://europa.eu.int/comm/environment/docum/bkh_annex_01.pdf Brucker-Davis, F. Effects of Environmental Synthetic Chemicals on Thyroid Function. <i>Thyroid</i> . 8(9): 827–856. 1998. US EPA, AirRisk Information Support Center. <i>Health Effects Notebook for Hazardous Air Pollutants.</i> http://www.epa.gov/ttnatw01/hlthef/hapindex.html US EPA. Announcement of the Draft Drinking Water Contaminant Candidate List; Notice. 62 <i>Federal Register</i> 52193–52219 (October 6, 1997). (Table 6). http://www.epa.gov/safewater/ccl/dwcccl.pdf US EPA. Addition of Certain Chemicals; Toxic Chemical Release Reporting; Community Right to Know. Proposed and Final Rules. 59 <i>Federal Register</i> 1788 (Jan 12, 1994); 59 <i>Federal Register</i> 61432 (November 30, 1994). Guillette, L. J., and E. Guillette. Environmental Contaminants and Reproductive Abnormalities in Wildlife: Implications for Public Health? <i>Toxicology and Industrial Health</i> . 12(3): 537–550. 1996. Illinois EPA. Endocrine Disruptors Strategy. 1997. (Table 1: Preliminary List of Chemicals Associated with Endocrine System Effects in Animals and Humans or In Vitro). http://www.nihs.gov/hse/enviro/illiepatable.htm Japanese National Institute of Health Sciences. Lists of Paradigmatic Chemicals. http://www.nihs.go.jp/hse/endocrine-e/paradigm/paradigm.html Keith, L.H. (ed.). <i>Environmental Endocrine Disruptors</i> . John Wiley & Sons, NY. 1997. http://www.wileyurope.com/cda/product/0,0471191450%7Cdesc%7C3037,00.html New Jersey Department of Health Services. Right to Know Program, NJDOH, Trenton, NJ. http://www.state.nj.us/health/eoh/rtkweb/rtkhsfs.htm California EPA, Office of Environmental Health Hazard Assessment. <i>Air Toxics Hot Spots Program Risk Assessment Guidelines, Part III: Technical Support Document "Determination of Noncancer Chronic Reference Exposure Levels"</i> . Includes all Chronic Reference Exposure Levels (CRELs) adopted by OEHHA as of August 2003 (http://www.oehha.ca.gov/air/chronic_rels/AllChrels.html), plus draft CRELs proposed through March 2004 (http://www.oehha.ca.gov/air/chronic_rels/index.html). National Institute for Occupational Safety and Health's Registry of Toxic Effects of Chemical Substances. World Wildlife Fund. Our Stolen Future. Widespread Pollutants with Endocrine-disrupting Effects. http://www.ourstolenfuture.org/Basics/chemlist.htm . The WWF list is derived from references detailed at http://www.ourstolenfuture.org/Sources/chemsources.htm and was originally published in: Colborn, T., F.S. vom Saal, and A.M. Soto. Developmental Effects of Endocrine-Disrupting Chemicals In Wildlife and Humans. <i>Environmental Health Perspectives</i> 101(5): 378–384. 1993. NIOSH Pocket Guide to Chemical Hazards (www.cdc.gov/niosh/npg/default.html) Environmental Working Group, Skin Deep ingredient profiles, http://www.cosmeticsdatabase.com . Scorecard, http://www.scorecard.org Scorecard, http://www.scorecard.org
Symptoms	
Allergies/Immunotoxicity	American Conference of Governmental Industrial Hygienists, 2004, ACGIH cancer classification system.
Recognized Health Hazard	International Agency for Research on Cancer, Monographs on the Evaluation of the Carcinogenic Risks to Humans, http://monographs.iarc.fr/ENG/Classification/index.php
Suspected Health Hazard	US National Toxicology Program, Report on Carcinogens, http://ntp.niehs.nih.gov/index.cfm?objectid=72016262-BDB7-CEBA-FA60E922B18C2540
Carcinogenicity	

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A feasibility and cost comparison of perchloroethylene dry cleaning to professional wet cleaning: case study of Silver Hanger Cleaners, Bellingham, Massachusetts

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ABSTRACT

The Toxics Use Reduction Institute (TURI) has been working with the dry cleaning sector for over 10 years – focusing on the ultimate goal of eliminating the use of perchloroethylene in this sector due to the availability of less toxic, feasible alternatives. Professional wet cleaning has been identified as one of these alternatives and has been a focus of the Institute in recent years. In 2008, the Institute provided a matching grant to Silver Hanger Cleaners in Bellingham, Massachusetts to convert their operations from perchloroethylene-based to water-based processes. Two years of data have been collected from the facility, reflecting one year of solvent use and one year of dedicated professional wet cleaning. The analysis of that data is presented here, including capital costs, performance data and associated costs, operational costs, and resource use and associated costs.

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1. Introduction

The concept of wet cleaning in the professional garment care industry has been in existence for several decades. However, it is only in the last 10 years or so that advancements have been made to the technology that allows for 100% of garments to be cleaned using the wet cleaning system. In 1998, Koeleian, et al. recommended in the Journal of Cleaner Production that larger cleaners could consider operating mixed mode facilities that use both dry cleaning and wet cleaning equipment (Koeleian et al., 1997). Today over 150 cleaners in California are operating as dedicated wet cleaners, a state where perchloroethylene (commonly known as perc or PCE) is being phased out through regulations (California Air Resources Board amendments will over time phase out the use of PCE dry cleaning machines and related equipment by January 1, 2023). Still, the shift to wet cleaning from solvent based cleaning has been slow, especially where regulations phasing out solvent use do not exist. At the time of writing, there were three dedicated wet cleaners in Massachusetts known to the Institute. Cleaners believe that insurmountable obstacles exist that do not make wet cleaning a feasible alternative – their concerns include increased costs, garments and fabrics that require extra care, and additional time investments. The

data has shown that these concerns are now lessened if not eliminated due to the newer technology. Sinsheimer et al. concluded in the Journal of the Air and Waste Management Association in 2007 that cleaners they studied in California who switched to professional wet cleaning were able to maintain their level of service and customer base while lowering operating costs. They also found that the cleaners were able to transition to professional wet cleaning without a great degree of difficulty and were highly satisfied with the new technology (Sinsheimer et al., 2007).

This case study based on a Bellingham, MA cleaners shows that electricity and natural gas usage decreased as much as 20%, and even water use was reduced at a dedicated professional wet cleaner. For this facility, equipment costs were reduced by \$500 over 12 months, performance costs (claims) were reduced by \$1000 over 12 months, operational costs (mainly due to costs of detergents) increased by \$1069 over 12 months, and costs associated with resource use (calculated using normalized rates) were reduced by \$2318 over 12 months, totaling \$2749 in savings over the 12 months of the study. The facility spent approximately \$12,000 (in actual costs, but not factoring in discounts and grant monies received) more than it would have to simply replace their solvent machine. This equates to a return on investment realized in just under 4.5 years.

With appropriate training and practice the personnel at this facility have been able to master difficult garments and even boast

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Table 1
Comparison of performance attributes.

Attribute	PCE	Wet cleaning	Qualitative analysis
Send-outs	5 items/month	Initial: 15–40 items/month After experienced: 5 items/month	Learning curve applies; eventually no difference
Re-dos	0	Initial: 3 items/month After experienced: <3 items/month	Staff learning curve effects rate of re-dos; eventually slight increase
Claims	\$1226	Initial: \$1125 After experienced: \$0	Saved >\$100/year initially; saved >\$1000/year with experience

that whites come out whiter and colors brighter in wet cleaning. Time spent cleaning is difficult to quantify, however, again with proper training and practice, total cleaning time can be reduced due to less pre-spotting, the ability to simultaneously wash and dry in separate machines (unlike the all-in-one traditional dry cleaning machines), and a mastery of the finishing equipment. Indirect benefits of improved air quality, reduced liability, elimination of regulatory oversight, and environmentally friendly niche marketing should all also factor into the overall analysis of the professional wet cleaning system.

1.1. Background

Able to dissolve most organic materials, PCE is the most widely used dry cleaning solvent in Massachusetts and nationally. It has been estimated by the Environmental Protection Agency that approximately 85% of cleaners use PCE as their primary solvent. PCE is also a major contributor to contamination at dry cleaning shops, mainly due to past unsafe handling practices. PCE is reported to be the chemical most widely found in groundwater contamination at Superfund sites (Anon., 2007), dry cleaning being one of the main sources. Studies suggest that long-term frequent over-exposure to organic solvents such as PCE may cause lasting and possibly permanent central nervous system effects. Fatigue, lack of muscle coordination, loss of concentration as well as short term memory loss, and personality changes exhibited as nervousness, anxiety or irritability are some of the potential permanent long-term effects of chronic and frequent exposure (Anon., 2007). In addition, PCE inhaled by pregnant women can cross the placenta, causing exposure of the developing fetus. PCE, which has been listed by The International Agency for Research on Cancer as “probably carcinogenic to humans,” has also been found in breast milk of mothers exposed to the chemical (Anon., 2007).

Professional wet cleaning has been determined in previous studies to be an energy efficient, nontoxic, zero-emission technology – and can be used to process those garments previously dry cleaned (Sinsheimer et al., 2007). The new wet cleaning technology, consisting of a washer, dryer, and tensioning equipment, allows

“dry-clean-only” clothes to be washed with water and detergents in computer controlled machines, dried in moisture controlled machines, and then finished with tensioning and pressing equipment.

1.2. Case study site, Silver Hanger Cleaners

In 2008, the Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell awarded Silver Hanger Cleaners of Bellingham, Massachusetts a \$17,000 matching grant to switch to 100% wet cleaning technology. Mark Isabelle (hereafter referred to as “the cleaner”), owner of Silver Hanger Cleaners for 14 years, renovated his existing store, removed the PCE machine, and installed wet cleaning equipment. With a few days of down time for the conversion, he opened his facility as a dedicated wet cleaning facility in November of 2008.

Silver Hanger Cleaners was using a third generation PCE machine and now conducts wet cleaning and laundry operations in about 1300 square feet of renovated space. The cleaner hopes to expand soon to accommodate another wet cleaning machine. The facility operates with about 7 full-time equivalent employees (FTEs) and cleans an average of 110 items per day – relatively consistently throughout the study period.

2. Data analysis

A portion of the matching grant money provided to Silver Hanger by TURI was used to fund the collection of data about the performance and costs associated with wet cleaning as compared to PCE dry cleaning. The data was collected from December 2007 through November 2009. Twelve months of PCE use data (December 2007 through November 2008, referred to as “2008 PCE Data” in this report) is compared to 12 months of wet cleaning use data (December 2008 through November 2009, referred to as “2009 Wet Cleaning Data” in this report).

The categories for which data was collected are: capital costs, performance, operation costs, and resource use. Performance data consisted of send-outs, re-dos, and claims. The operational data

Table 2
Summary of costs/savings – operating expenses.

Item	Costs/month (areas where costs are higher with wet cleaning)	Savings/month (areas where costs are lower with wet cleaning)	Costs/savings per year [(–) = savings, (+) = costs]
Maintenance	–	\$227	–\$2721
Filters	–	\$26	–\$316
Solvent	–	\$130	–\$1560
Detergent	\$631	–	+\$7572
Spotting agents	\$41	–	+\$492
Hazardous waste disposal	–	\$179	–\$2148
Regulatory fees	–	\$21	–\$250
Totals	\$672	\$583	
Total costs	+\$89		+\$1069

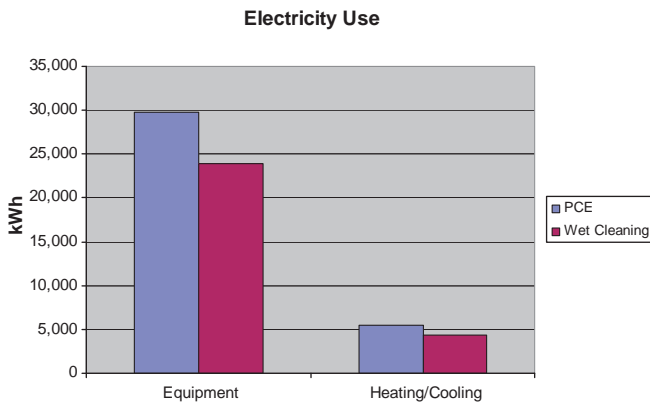


Fig. 1. Equipment and heating/cooling electricity use comparison.

included costs for machine maintenance, solvent filters, solvent product, detergent, spotting agents, hazardous waste disposal, regulatory fees, and a discussion of labor time. Resource use data included electricity for equipment (kilowatt hours or kWh), electricity for the facility heating and cooling (kWh), natural gas for the boiler to produce steam and hot water (therms), water, and sewage (both in gallons). Resource use data was also converted to dollar amounts using average unit costs for each year.

2.1. Capital costs

The cleaner was in the market for a new PCE machine when he decided to purchase the wet cleaning system. A new PCE machine would have cost him \$44,000 (according to his equipment supplier). Instead, he invested \$12,120 in a washer, \$4515 in a dryer, \$11,008 in a tensioning pants toppler, and \$19,540 in a shirt finisher (it should be noted that the cleaner purchased a shirt finisher providing more flexibility than generally required for a professional wet cleaner and he could have spent closer to \$12,000 on an adequate machine), totaling \$47,183. The costs the cleaner incurred for this wet cleaning equipment reflect discounts the vendors offered so that their equipment would be featured in demonstration events coordinated by TURI. The discounts provided to him totaled almost \$8800. The cleaner also received \$17,000 from TURI and \$2500 from National Grid (the facilities electricity and gas provider) – a total of \$19,500 – to help offset his capital investment, and therefore spent \$27,700 out of pocket. This amount is about \$16,300 less than he would have spent on a new solvent machine. However, without discounts and grant assistance, he would have spent \$12,000 more than if he had purchased a new PCE machine.

To compare equipment costs for a year of PCE cleaning to a year of wet cleaning, the useful life of each type of equipment was considered and an annualized cost of equipment determined. The capital cost of a new PCE machine being \$44,000, assuming a 15-year life for the equipment, based on industry standards, and a cost of capital of 5%, the annualized cost of using a PCE machine is

\$3054. To determine an appropriate capital cost to use in an annualized cost equation for the wet cleaning equipment, the vendor discounts were added back on to the cost of equipment, however, a lower price for the shirt finisher was used as the additional features of the more expensive shirt finisher the cleaner purchased are not part of a standard wet cleaning system. This leads to a capital cost of \$48,443 for the cleaner’s wet cleaning equipment, assuming a 20-year life for the equipment, based on industry standards, and a cost of capital of 5%, the annualized cost of using wet cleaning equipment is \$2553. This equates to an annual cost savings of approximately \$500 by using the wet cleaning system.

2.2. Performance

Send-outs. Send-outs are items that a cleaner chooses to send to another shop to be cleaned, typically because the other cleaner has capabilities that augment the facilities’ capabilities. This is a common practice in dry cleaning. When using PCE at his facility, the cleaner sent out only fur, leather, and suede items to a leather processor. The cleaner sent out an average of about five items each month. Immediately after his initial conversion to wet cleaning the cleaner sent out between 15 and 40 items each month to be cleaned elsewhere. His send-outs included fur, leather, and suede items, as well as hard to clean items like ties, pleated skirts, and draperies. Once the cleaner and his staff became more confident in the abilities of the new equipment, he reduced the amount of send-outs significantly and is now back to only sending out fur, leather, and suede items at the same rates he experienced when using PCE.

Re-dos. Re-dos are those items which did not meet visual cleaning or finishing standards as evaluated by the cleaner and are re-processed to fix the issue. The cleaner reports that he did not have any re-dos at his facility over the 12 months prior to converting his facility to wet cleaning. However, starting in December of 2008, his wet cleaning operations required 32 re-dos over 12 months for a monthly average of about 2.7 items. This rate of re-dos can be attributed to the learning process, and decreased as the cleaner and his staff became more comfortable with the use of the new equipment.

Claims. Claims are the items for which customers requested compensation if they felt the items were not properly cared for. The cleaner tracked the dollar amount of his claims to compare PCE use to wet cleaning. In 2008, the cleaner compensated his customers for a total of \$1226, or an average of about \$102 per month in claims associated with his PCE operation. In the first five months of 2009, the cleaner compensated his customers for a total of \$1125 on claims, or about \$94 per month on average. However, the claims dropped off to zero between April and October of 2009. The difference between 2008 and 2009 was a saving of \$101 in claims or about \$8/month. If the cleaner can maintain a \$0 claim rate then he would see an average savings of about \$1200 annually due to conversion to wet cleaning. A more conservative estimate of savings associated with reduced claims, however, is \$1000 annually (Table 1).

Table 3
Electricity use and associated savings.

	2008 PCE data	2009 Wet cleaning data	Decrease in use (from PCE to wet cleaning)	Savings (in dollars at rate of 16.961 ¢/kWh)
Total annual electricity use for equipment (kWh)	29,736	23,892	5844	\$991
Monthly average electricity use for equipment (kWh)	2478 (29,736/12)	1991 (23,892/12)	487 (5844/12)	\$83 (\$991/12)
Total annual electricity use for heating/cooling (kWh)	5489	4377	1112	\$189
Monthly average electricity use for heating/cooling (kWh)	457 (5489/12)	365 (4377/12)	93 (1112/12)	\$16 (\$189/12)

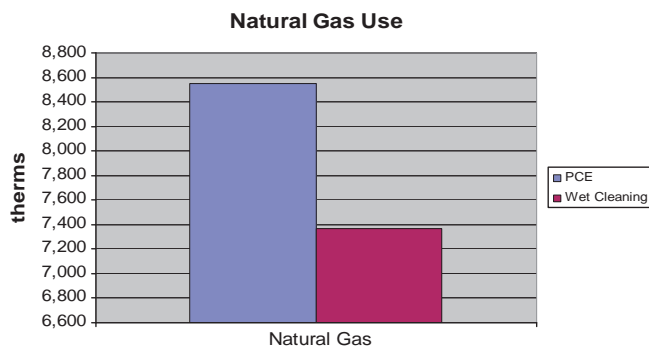


Fig. 2. Natural gas use comparison.

2.3. Operational costs

Labor. Though no labor costs were collected or reported during this study, some anecdotal information was collected based on the cleaners and pressers experience with both the PCE and wet cleaning equipment. After using the tensioning equipment purchased with the wet cleaning system, the cleaner's presser stated that he was able to leave earlier each day as he was able to process the garments more quickly than he had previously. With the wet cleaning washer and dryer, the cleaner is able to run wash and dry loads simultaneously, saving time there. He does hang some hard to dry items in the boiler room overnight for even more gentle drying and this processes adds time; this is only an issue if same day service is requested.

Maintenance. No expenditures on maintaining equipment at Silver Hanger Cleaners were reported by the cleaner. However, when operating PCE equipment, the cleaner would spend time cleaning and changing out filters and otherwise keeping the equipment in working order. With the wet cleaning equipment, there are no solvent filters to be cleaned, however parts do need to be kept in working order. A comparison is made here using industry standards for regular maintenance costs for PCE versus wet cleaning equipment. Sinsheimer et al. estimate that the total expense of maintaining wet cleaning equipment (including parts and labor) comes to \$379 per year based on a 15-year life span. The maintenance of a traditional solvent dry cleaning machine was estimated at 1.02% of a facility's annual revenue (Sinsheimer et al., 1997). Based on 2009 revenue of \$304,000 at Silver Hanger, the maintenance costs for a PCE machine would have been \$3100 for the cleaner. This totals an annual savings of \$2721 (\$3100 – \$379) or \$227 monthly.

Filters. When using PCE in 2008, a total of \$316 was spent on filters for the PCE machine or about \$26/month on average. No filters are necessary for wet cleaning equipment.

Solvent. The purchase of product solvent is, of course, a cost for a PCE facility. In 2008 the cleaner purchased 120 gallons of PCE. In 2009, using all wet cleaning, the cleaner did not purchase any PCE. Although the cost of PCE has gone up slightly over the past few years, the average cost over the study period was about \$13/gallon. The total amount spent on solvent in 2008 was \$1560

or \$130 per month – a total savings as no solvent is necessary for wet cleaning.

Detergent. Because there are several detergents and other products (e.g. softeners and conditioners) that are an important part of the wet cleaning process, the costs for detergent are greater for a facility using wet cleaning, than they are for dry cleaning. The cleaner made an initial purchase of detergent for the wet cleaning of about \$2000 that was used to stock his facility. Based on a comparison of 2008 and 2009 data, it can be estimated that for each \$10 spent on wet cleaning detergents, about \$1 is spent on detergents for laundry (i.e. not wet cleaning loads) done at the facility. A total of \$9394 was spent on detergents in 2009, of which approximately 90% can be attributed to the wet cleaning processes at the facility or \$8455 or \$704/month.

The current average cost of \$704/month for detergents minus the previous costs of \$73/month is a difference of \$631/month that the cost of detergents has increased or \$7572 annually.

Spotting agents. The cost for spotting agents went up in the first year of operation as a wet cleaning facility. However, the experience of wet cleaners in California is that the need to apply spotting agents decreases as the technology becomes better understood. This has been the cleaner's experience as well. The cleaner also notes that it is more difficult to remove grease stains with spotting agents appropriate for wet cleaning – as these are spotting agents that do not rely on solvents.

With an average of \$48 a month spent in 2009 on spotting agents, this is an increase of \$41/month or \$492 annually from 2008.

Hazardous waste disposal. Because hazardous waste is generated by the use of PCE, the cleaner spent an average of about \$179/month on hazardous waste disposal in 2008, or a total of \$2148. When the switch to wet cleaning was made these costs were eliminated because wet cleaning does not generate any hazardous waste.

Regulatory costs. Any dry cleaning facility that uses PCE in Massachusetts is required to submit paperwork and annual fees to the Massachusetts Environmental Results Program (ERP). All regulated media (air, water, waste) are included in this program. The fee associated with the ERP is \$250/year or an average of \$21/month. A facility using no PCE, such as Silver Hanger, no longer has to pay this annual fee, fill out paperwork (a small savings of labor time), or have the regulatory oversight that goes along with using PCE.

2.3.1. Summary of operating expenses

In the first 12 months of operation as a dedicated wet cleaning facility, detergent and spotting agent costs have increased on a monthly basis. Others costs have been completely eliminated. As noted in the summary table below, the use of wet cleaning has increased operating costs in the first 12 months \$89/month on average (Table 2).

2.4. Resource use

The cleaner collected data on resource use to compare resources used for operating a PCE facility versus a dedicated wet cleaning facility.

Table 4
Natural gas use and associated savings.

	2008 PCE data	2009 Wet cleaning data	Decrease in use (from PCE to wet cleaning)	Savings ^a (in dollars)
Total annual natural gas use for boiler (therms)	8547	7367	1180	\$1090
Monthly average natural gas use for boiler (therms)	712 (8547/12)	614 (7367/12)	98 (1180/12)	\$91 (\$1090/12)

^a Reflects average rates over the two years.

Table 5
Water usage.

	2008 PCE data	2009 Wet cleaning data	Decrease in use (from PCE to wet cleaning)	Savings (in dollars)
Total annual water usage (gallons)	223,000	217,000	6000	\$20
Monthly average water usage (gallons)	18,583 (223,000/12)	18,083 (217,000/12)	500 (6000/12)	\$1.67 (\$20/12)

Electricity use. Electricity provided by National Grid is used to power the garment cleaning equipment in the facility as well as the general heating and cooling equipment. The washers and dryers use electricity for mechanical action and the operation of computers, sensor systems, and detergent pumps. Tensioning equipment uses electricity to operate fans and computer systems (Sinsheimer and Grout, 2004). The amount of electricity used to power the facility equipment declined after the conversion to wet cleaning. The electricity use for wet cleaning and laundry equipment dropped an average of 487 kWh/month, or a monthly decline in electricity use of 20%. This drop in electricity consumption most likely can be attributed to the fact that there is no longer a solvent recovery system in use, an energy intensive process. The electricity used to power the heating and cooling system also declined after the conversion to wet cleaning, dropping an average of 93 kWh/month or a monthly decline in electricity use of 20%.

To convert this data into dollar figures, National Grid delivery and supply charges were used. Rates for delivery service (aside from a consistent monthly customer charge) are currently 5.961 ¢/kWh, and rates for basic service supply have averaged 11 ¢/kWh during the time period of this study, making the total charges for electricity 16.961 ¢/kWh. This equates to a total savings of \$1180 over 12 months for equipment and heating/cooling electricity use (Fig. 1, Table 3).

It is important to note the construction contractor completing major renovations at the strip mall where the facility is located was using the electricity from the cleaner's facility (by stringing a power cord through his window to power construction tools and equipment). Therefore, the decline in electricity use associated with the conversion to wet cleaning is actually lower than what is reflected here.

Natural gas use. Natural gas is used at the facility to provide steam for equipment and hot water for equipment and the facility. After the conversion to wet cleaning, the natural gas decreased from 8547 therms to 7367 therms for the entire facility, or an average of 98 therms/month. This is an average decrease in the use of natural gas at the facility of 14%. It is likely that this decrease was due to the elimination of the solvent distillation process used with the PCE machine.

To convert this data into dollar figures, Bay State Gas (the cleaner's gas provider) rates were used. Rates for gas service were 1.0645 \$/therm in 2008 and 0.7812 \$/therm in 2009. Assuming this drop in natural gas rates occurred at the beginning of January 2009,

we estimate that the average cost of natural gas over the course of this study was 0.9229 \$/therm. This equates to a total savings of \$1090 (though actual savings were \$3343 based on actual rates) (Fig. 2, Table 4).

Water use and sewage discharge. Water is used at the facility in the equipment as well as for the general sanitary uses. The amount of water used declined at the facility once wet cleaning was installed. As shown in Table 5, water use declined an average of 500 gallons/month or 2.7%. It is likely that this decline occurred due to the elimination of the condensing/chilling operations associated with the PCE process.

The water supply charge in 2008 and 2009 was \$3.25/1000 gallons according to the Bellingham Department of Public Works which provides water and sewer services. This equates to a total savings of \$20 over 12 months (Table 5).

As sewage discharge at the facility correlates to water usage, the decrease in the amount of sewage water discharge to the local treatment plant decreased the same 2.7%. The sewage costs did increase from 2008 (\$4.15/1000 gallons) to 2009 (\$4.80/1000 gallons), however, the costs were normalized for the purposes of comparison and an average rate of \$4.48/1000 gallons was used. The savings based on this average rate is then \$28 over the course of a year or \$2.30/month. It should be noted here that in Massachusetts, any laundry or dry cleaning shop is not allowed to discharge their wastewater to a septic system without a groundwater discharge permit from the Department of Environmental Protection (Table 6).

3. Additional savings and benefits

In addition to the various costs and savings noted in the data reported above, there are non-tangible savings associated with a conversion to wet cleaning. Many cleaners are concerned that wet cleaning takes more time than traditional PCE cleaning. The cleaner states that the process, in fact, does not take any longer once the wet cleaning system is learned. In fact, less time is spent on pre- and post-spotting. Just a few months in to using the new technology, his finisher was completing his work earlier each day than when they were using PCE.

Both the cleaner and his employees are happy with the new technology and the significantly improved air quality in the facility. As a facility using PCE, there was a noticeable smell of solvent in the air. Using wet cleaning, that odor has been eliminated. The cleaner

Table 6
Summary of costs/savings – resource use.

Item	Increased use/month (areas where use is higher with wet cleaning)	Reduced use/month (areas where use is lower with wet cleaning)	Savings per month (in dollars)	Savings per year (in dollars)
Electricity use for equipment (kWh)	–	487 or 20%	–\$83	–\$991
Electricity use for heating/cooling (kWh)	–	93 or 20%	–\$16	–\$189
Natural gas for boiler (therms)	–	98 or 14%	–\$91 ^a	–\$1090 ^a
Water use (gallons)	–	500 or 2.7%	–\$1.67	–\$20
Sewer discharge (gallons)	–	500 or 2.7%	–\$2.30 ^a	–\$28 ^a
Total savings	–\$193 ^a			–\$2318 ^a

^a Reflects average rates over the two years.

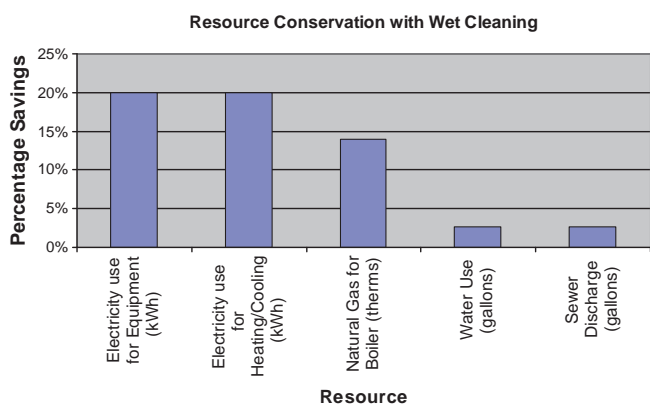


Fig. 3. Resource use and savings.

also states that customers are happy with the conversion to wet cleaning – as more and more consumers are looking for environmentally friendly services. The cleaner chose not to promote the use of wet cleaning as he was concerned that customers would not trust the use of water on their dry clean only garments. However, he would inform customers about the new technology if they inquired. He did post signs noting that he was an environmentally friendly cleaner and has a section on his web site about his non-PCE practices.

4. Conclusions and recommendations

This report has provided an analysis of capital, performance, operational, and resource use costs for one facility which converted from the use of PCE to professional wet cleaning equipment in their garment care business. The facility analyzed realized a \$2749 savings during the first year of operation as a wet cleaner and a considerable reduction in their use of natural resources (Fig. 3, Table 7).

With more time, it is hoped that annual savings could even increase. It is also the indirect benefits, not measured in this study, that help make the case for wet cleaning as a feasible and desirable alternative technology to solvent cleaning. The hope is that this analysis can serve to educate policy makers, pollution prevention programs in other states, and cleaners, to the financial benefits of wet cleaning.

It should also be noted that this case study is specific to one cleaner in Massachusetts. However, the data and results are comparable to similar studies conducted in California (Sinsheimer et al., 1997; Sinsheimer and Grout, 2004). This demonstrates that results from studies conducted in both locations are not geographically specific to either region.

It is recommended that Massachusetts continues to work with this small business sector to create healthier work environments within our neighborhoods – as garment care shops are prevalent in so many communities. Though Massachusetts has designated PCE as a higher hazard substance under the Toxics Use Reduction Act, further policy shifts towards a phase out of the solvent would help urge the sector to more seriously consider the wet cleaning alternative.

A more comprehensive assistance program would compliment a PCE phase-out policy and should focus on and support the conversion of more shops to professional wet cleaning. Due to the electricity and gas savings noted in this study, further partnerships

Table 7

Total wet cleaning cost/savings.

Item	Annual costs	Annual savings
Equipment		\$500
Performance (Claims)		\$1000
Operations	\$1069	
Resource use		
Electricity		\$1180
Natural gas		\$1090
Water		\$20
Sewer		\$28
Total cost/savings in 12 months	\$1069	\$3818
Total savings	\$2749/year	

with utility companies would help create a program with additional depth. The establishment of a national professional wet cleaning assistance program would help provide support to cleaners across the country who currently work with PCE on a daily basis.

Acknowledgements

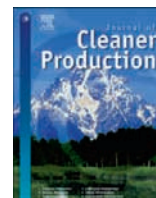
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Engineered nanoparticles: safer substitutes for toxic materials, or a new hazard?

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ABSTRACT

Nanotechnology has the potential for the development of new materials and processes that can substitute for toxic materials now used in industry. Excitement over this possibility is tempered, however, by the potential adverse environmental health and safety aspects of the new nanomaterials. Although a few examples from the literature are encouraging, *e.g.*, wire and cable insulation, great care must be taken to perform complete alternatives assessment evaluations of any new nanotechnology-enabled product before its adoption.

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1. Introduction

Nanotechnology is a rapidly-growing field that shows great promise in many disciplines, but it is also one that has engendered considerable concern in the field of occupational and environmental health and safety. The intersection between the possible benefits of nanotechnology and its risks was the subject of a recent Special Issue of the Journal (Helland and Kastenholz, 2008). There seems to be a general consensus that the use of engineered nanoparticles (ENPs) is likely to bring great benefit to society. Researchers are pursuing new applications in fields as diverse as medicine, electronics, textiles, energy, and construction; ENPs with a high potential for successful industrial use include carbon-base materials (*e.g.*, carbon nanotubes, fullerenes), nanocomposites, metals and metal oxides, biological nanomaterials, nano glasses and nano ceramics (Bauer et al., 2008).

Three terms frequently are used interchangeably, but have distinct definitions, *i.e.*, *nanotechnology*, *nanomaterial*, and *nanoparticle*. The following are generally accepted consensus definitions of these terms. According to the National Nanotechnology Initiative (NSTC, 2007),

Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications. Encompassing nanoscale

science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.

This definition has also been adapted by the International Standards Organization (ISO, 2008).

Based on the above definition, it follows that a nanomaterial is any material consisting of, or containing, structures with at least one dimension between 1 and 100 nm. It also follows that a nanoparticle is an individual particle of matter with at least one dimension in the 1–100 nm size range.

The 100 nm diameter given as the upper limit for a particle to be defined as a nanoparticle should not be taken as a strict cut-off. Since aerosols typically have a log-normal size distribution (Hinds, 1991), an aerosol whose median diameter is smaller than 100 nm may well have a significant number of particles larger than 100 nm. In addition, particles in the nanometer size range have very high mobility due to Brownian motion, and can agglomerate quickly soon after they are generated.

There is general agreement among scientists that particles in the nanometer size range fall into three categories. Naturally-occurring nanoparticles are nanoparticles in the nanometer size range that are found in nature, such as particles released by volcanic eruptions, particles produced by forest fires, salt particles produced by oceanic wave action, etc. Industrial nanoparticles are particles in the nanometer size range produced as *unwanted byproducts* of our modern industrial society. Common examples include welding fume, diesel exhaust, combustion smoke, etc. Finally, engineered

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nanoparticles are particles in the nanometer size range produced specifically for a purpose – *i.e.*, they are *engineered* to be in the nanometer size range. Engineered nanoparticles range from the very simple (*e.g.*, carbon black) to the very sophisticated (*e.g.*, drug delivery nanospheres). They can be spherical (quantum dots), cylindrical (carbon nanotubes), plate-shaped (nanoclay), or irregular (nanoalumina).

2. Benefits and risks associated with engineered nanoparticles

With nanotechnology moving from development to commercialization at a more rapid rate, so too are calls increasing for a more comprehensive understanding of the production costs, environmental and occupational health risks, and broader societal impacts associated with various nanomanufacturing processes. Commercialization of nanotechnology is proceeding quickly, with over 1000 products containing nanoparticles identified in commerce (WWICS, 2009). Global spending in 2006 was cited at more than 12 billion U.S. dollars (Maynard, 2007). However, this enormous investment dwarfs the funding dedicated to the environmental health and safety (EHS) implications of nanotechnology (Maynard et al., 2006). There are indications that a range of engineered nanomaterials, including nanoparticles, agglomerates of nanoparticles, and particles of nanostructured materials, are likely to present potential risks to human health and the environment. Possible negative properties of these materials include their ability to penetrate dermal barriers, cross cell membranes, travel neuronal pathways, breach the gas exchange regions of the lung, travel from the lung throughout the body, and interact at the molecular level (NIOSH, 2007).

Several recent articles have investigated the toxicity of carbon nanotubes (CNTs) (Donaldson et al., 2006; Erdely et al., 2008; Kane and Hurt, 2008; Kisin et al., 2007; Lam et al., 2006, 2004; Li et al., 2007; Miyawaki et al., 2008; Poland et al., 2008; Shvedova et al., 2008a,b,c, 2005; Takagi et al., 2008; Warheit et al., 2004; Ma-Hock et al., 2009). This literature indicates that there may be significant health effects associated with exposure to CNTs, including granulomatous pneumonia, oxidative stress, acute inflammatory/cytokine responses, fibrosis, and decrease in pulmonary function, and cardiac tissue inflammation. Recent studies findings precursors of mesothelioma following the peritoneal instillation of CNTs in mice (Poland et al., 2008; Takagi et al., 2008) are of particular concern, since mesothelioma is fatal cancer known to be caused by exposure to asbestos. CNTs are fibrous particles with morphology similar to asbestos but with diameters two orders smaller than asbestos.

Given such concerns for the potential toxicity of ENPs, attention must be paid to the potential for exposure to these materials. Occupational exposures are possible during the manufacture of the ENP and during its incorporation into a product. Environmental exposures may occur during manufacturing, product use, and when the product is disposed of. There is concern both for inhalation and dermal exposure. Currently, there are no exposure standards specifically aimed at ENPs in either the occupational or the general environment.

Such concerns are leading to more public calls for increased attention to environmental health and safety issues related to this emerging technology (Maynard et al., 2006; Maynard, 2006). In September 2006, the U.S. House Committee on Science expressed its desire for greater federal research on and coordinated action to address the potential EHS risks of nanotechnology (Committee on Science, 2006). The U.S. Environmental Protection Agency has announced its intent to develop a roadmap for EHS research needs (EPA, 2007). The National Institute for Occupational Safety and Health (NIOSH) has provided an overview of the research undertaken at that

agency, along with summaries of accomplishments and suggestions for additional research needs (NIOSH, 2007). Although NIOSH has suggested preliminary guidelines for working safely with nanomaterials (NIOSH, 2008), research clearly is needed to define risks and provide guidance for safe handling of nanomaterials and to minimize workplace exposure. Various other U.S. government agencies are involved in contributions to the EHS research effort, and an overview of the primary EHS research and information needs recently was developed by the National Science and Technology Council (NSTC) of the U.S. National Nanotechnology Initiative to guide the vast effort deemed necessary to ensure responsible development of nanotechnology (NSTC, 2006).

3. Can engineered nanoparticles substitute for toxic chemicals?

As discussed above, ENPs are being developed for many industrial applications. Given the evidence for toxicity of at least some ENPs and the potential for occupational and environmental exposures, the question arises as to whether it is possible to substitute such particles for other, more toxic chemicals currently in use in various applications, or whether the use of ENPs or, more broadly, nanotechnology (NT) will likely increase the risk associated with these products.

In an attempt to address this important question, this Section will first review some basic concepts underlying substitution, then look at a few examples of substitutions involving ENPs as documented in the literature, and finally explore in some detail a current ENP substitution research project involving the use of nanoclays.

3.1. Substitution as applied to nanomaterials

Fiedeler and his colleagues at the European Technology Assessment Group (ETAG) make the important point that ENPs and NT must be looked at differently from simple chemical substitution (Fiedeler, 2007):

The original meaning of chemical substitution is quite clear and narrow: one chemical substance is replaced by another, for whatever reason (availability, costs, requirements).

Due to the fact that NT is neither a group of substances nor a group of products but an enabling technology the way NT can provide solutions is more fundamental than just replacing the function of the substitute. It is assumed that NT provides new effects which are not based on chemical properties of the related material but on the physical properties caused by its size and shape. It can be used to develop completely different processes or different products which serve the same purpose but in a completely different way.

Given this necessarily broader definition of substitution as it relates to NT and ENPs, it is likely that any practical use of ENPs as a replacement for a more hazardous material will encompass aspects of both *material substitution* and *process change*. In other words, the successful use of ENPs as safer substitutes likely will entail substantial changes in the overall production process and final product, as opposed to a similar “drop-in” material substitution. Such large fundamental changes in production processes will make the process of evaluating the relative health and safety impact of the current process and the proposed change much more difficult than is the case when a simple chemical substitution is contemplated. The alternatives assessment process will likely have to assess the known adverse impacts of the current process against what might be very limited data for the NT-enabled alternative.

It is thus important to use a comprehensive alternatives assessment strategy when evaluating NT-enabled alternatives. The

Lowell Center for Sustainable Production (LCSP) has devoted much attention to this topic in recent years, and has published an Alternative Assessment Framework that outlines the essential elements of a comprehensive assessment approach (Rossi et al., 2006):

At the base of the Framework is the **Foundation**, where values are made explicit by clearly articulating the Principles, Goals, and Rules that guide decisions made during the assessment of alternatives. At the center of the Framework is the **Assessment Processes**—the methods, tools, and criteria used to evaluate which chemicals, materials, or products are safer and socially preferable. The Comparative Assessment Process and the Design Assessment Process are two separate yet overlapping tracks, depending on whether the subject of evaluation is an existing product or a product under development. Necessary to the Assessment Process are the **Evaluation Modules**, which evaluate the economic feasibility, technical performance, human health and environment impacts, and social justice impacts of alternatives.

Beyond alternatives assessment, it will also be important to subject ENP substitution to a full life cycle assessment (LCA). Bauer et al. outline the required elements in the application of LCA to ENPs, and give examples of how it might be used (Bauer et al., 2008); von Gleich et al. suggest a three-tiered assessment approach that incorporates elements of alternatives and life cycle assessment (von Gleich et al., 2008).

3.2. Examples from the literature

A review of the literature reveals very few examples where ENP substitution has made its way into commerce, with the notable exception of medical applications. Nanoparticles are rapidly being developed for many medical applications (Salata, 2004). Some of these new applications are meant to replace others that require the use of hazardous chemicals. The development of nanoparticle-based drug delivery systems for cancer therapy is receiving much attention, because of the widespread, highly-debilitating side effects of drugs now used for cancer treatment. One recent example is research conducted at Washington University into the use of gold nanocages (Skrabalak et al., 2008) for cancer treatment (Chen et al., 2010). The nanocages are first coated with polyethylene glycol (PEG) for biocompatibility and, when injected into the bloodstream, collect preferentially in tumors. They are then irradiated with a laser beam, tuned to a frequency that penetrates body tissues but is absorbed by the nanocages. The absorbed light heats the nanocages, which kills the surrounding tumor cells. This example illustrates the type of advantages the use of ENPs might bring to medicine. There is little in the literature, however, that discusses any potential adverse side effects that might be caused by the ENP due specifically to its small size.

There are limited examples in the published literature of ENPs being successfully used as substitutes for toxic chemicals in industrial applications, and none of the available examples have been subjected to the comprehensive alternatives and life cycle assessments described in Section 3.1. One area that holds some promise is the development of substitutes for solvents. While it is probably not possible to directly substitute an ENP for a solvent, ENPs may be a *component* of a water-based system that substitutes for a solvent-based one. For example, some paint manufacturers claim that nanoparticles are a component of a water-based paint system that can offer similar characteristics to their solvent-based paint products. Incorporation of zinc oxide or titanium dioxide nanoparticles into the formulation may make the paint surface more durable, allowing for thinner paint coatings and an overall reduction in chemical use (Fiedeler, 2007).

To reduce biofouling in such applications as ship hulls typically requires the use of paints incorporating toxic agents such as tributyl tin. If the surface adhesion properties could be changed, the fouling agents may be kept from ever reaching the surface and obviate the need to kill them. The incorporation of nanoparticles into the paint may reduce adhesion through what is commonly called the lotus effect, since lotus leaves are known to readily shed water droplets. Cheng has shown that the presence of nanometer-scale hairlike structures on the lotus leaf surface are responsible for the very high contact angle that leads to water shedding (Cheng et al., 2006). If a marine paint could be developed that incorporated similar structures, the use of tributyl tin could be eliminated.

Another example is the use of nano-emulsions of chemicals in water as a cleaning agent and as a substitute for perchloroethylene used in dry cleaning. For example, EPA recently funded an SBIR project to "...develop a non-toxic nanoemulsion for decontamination of facilities and equipment contaminated with anthrax. The nanoemulsion is an oil-in-water emulsion with broad-spectrum antimicrobial activity optimized for decontamination of *Bacillus anthracis*" (Hamouda, 2006).

One area that is the subject of recent research is the use of nanoclays as part of a package designed to substitute for several hazardous chemicals used in wire and cable insulation. Since this work was performed in our laboratories with partial funding from the Toxics Use Reduction Institute, it will be described in more detail in order to shed some light on the process needed to develop an ENP substitute.

3.2.1. Introduction and background

Wire and cable jackets typically are made of polyvinyl chloride (PVC) and include a plasticizer for flexibility and lead compounds for heat stabilization. Lead-based heat stabilizers are commonly used in the United States because they are inexpensive and very effective at stabilizing PVC, especially when the wire and cable insulation is wet. Although alternative lead-free formulations are now commercially-available, they are more expensive than the lead-based products and may not offer the levels of stabilization required for safe use in highly demanding applications. Some contain other toxic heavy metals (barium or cadmium), some contain organotin (high performance but potentially toxic due to impurities and definitely more expensive than lead), and some contain relatively benign materials but have relatively poor heat-stabilizing properties (calcium, magnesium and zinc-based stabilizers). To summarize what is now available, it would appear that commercially-based lead-free alternatives do not yet equal the performance and cost of lead-based systems.

Analysis of the data collected in Massachusetts under the Toxics Use Reduction Act (TURA) indicates that Massachusetts firms used almost 3.5 million pounds of lead compounds in 1999 in wire and cable insulation. Due likely to reduced wire and cable production in the Commonwealth, this number dropped to 300,000 pounds in 2007.¹

In addition to lead, PVC wire and cable insulation commonly contains phthalates; plasticizers provide flexibility to PVC, and phthalates are used because they are relatively inexpensive and effective. A typical wire and cable insulation can contain up to 30% phthalates by weight. Unfortunately, the weight of evidence strongly suggests that phthalates are endocrine disruptors (see for example (Hirosawa et al., 2006)), and their use is now restricted or banned in many jurisdictions and applications.

¹ Massachusetts Toxics Use Reduction data available at <http://turadata.turi.org/>.

3.2.2. Work in progress

Research by Schmidt studied whether a more environmentally-acceptable alternative could be developed to replace both the lead and the phthalates in wire and cable insulation. Schmidt investigated the use of a combination of alkylammonium-modified clay and an epoxidized linseed oil (ELO) plasticizer with various heavy metal free heat stabilizers could substitute for lead and phthalates (Dorairaju et al., 2008). In processing, the clay disperses throughout the polymer in the form of nanometer-sized sheets. The research tested whether the nanoclay, when combined with ELO and non-lead heat stabilizers, would be able to offer the needed combination of heat and process stability, coupled with appropriate mechanical and fire properties. The theory was based on the following factors:

- Alkylammonium-modified nanoclays, when used in PVC, reduce its process and heat stability but enhance its mechanical, barrier and fire properties;
- ELO is known to increase PVC heat stability and to interact favorably with the nanoclay;
- Epoxy plasticizers such as ELO are subjected to hydrolysis, which may cause them to become incompatible with PVC over time; however, favorable interactions with the nanoclay coupled with nanoclay-enhanced barrier properties that reduce moisture ingress may enhance the long-term stability of the ELO; and
- Although PVC is inherently a poor fuel, the presence of well-dispersed nanoclay may enhance the flame retardance of the new formulation.

Nanoclay, or montmorillonite, is a naturally-occurring material (de Paiva et al., 2008; Hofmann, 1968; Uddin, 2008). While nanoclay is a non-renewable resource, it is widely abundant in surface deposits and thus can be utilized with relatively minor environmental impact, especially when compared to the processing required to produce lead salts. One important property of nanoclays produced commercially for nanocomposite formation is that, in the bulk dry powder form, individual particles are in the micrometer size range; it is only when the powder is processed with a polymer that each micrometer-sized particle disperses into nanometer-sized particles. Nanoclay is a type of nanomaterial which is difficult to be dispersed to individual airborne clay nanosheets during processing. Thus, the related occupational exposures and environmental releases during processing nanoclay will primarily involve the larger particles, not those in the nanometer size range. However, some other nanomaterials with easy dispersion properties can cause more serious occupational exposure and environmental release than the same material in the micrometer size range, so each scenario must be individually evaluated. Nanoclay is inexpensive (~\$3/lb); the toxicity of nanoclay has not been studied widely, but the information available indicates that it is relatively benign (IPCS, 2005); after a thorough review, the Cosmetic Ingredient Review Expert Panel approved montmorillonite for use as an ingredient in cosmetics (Elmore, 2003). ELO is a bio-based product which is biodegradable and FDA approved for food packaging (FDA, 2010). These factors all lead to the suggestion that nanocomposite formation in the presence of a properly chosen additive package may allow for the replacement of lead in wire and cable insulation, provided, of course, that the required mechanical and chemical properties are present.

Schmidt first investigated the use of nanoclay as a means of enhancing the properties of lead-free, phthalate-plasticized medical grade PVC. Test results found that a nanocomposite of PVC and 2% nanoclay by weight provided "...inherent flame retardance, due to formation of silicate char once burning begins at an exposed surface," and that the desirable mechanical properties

were retained so long as the clay content was kept low (Francis and Schmidt, 2006).

Schmidt then found that a combination of nanoclay, non-lead heat stabilizer (Ca, Mg, and/or Zn based), and ELO were able to provide heat stability, fire protection and flexibility in a single lead- and phthalate-free additive package. This leads to the hope that a commercial product containing an appropriate combination of nanoclay, a relatively non-toxic metal salt, and ELO has the potential to replace lead and phthalates in wire and cable insulation.

3.2.3. Summary

Since this approach is still in the research phase, it is not possible at this time to perform complete alternatives or life cycle assessment. It seems certain that the substitution of nanoclay and ELO for lead and phthalates in wire and cable insulation will result in a less hazardous product, although questions of economic and technical feasibility remain not fully answered. Nonetheless, this is an excellent example of the potential for the environmentally-advantageous use of a nanomaterial.

4. Conclusions

Although there are few examples of ENPs now being used as substitutes for more hazardous chemicals in industrial settings, that situation is likely to change rapidly. The very large current investment in ENP research and development holds the promise for many more such possible substitutions reaching the commercial stage in the near future.

The possible use of ENPs as substitutes for toxic materials in manufacturing holds great promise, but also many risks. For every possible application, alternatives assessment tools, such as the LCSP Alternative Assessment Framework, must be used to carefully analyze the risks and benefits. In the near future for most cases, such assessments will be made more difficult because the risks of the current process will be well-known but the risks associated with the ENP will not have been fully studied. In addition, effective measures for the control of exposure to nanomaterials are under development, as well as the end of life treatment for nanotechnology-enabled products. Such developments will help to overcome the challenges currently experienced when considering the use of nanomaterials and since well-controlled nanomaterials can successfully substitute for the current use of some toxic materials even with unanswered questions as to their toxicity. However, it is recommended at the present that a precautionary approach be taken, and that such substitutions be made only in cases where the ENP clearly represents an improvement over the current materials being used, and where nanoparticle releases to the environment can be controlled.

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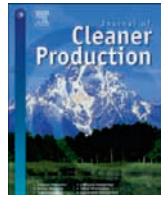
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Primary prevention for worker health and safety: cleaner production and toxics use reduction in Massachusetts

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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.

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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 (NCFL) 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, LD₅₀, 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 Evaluation	Management leadership and employee participation		X	
	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 Pollution Prevention Options Analysis System	Acute human effects ^a	X	X	
	Chronic health effects ^a	X	X	
	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
	Open-ended survey	Exposure potential ^a	X	X
		Positive effects of CPPP/TUR intervention on worker safety and health		X
Key informants	Barriers or limitations of CPPP/TUR interventions to positively impact worker safety and health		X	
	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 trichloroethane) and the elimination of glycol ethers in outer layer resist processing and outer layer developing. 1,1,1 trichloroethane 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 were 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.

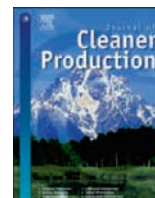
This study continues the, so far limited but necessary, dialog around the effects of environmental intervention programs on worker health and safety. We have demonstrated that while CPPP/TUR reduces exposure to toxic substances in the ambient environment, it also offers unique opportunities to reaffirm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

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Note from the Field

The experiences of four corporate officials managing compliance with the Massachusetts Toxics Use Reduction Act

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ABSTRACT

The Massachusetts Toxics Use Reduction Act (TURA), one of the original pollution prevention laws, has faced repeated repeal attempts and budget cuts. Yet the Massachusetts toxics use data and other analyses have provided firm indications that the law has actually worked. Though the program has survived it is notable that an approach that both saves money and reduces pollution has been reduced and not expanded. This paper does not attempt to answer the question of why the strategies of TURA have not seen wider application, but offers four stories to illustrate what happens when they are properly applied. The experience of corporate officials who had to comply with TURA, related at a symposium on the occasion of the law's 20th anniversary, shed light on how a strong pollution prevention law can benefit regulated companies as well as the environment and worker and public health, and provide suggestions, in addition to data and surveys, that TURA-like sets of governance tools should receive wider consideration.

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1. Can an environmental law be good for manufacturing?

After the Massachusetts legislature passed the Toxics Use Reduction Act (TURA) unanimously in 1989, many worried that it would have a negative impact on manufacturing in the state. Although the bill had been crafted by a diverse group of stakeholders including prominent business representatives, in 1992 a new trade association, (the Massachusetts Chemistry and Technology Alliance (MCTA)), was created to represent companies using chemicals in the state, and began a long-term campaign to repeal or substantially modify the law. The primary lobby for manufacturing in the state, the Associated Industries of Massachusetts, had already formed and held regular meetings of a “Toxics Use Management” committee, (note: *use management* as opposed to *use reduction*). Although both organizations consistently promoted environmental responsibility, both criticized the specific requirements of TURA, with MCTA sponsoring several legislative attempts to repeal or radically alter the state's program. None of these bills succeeded and when in 2006 the Act was amended, none of the features causing complaints – its focus on input substitution, documentation of biennial TUR planning, the requirement that certified Toxics Use Reduction Planners

(TURPs) certify the TUR plans, the public reporting of chemical input, and the fees for chemical use – were removed.¹

Rather, flexibility was provided to companies covered under the act to do Resource Conservation planning instead of TUR planning if they had already done several TUR plans, and to incorporate TUR planning into Environmental Management Systems if they had them in place. None of the basic principles or aims or mechanisms of the law were changed. Its basic approach was *expanded*. It is possible that this is because critics of TURA as it has been implemented did not make a sufficiently forceful case for a basic change in the fundamental strategy of the law. But it is also possible that whatever the merits of their arguments, the TURA experience has by and large been positive for companies covered by the law. Indeed, the Massachusetts TUR data and some surveys have provided quantitative indications that the law has been successful in reducing pollution, and that many covered by it have ended up saving money and sometimes jobs, and that the act has prompted upgrading, operational improvements, and information sharing between

¹ TURA requires large chemical users to do “TUR plans” – which means that they document an examination of their chemical use and opportunities for using less, including “input substitution”, (which means using another chemical), or using chemicals more efficiently. These plans must be certified as adequate by a trained “TUR Planner”. The act also provides for significant assistance and educational activities, and requires that companies covered by the act pay a fee for using toxics and submit reports on their use, waste and releases.

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companies and between companies and government.² Companies testified at hearings on bills to repeal TURA that its program services had been useful. When the program faced budgetary reductions in 2008 and 2009, dozens of companies wrote to the governor and the state's environmental secretary to ask that the program be fully funded.³ Many anecdotes from case studies, awards and recognition programs, the on-site visit and laboratory analysis services, and the many educational events of the TUR program provide indications that it has created good solutions to vexing compliance and risk issues.⁴ Nevertheless, the policy response to these indications has not been widespread adoption and scaling up of what appear to be effective tools of environmental governance.⁵

This article reviews some of the indications that the TURA example is worth consideration for more widespread application, and introduces four examples of how it works in practice. There is already a robust anecdotal literature on pollution prevention⁶ and much has been shown to merit closer consideration of preventive governance tools such as chemical-input reporting, planning, and concerted assistance and education.⁷ It is possible to speculate on why the apparent success of TURA and programs like it, even if illusory, has not prompted more frequent attention to its methods as options for agency mandates. The widespread assumptions that corporations already act in self-interest to be as efficient as they can be, and government should not intervene in the market, may dampen impetus to further explore how well TURA-like approaches could work. Doubt about the credibility of the program's claims of success, raised by the Chemical Manufacturer's

Association and others, may have also played a role.⁸ It is also possible that it is hard to picture just how something like TURA really works. This might make it harder to see its value and importance, and prevent incorporation into an accepted canon of essential elements of environmental governance. This article is another attempt to supply some illustration. The four professionals managing corporate responses to TURA were some of the first who ever had to perform the task, and they shared their stories at a symposium reviewing TURA's 20th year, held in Massachusetts in November, 2009. Their stories encompass an historical perspective from the beginning of the problem up to the present, and thus are not "snapshots" in time. Three had very positive stories to tell (for example, savings of more than a million dollars per year for one company), and one had a more mixed by generally positive story. Their stories do not answer the question of whether something like TURA will work every time, for every similar problem, but they help show how the idea can work.

TURA does not require any specific toxics use reduction. It focuses on thinking about the issue of toxics use and the opportunities to reduce, providing drivers and assistance – arguably a more gentle push and pull than more conventional command and control regulation.⁹ What it requires has been described as using "mandatory self-monitoring to induce firms and citizens to acquire information that reveals problems and possibilities for their solution."¹⁰ Perhaps we are too habituated to thinking of environmental governance as being about defining clear and universal standards and policing compliance. These stories show another version of standards, more flexible, stimulating beyond compliance performance; and another hand of government (assistance and education), more user-friendly, complementing enforcement. If the four officials whose stories are related here were the only ones to have had good experiences with the law and the program, it would still be important to understand this strategy and learn how to make it work, for unless you believe that companies are already as efficient as they can be, there is a logical basis to it. If a company has not become efficient in its use of toxic materials, the Act's intrusion should not be regarded as untoward, for what it causes them to examine will be worth the attention. If a company has already

² See General Indications of Massachusetts Success, below.

³ Letters available upon request to OTA.

⁴ For example, OTA case studies Acushnet Rubber Company, Brittany Dyeing and Printing, etc. at www.mass.gov/eea/ota, (click to Education and Outreach, then Publications). See also the resources at www.turi.org, the website of the Toxics Use Reduction Institute. Of especial interest is the recent *Toxics Use Reduction Act Program Assessment, 2009*: www.turi.org/policy/ma_tura_program/tura_program_assessment. For an independent description of how the TURA program holds lessons for better environmental governance, see O'Rourke, Dara, and Lee, Eungkyoon; *Mandatory Planning for Environmental Innovation: Evaluating Regulatory Mechanisms for Toxics Use Reduction*, <http://nature.berkeley.edu/orourke/PDF/TURA.pdf>. "By analyzing the underlying mechanisms of TURA, a start can be made to generate hypotheses, admittedly preliminary at this time, on how regulation can motivate firms to innovate, how regulation can support learning within firms and among regulators and how regulation can support implementation of innovative environmental practices."

⁵ Indications of not scaling up: 1. EPA not going forward with national chemical use reporting: see EPA's Toxics Release archives, <http://www.epa.gov/tri/archive/1990s.html>, under 1997. The TRI Phase 3 fact sheet notes: "EPA believes that chemical use information could expand the public's ability to evaluate a range of important environmental issues." EPA issued an Advance Notice of Proposed Rulemaking (ANPR) at 61 Federal Register 51321–51330 but did not issue a proposed rule. 2. EPA's 2010 P2 Grant program Request for Proposals offered only \$4.1 million nationwide, in contrast to the 1990 Pollution Prevention Act authorization of \$8 million from 1991 to 1993 for P2 grants to the states (42 USC 13109). These grants have been competitive and require match, in contrast to base grants for activities considered essential.

⁶ See, for example, http://www.p2rx.org/new_home/case_studies.cfm; <http://www.p2.org/wp-content/road-to-sustainability-2004-20062.pdf>; <http://www.newmoa.org/prevention/pubs.cfm>; <http://www.pprc.org/pubs/publist.cfm>.

⁷ The 1997 TURA program evaluation by Abt Associates, overseen by TURI, for example, showing benefit to companies covered by the Act (http://www.turi.org/policy/ma_tura_program/1997_program_evaluation), and the 2006 evaluation by OTA of TURA data, showing that companies visited by MA OTA's assistance program reduced significantly more toxics use and waste than those not visited by the program. *The Effect of Providing On-site Technical Assistance for Toxics Use Reduction, 2006*: http://www.mass.gov/Eoea/docs/eea/ota/programs/ota_effectiveness_study_final_2006.pdf. (Reibstein, principal author).

⁸ CMA claimed that TURA success in fact represented economic slow-down and not true reductions in toxics use. Concerning slow-down, the Massachusetts Department of Environmental Protection uses company-reported data to adjust for production. The data shows substantially less toxics being used *after accounting for changes in the amount of work performed*. The impact of company shutdowns, which involves companies leaving the system, is not so easy to assess from the TURA data. Using information from follow-up to companies dropping out of the program and web-searches, OTA established in 2006 that for most years of the program the impact on reductions from company shutdowns has been minimal. "In 1999, the maximum percentage of reduced pounds of toxics use that could possibly have been due to business shutdowns was less than one percent. In 1997 it was less than five, and in 1995 it was less than three. Only in 1998, when the maximum possible amount was 19.3%, and in 1996, when it was 27%, could the shutdown factor have possibly contributed anything meaningful to the measured changes in performance." *The Effect of Providing Onsite Technical Assistance*, p. 3.

⁹ It is critical to note that TURA does not replace but supplements existing regulations such as Clean Air Act, Clean Water Act, etc.

¹⁰ Karkkainen, Fung, and Sobel, *After Backyard Environmentalism: Toward a Performance-Based Regime of Environmental Regulation*, *American Behavioral Scientist*, Vol. 44, No. 4, December, 2000, p. 696. "Taken together, plans, planners, TURI, and OTA create an inspection regime in which current conditions in individual firms or industrial segments can be compared with each other and with expert understanding of best practices, even as that understanding improves through exposure to innovative firms. Finally, applying the pragmatist principles of adjustment of means and ends to these novel institutions themselves, TURA provides a high-level governance structure that periodically suggests modifications in services and reporting requirements in light of its evaluation of progress toward the act's overall reduction target." <http://www.archonfung.net/papers/FungAmBevSci00.pdf>.

become as efficient as it can be, then the TURA requirements should not be very burdensome. Except for the fees, the burden will consist of documenting what it has already done.

That the stories told in this paper are representative of many more who have passed through the TURA process, received assistance from TURA services, and ended up moving from resentment at being regulated to appreciation for the results, is shown in the extensive documentation created over the years, and the fact that there has been extraordinary participation in the voluntary aspects of the program.¹¹ These stories are clues to how we might more effectively address the risks of toxics in our society.

2. The general acceptance of pollution prevention concepts

In 1990 all fifty states in the United States had some form of a pollution prevention program, predominantly focused on providing assistance or education.¹² These voluntary programs were inspired by the concept that businesses would find cost-saving opportunities, and some would even find marketing advantages or benefit from the innovation prompted by a search for solutions to environmental problems in process and/or input changes (in contrast with leaving the process or input materials unexamined, and simply installing control equipment to mitigate pollutant releases).¹³ Congress reinforced earlier work by EPA to instill a preventive strategy in state environmental programs,¹⁴ stating in the 1990 Pollution Prevention Act that “Pollution Prevention is fundamentally different and more desirable than waste management and pollution control.”¹⁵ In 1992 the United Nations convened its conference on Environment and Development, at which participating countries adopted Agenda 21 and related conventions, a declaration by the world community of policies needed for sustainable development. Chapter 30 explicitly recognizes that cleaner production is a route toward improved

manufacturing, and not just necessary for public health and environmental protection.¹⁶

Many companies had joined, and some led, this evolution in policy thinking, and in the mid-1990s pollution prevention concepts started to become arguably mainstream in the corporate world. This was well illustrated by the 1997 publication of *EcoEfficiency*, by the World Business Council for Sustainable Development. The book begins by noting that McKinsey consultants Noah Walley and Bradley Whitehead had written in a 1994 issue of the Harvard Business Review that win–win thinking, (in which environmental and economic aims are met at the same time), is “unrealistic”,¹⁷ but then proceeds to detail story after story of win–win examples and to elucidate the concept of “hidden costs”, which helps explain why managers don’t automatically find the most environmentally efficient solutions to production problems.¹⁸ By 1999 the *Harvard Business Review* had published “A Road Map for Natural Capitalism”, by Paul Hawken and Amory and Hunter Lovins, showing how preventive and whole-system design would result in the very win–win that had been doubted in the *Review*’s pages just five years earlier. These articles paralleled discussions that had been taking place in state and federal environmental agencies, at meetings of the State Roundtable on Pollution Prevention, conferences on “source reduction” and “waste minimization”, and in the pages of *Pollution Prevention Review*, for several years.¹⁹

3. The limited spread of strong pollution prevention mandates

Despite widespread institutional acceptance of pollution prevention concepts, the spread of pollution prevention requirements in the United States has effectively been halted since the early 1990s. By the end of that decade, only 38 states had a statute concerning pollution prevention, only 18 of which had mandatory elements,²⁰ and the Clinton Administration’s attempt to expand the Toxics Release Inventory (TRI) to require chemical-input reporting as performed in Massachusetts and New Jersey (“TRI Phase III”) had been abandoned. Instead, purely voluntary partnerships had proliferated (for example, the EPA’s 33/50 program, Climate Wise, Energy Star, the Environmental Leadership Program, and WasteWi\$e).²¹ In light of the tendency to implement voluntary approaches without

¹¹ Though no company has ever been required to have OTA on-site, and OTA has no inspection authority, its staff have made more than 3600 visits to about 1700 facilities, all by invitation.

¹² There appears to have been at least a twenty percent decline in states with P2 technical assistance programs: less than 40 states now list programs providing P2 assistance in the national directory of p2 programs at P2 Resource Exchange, (P2Rx™), a “consortium of eight regional pollution prevention information centers, funded in part through grants from EPA. These centers all provide pollution prevention information, networking opportunities and other services to States, local governments and technical assistance providers in their region.” <http://www.p2rx.org/programs/>.

¹³ For an example of strong skepticism applied to the notion that regulation can spur innovation, see: Shaw, Stroup, “Do Environmental Regulations Increase Economic Efficiency?”, in *Regulation*, Vol. 23, No. 1, Spring, 2000. One of the companies mentioned as an example is one of OTA’s case studies, the Robbins Company. The article notes that Robbins saved a few hundred thousand dollars a year moving to a closed-loop system, but fails to note that treating water for reuse also improved the quality of water input, reducing product reject rate. Robbins president Robert Chatel told OTA that the greatest benefit of ceasing water discharge was in productivity, a value far outweighing the reduction in water management costs.

¹⁴ For example, in 1989 EPA gave Massachusetts \$821,000 to expand an existing technical assistance source reduction program, provide technical assistance coordinated with a multimedia regulatory inspection program, and provide for outreach to generators and other states. EPA gave Rhode Island \$763,000 to perform in-plant audits, document case studies, establish a library of waste reduction technologies and procedures, and develop training programs and seminars. And EPA gave the New England Waste Management Officials Association (NEWMOA) \$630,000 to establish a regional information clearinghouse, provide state training and industry workshops, and develop options for source reduction for waste streams destined for resource recovery systems: <http://epa.gov/oppt/p2home/pubs/archive/1989.html>.

¹⁵ 42 U.S.C.A. 13101(a) “Findings” (4).

¹⁶ At 30.5, *Basis for Action*: “There is increasing recognition that production, technology and management that use resources inefficiently form residues that are not reused, discharge wastes that have adverse impacts on human health and the environment and manufacture products that when used have further impacts and are difficult to recycle, need to be replaced with technologies, good engineering and management practices and know-how that would minimize waste throughout the product life cycle. The concept of cleaner production implies striving for optimal efficiencies at every stage of the product life cycle. A result would be the improvement of the overall competitiveness of the enterprise. The need for a transition towards cleaner production policies was recognized at the UNIDO-organized Ministerial-level Conference on Ecologically Sustainable Industrial Development, held at Copenhagen in October 1991.” (Italics added).

¹⁷ Noah Walley and Bradley Whitehead, “It’s Not Easy Being Green,” Harvard Business Review, May–June 1994, pp. 46–52.

¹⁸ O’Rourke and Lee state in *Mandatory Planning for Environmental Innovation* (noted above) that “it appears to us that industry consistently fails to implement even the ‘low hanging fruit’ of economically efficient pollution prevention options.”

¹⁹ For example, Massachusetts’s former Department of Environmental Management’s Office of Safe Waste Management hosted four national conferences on Source Reduction of Hazardous Waste, 1984–7. No history of pollution prevention is complete without mention of the publication of *Serious Reduction of Hazardous Waste* by the former Office of Technology Assessment, 1986. <http://www.fas.org/ota/otareports/topic/ghtopics/>.

²⁰ *A Comparison of Voluntary and Mandatory State Pollution Prevention Program Achievements*, Heather Tenney, (Masters Thesis), Civil and Environmental Engineering, Tufts University, May 2000.

²¹ Partnerships in Preventing Pollution, U.S. EPA 100-B-96-001, Spring 1996.

hard requirements it is important to note that production-adjusted reductions of waste averaged 51 percent in states with mandatory programs, as opposed to only 25 percent in those with purely voluntary programs.²² A 2003 paper by a Harvard Kennedy School of Government researcher described the obstacle that seemed to stand in the way of acceptance of strong legal requirements for pollution prevention efforts: “The concept of the government requiring plants to evaluate their production process with an eye toward opportunities to reduce risk, but allowing plants the discretion to adopt only those activities that the plant finds profitable, appears at odds with the commonly held concept that plants act as profit-maximizers. If the plant is profit-maximizing it should always be reviewing its production processes and actively seeking and implementing cost-saving changes. If the regulation does not require plants to do anything that is not in their own best interest, how could government-mandated planning requirements change the outcome?”²³ The paper answered this question by noting that plants may not be optimizing, and then concludes through an analysis of TRI data that pollution prevention planning requirements have “had a measurable positive effect on the environmental performance of manufacturing plants”, including “larger decreases in total pounds of toxic chemicals released” and a greater likeliness of engaging in source reduction activities.

There has been general acceptance of the concepts of pollution prevention, and there are other, related trends, such as increased attention to sustainability, energy efficiency, green chemistry, green buildings, and product stewardship. There is a recent trend toward bans or limitations on individual chemicals in Washington, Maine and other states (such as Bis-Phenol A or brominated flame retardants). There have been new requirements that state and federal agencies implement environmental purchasing programs. And enforcement agencies have widely adopted assistance modes, which can increase effectiveness if the deterrence message is not diluted, but is unlikely to produce the same results as a dedicated assistance provider.²⁴ EPA and state environmental agencies have also adopted explicit pollution prevention policies. But there has not been widespread adoption of strong pollution prevention legislation in the United States, at the state or national level, or expansion of on-site technical assistance programs. (For the purposes of this paper, “strong” pollution prevention programs are those that have mandatory planning of some kind to ensure P2 options are considered, chemical use reporting to ensure public scrutiny of performance and cognizance of risk, and robust assistance and educational programs to combat the tendency to do the minimum to comply). There is an opportunity cost of not having such programs. It is impossible to estimate that cost with any precision. However, the data shows that Massachusetts companies covered by TURA reduced at least half a billion pounds during the first decade of the program.²⁵ Such reduced use must have also led

to reduced releases, spills, exposures and costs across the entire life cycle of the chemical, from extraction and refinement to shipping, storage, processing, use, and post-use disposition. Because of this, and many other indications that most companies were not hurt, but benefited from coverage, the Massachusetts example merits further scrutiny.

4. General indications of success in Massachusetts

In 1997 the state contracted for a study of companies regulated by TURA, and the results were widely touted in the pollution prevention field: total aggregated benefits to companies exceeded total aggregated costs.²⁶ Monetized costs to regulated companies were \$76.6 million, while benefits were \$90.5. It is important to note that capital investments of \$27.1 million were included in the cost category, although no company is required to make such investments under TURA – only to evaluate their options. If these capital investments are removed from the cost category, because they were voluntarily made and are presumed to be good for business, it becomes apparent that *coverage under the act brought benefits to the companies about twice as large as costs*. It is also important to note that the benefits and costs were self-reported by the companies, and did not include quantification of benefits that have recurred over the years since implementation, or benefits that are not easily identified (such as reduced accident or liability risks) or quantified (such as improved relations with regulatory authorities, the public, staff, investors or business partners). A full assessment of the value of the act would focus as well on the many expected benefits to the community and the environment from reduced toxics use, and would consider the value of obtaining such benefits through comparatively efficient means.

A companion study looked closely at what happened to companies required to report and plan under TURA: “As a result of implementing their TUR projects, 67% (235 of 351) of respondent companies claimed they actually saw direct cost savings, for example, on materials use or waste disposal. Improved worker health and safety was the other major benefit of TUR implementation, a total of 66% (230 of 351) of respondents realized some improvements in this area.”²⁷ The report notes that worker health and safety improvements lead to decreased worker sick days or accidents, which improve facility productivity and decrease other potential costs, such as insurance premiums. Nearly half of respondents (158) had reduced regulatory compliance requirements, more than a third (133) indicated that they “improved their environmental image”, and more than a quarter (95) of respondents “realized marketing advantage, such as environmentally friendly products, from TUR project implementation.”

One major point raised by critics²⁸ has been that although the process of carefully tracking chemicals and examining options for reducing use and/or byproduct often leads to design or operational improvements, such benefits decline over time as the available options are implemented, and some have claimed that the planning process (repeated every two years unless an alternative path is allowed) can become a valueless paperwork exercise. Although the program has noted that updating plans need not be as significant a labor as initial planning, some companies have cited the cost of

²² Tenney, page 93.

²³ “Are Management-Based Regulations Effective? Evidence from State Pollution Prevention Programs”, Lori D. Snyder, Regulatory Policy Program, Center for Business and Government, JFK School of government, Harvard University, RPP-2003-21, p. 5.

²⁴ Many companies will be unwilling to ask for assistance from the enforcer, or share information that might put them at risk. Besides being in a better position to establish a working relationship, dedicated technical assistance providers have concentrated expertise that inspectors, focusing on compliance and inspection time tables, may not have the time to develop.

²⁵ *The Effect of Providing Onsite Technical Assistance*, Abstract. “Data reported by companies covered by TURA shows that from 1993 to 2002, chemical input by all companies combined was approximately 500 million pounds less than what was expected. The study showed that for every company covered by TURA requirements that did not improve performance, there were nearly four companies that did improve.”

²⁶ *Benefit–Cost Analysis of the Massachusetts TUR Act*, Methods and Policy Report #15, Abt Associates, Currier et al., 1997. See pp. ES-5.

²⁷ *Survey Evaluation of the Massachusetts TUR Program*, Methods and Policy Report #14, Abt Associates, Keenan, et al., 1997, p. 28, at http://www.turi.org/library/turi_publications/toxics_use_reduction_policy_analysis.

²⁸ The author here refers to personal experience receiving comments from regulated entities while providing training in the requirements of the Toxics Use Reduction Act.

TURP certification as a concern (all TURA plans must be certified by a Toxics Use Reduction Planner (TURP) who must be qualified to certify plans). Although there is an expected value in a continuing responsibility to plan toxics use reduction because it provides assurances that companies will examine new technologies and practices as they become available or affordable, the TURA program decided in 2008 to revisit the question of TURA's impact. The Massachusetts Toxics Use Reduction Institute (TURI) contracted for a new survey of companies covered by the Act, and found that of 196 companies, health and environmental benefits were reported by more than half, just over 40 percent reported financial savings as a result of implementing TUR, a third indicated benefits related to compliance, just under a third indicated they achieved improvements in production efficiency as a result of implementing TUR, and others cited improved product, extension of innovations to facilities outside of Massachusetts, improved worker-management relations, improved community relations, and other benefits.²⁹ Although the results were not as dramatic as the earlier study, TUR plans and the other features of TURA were clearly continuing to provide value to many companies, beyond assurances against an atavistic return to a manufacturing culture that does not sufficiently examine options for reducing environmental impacts and production costs caused by the use of toxic materials.

These surveys paint a picture of an environmental law that has helped many businesses. Environmental regulation has long been justified as a means of imposing costs that might otherwise be external to management decision-making. There is an argument that it is also justifiable because if designed well, it can be good for regulated companies (the Porter Hypothesis).³⁰ The story of TURA illustrates how an environmental regulation very much seems to have been good for business. It represents a new paradigm for regulation that directly stimulates and nurtures the innovation that is the root cause of economic benefit.

5. An environmental manager on the cutting edge

None of these hypotheses, surveys and data analyses, however, tell the story of how the law works on the ground, in real and personal terms. The only way to know that is to understand the actual experience of company officials who have had to deal with the requirements. At the twentieth anniversary symposium on TURA, held on November 18, 2009,³¹ several people who have been in that position shared their experiences. Not everything that they had to say was positive. For example, Stephen Greene, formerly corporate environmental manager for Polaroid, noted that TURA was an "additional cost", because the company was already essentially doing what the law required when it was instituted (in fact, this reporter drew attention at the symposium to the example of Polaroid as one that helped shape the specific requirements of the act). He also noted that having to comply with a state

requirement is far less business-friendly than if the requirement was national or international in scope. However, he told attendees that TURA "forced a thorough look at the production process", and stated that although Digital Equipment Company (DEC), where he worked before Polaroid, was "a good corporate citizen", that in his judgment what TURA required "was not something that DEC would have initiated" on its own, had the law not come about.

Others have noted Polaroid's role as an example that pollution prevention works: that although Polaroid's program began before TURA requirements, the closer scrutiny of chemical use that both promoted stimulated research that led to the elimination of hexavalent chromium, (planned for an oxidation step in the processing of a new dye), and the elimination of the use of mercury that "resulted in a more marketable battery pack as well as a more recyclable product."³² John Warner and Paul Anastas, the co-authors of the influential book *Green Chemistry, Theory and Practice* and often identified as "the fathers" of Green Chemistry, began developing the famous 12 principles of their intelligent and responsible approach to the design of chemical-using products after Warner shared information about innovative work he had done at Polaroid.³³

6. Getting the lead out and the value of planning

Gary Nedelman, Engineering Manager at AlphaGary Corporation in Leominster, MA, a developer and manufacturer of specialty thermoplastic materials, explained how complying with TURA caused AlphaGary to reduce lead in its products, from an average of 0.025 pounds per pound of product in 1999 to 0.001 pounds per pound of product in 2008, with more reductions planned, and its North Carolina facility now lead-free. The benefits to the company have included "satisfying multinational customer requirements", which have included a focus on lead-free items since the adoption of the Restrictions on Hazardous Substances by the European Parliament in 2003,³⁴ as well as "minimizing personal exposure" and the costs of managing toxic byproducts. The reductions were accomplished, he told attendees, by "injecting TUR techniques into the process", notably, the TUR activities of input substitution and process modernization. He described the process of adjusting to an initial imposition of what was experienced as a compliance and cost burden, to "understanding principles", a recognition of the "value of planning" and that "TUR was consistent with company objectives". In time, he said, the company learned to use TURA for the purpose of advancing materials and developing competitive advantage. The focus on carefully measuring materials and product has improved yields and reduced costs, and the company has applied the basic TUR strategies not just at the Massachusetts facility but generally throughout its operations, and not just to

²⁹ *Tracking Pollution Prevention in Massachusetts*, Ken Geiser, 1995, p. 7, <http://www.p2pays.org/ref/23/22682.pdf>.

³⁰ "The Right Chemistry", *American Prospect*, 3/19/2006, http://www.prospect.org/cs/articles?article=the_right_chemistry. "A key intellectual reaction occurred when John Warner, a chemist with Polaroid, met with EPA official Paul Anastas (who happened to be an old friend) to discuss a new innovation that, for once, had government regulators excited rather than worried. Warner had come up with a simpler and less toxic process, based on the use of tiny crystals, to help prevent Polaroid's instant film from deteriorating on the store shelf. Anastas recognized that Warner and Polaroid had accomplished all of the EPA's pollution prevention objectives through chemical design and scientific innovation, rather than through after-the-fact regulatory action."

³¹ Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, *Official Journal L 037*, 13/02/2003 P. 0019–0023. At: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0095:EN:HTML>.

²⁹ *Progress Report on Toxics Use Reduction in Massachusetts, a report to Governor Patrick*, November, 2008. http://www.turi.org/policy/ma_tura_program/tura_report_to_governor_patrick.

³⁰ Developed by Michael E. Porter and Claas van der Linde. See, <http://www.sustainableprosperity.ca/event/porter-hypothesis-20-june-27-28-montreal-qc>, a conference on "The Porter Hypothesis at 20". "On June 28 in Montreal, just prior to the World Congress of Environment and Resource Economists (WCERE), Sustainable Prosperity (SP) and Resources for the Future (RFF) are bringing together leading global scholars in this field for a high-level dialogue to compare research, share insights, and identify future policy research priorities on understanding how environmental regulation might enhance innovation and increase competitiveness." Michael Porter's powerpoint: <http://www.sustainableprosperity.ca/files/PH@20%20Michael%20Porter%20Keynote%20slides.pdf>.

³¹ http://www.turi.org/tura_program_2010/what_s_new_at_tura_1/tura_20th_anniversary_symposium_and_conference/speakers_and_presentations.

covered toxics. It has improved blending operations, eliminated leakages of dust and byproduct, reduced lubrication wastes by reducing the need for lubrication at the source, and realized not just lower waste management costs but minimized worker exposures to fugitive dusts. TURA has enhanced the company's cultivation of a culture of continuous improvement, its relations with regulators, and its business reputation, "contributing to maintaining a competitive position" within the industry.

7. Reducing wastes and creating smarter employees

Raymond Lizotte shared his experience as Director of Environmental Stewardship at American Power Conversion (APC), which makes products for sensitive electronic, network, communications and industrial equipment; and as a TURP for Texas Instruments (TI) and other companies. At all companies with which he has worked, TURA's approach has contributed to competitive advantage, which he defined as "a condition which enables a company or entity to operate in a more efficient or otherwise higher-quality manner than those it competes with, and which results in benefits accruing to that company/entity." At TI's plating shop, where he first dealt with TURA's requirements, careful tracking of materials on a production unit basis, a key component of TURA, led to the identification of ways to reduce spills and "drag-out" (chemicals pulled out of the process by the movement through chemical baths of parts being plated). The company instituted "simple process changes" that saved \$200,000 per year by avoiding the waste of raw materials – these losses had not been recognized before TURA. A consequence of this improvement was another \$50,000 savings in reduced compliance costs, for what had previously been spilled and dragged out had required the addition of wastewater treatment chemicals to prevent their discharge. Wastes from using cyanide, silver, sodium hydroxide and acids were calculated per unit of product produced, and were each reduced by one-third to one-half per unit of product.³⁵ (TURA requires the tracking of product as well as chemical use and waste (byproduct), so that progress can be understood in relation to changes in production).

Lizotte noted that "TUR provides practitioners with skills that increase their value," which is a personal value for them, and that the value provided to the company includes the fact that these skills are integrated into company operations at lower cost than outsourcing to a third party with the requisite skills. He noted that the value for the state, besides reductions in toxics in the environment, also includes the fact that TURA has created "A generation of environmental practitioners who understand the relationship between environmental and business performance and have the tools to affect it."

8. Reducing costs and gaining marketing advantage

Don Alger, Senior Environmental Engineer of Allegro Microsystems of Worcester, MA, a maker of "high performance power and Hall-effect sensor integrated circuits", described how savings that exceeded \$1 million per year were achieved as a result of the company's having to comply with TURA. One major step was converting to a water-based photographic development system, which eliminated a hazardous waste costly to dispose, and the need to use isopropyl alcohol for rinsing. Some wet etching processes were changed over to dry etch, eliminating the use of acids. Components

that had been washed in baths were now washed with spray systems, reducing the volume of chemical use, and other cleaning operations were examined and converted to high efficiency. An ion-exchange system used for producing de-ionized water was discarded in favor of a more efficient reverse-osmosis system, spent process chemicals found secondary use in wastewater treatment neutralization, and temperature and other parameters for various operations were optimized.

Allegro took advantage of the option to do Resource Conservation planning after TURA was amended, and estimates that it has had annual savings of \$1.5 million per year (some of them precede their inclusion in TURA planning). These include reducing water use, changing lighting, installing variable frequency drives on motors and occupancy sensors throughout the building, reclaiming production waste, turning off equipment when not needed, discontinuing an ultrafiltration system, and using a heat exchanger so that wastewater could be used to preheat incoming water.

A major result of Allegro's initiatives has been its ability to easily obtain registration to the ISO-14001 standard for environmental management, a certification that its customers strongly encouraged the company to obtain. Alger commented: "If we did not have an active TUR and resource conservation program, it would have been much more difficult to develop and achieve goals that are related to our significant aspects and environmental policy. If you do your homework, you can effectively identify projects that help the environment, have a reasonable payback, and help your company to be more competitive."

9. Concluding remarks

TURA seems to have met its statutory purpose of benefiting both the environment and the regulated community. The preamble of the law cites the legislature's intent to "sustain, safeguard and promote the competitive advantage of Massachusetts businesses, large and small, while advancing innovation in toxics use reduction and management". Four other cited purposes of the law are explicitly environmental, such as "to promote reductions in the production and use of toxic and hazardous substances within the Commonwealth."³⁶ In this respect TURA has certainly succeeded, and this significant value is not captured by analyses of benefits to companies. There are substantial benefits to many recipients, including nonhuman ones and future generations, from the fact that companies covered since 1990 have reduced toxic chemical use by 40 percent, toxic byproducts by 71 percent, toxics shipped in product by 41 percent, on-site releases of toxics to the environment by 91 percent, and transfers of toxics off-site for further waste management by 60 percent. (Because only 55 percent of chemicals reported are from companies covered since 1990, it is important to look at a more recent population as well: companies covered since 2000, representing 90 percent of reported chemicals, have reduced toxic chemical use by 14%, toxic byproducts by 34%, toxics shipped in product by 14%, on-site releases of toxics to the environment by 44%, and transfers of toxics off-site for further waste management by 39%).³⁷ Although progress in the second decade of TURA is not as marked as in the first, in both periods TURA has reduced toxics use significantly, leading to many benefits for those who are actually or potentially affected by toxic exposures and contamination.

Concerning the other purposes of the law, to promote economic efficiency, there is no question that the Toxics Use Reduction Act gave companies homework to do. It made them count up their

³⁵ For example, if a company made 100 widgets and had 50 pounds of cyanide waste before TURA, and a few years later made 100 widgets and had only 25 pounds of cyanide waste, it would have reduced its waste per unit of product by one-half.

³⁶ Chapter 265, Acts and Resolves of Massachusetts, 1989.

³⁷ 2007 Toxics Use Reduction Information Release, MassDEP, <http://www.mass.gov/dep/toxics/priorities/07relfin.pdf>.

chemicals before putting them into the process, and even count pounds of chemicals going into and coming out of production units, as well as on a facility-basis. It made them define a unit of product and then count how many units were produced in a year. It made them calculate how much of what they used became nonproduct output – waste, and if they weren't already reporting on releases under the federal Toxics Release Inventory, it made them do that as well. It made them solicit ideas from employees and come up with ideas about what might be changed to reduce chemical input and/or waste, and it made them assess the full cost of the chemical-using operations they were conducting, so that the options they identified would be accurately compared. And it made them report the pounds to the public, and hire or train a TURP to certify that they had done an adequate job of assessing their options. This is a lot of work to do, and if you think you're already doing everything you can do, it can seem like an enormous waste of time.

In 1993, Frances Laden and George Gray wrote that “We find that representatives of industry are, in general, opposed to TUR laws. There are several points of opposition. First and foremost, opponents say that the aspects of TUR that make sense are things that they have been doing all along.”³⁸ The authors recommended that TURA “must be carefully examined if it is to deliver on its promise of decreased risk to workers, consumers and the environment,” and that “Much greater experience with pollution prevention will be necessary” before we can know the true value of the approach. It is reasonable to question whether the stories related above are outliers, or illustrations of a general trend. The surveys cited earlier indicate that at the least, they are not unusual. Further pertinent information is contained in OTA's 2006 analysis of TURA data, which showed that the ratio of companies covered by TURA able to reduce input of toxic chemicals (proportionate to achieving the same level of production as before) was 3.75 to one.³⁹

Not one pound of this use reduction was required. All that the law requires is that companies track their use, and consider their options for reduction. Perhaps the minority of companies that did not achieve toxics use reduction had already done everything they could do, or perhaps they did not apply its requirements effectively. For Polaroid, the act seems not to have had as much benefit as it did for the other companies that were not as environmentally advanced at that time. But Polaroid was an exemplar: the TURA program used its Environmental Accounting and Reporting (“EARS”) system⁴⁰ for tracking materials use and releases as a model for teaching other companies and illustrating the link between good environmental practices and Quality Management. Stephen Greene noted that the other company where he worked, Digital Equipment Company, was also a “good corporate citizen”. In 1992 DEC had gained fame in the pollution prevention field for developing a “microdroplet” process for cleaning, reducing the use of chlorofluorocarbons for cleaning circuit boards from almost one million pounds in 1988 to less than 85,000 pounds in 1992.⁴¹ Yet Greene notes that even DEC would not, on its own, have initiated the “thorough look” at the production process that TURA requires.

Gary Nedelman's experience tells us that over time his company learned to use this activity for the purpose of

modernizing and competitive advantage, after the principles were understood and value of the planning became clear. Careful measurement has improved yields and now the company applies the TURA approach at all of its facilities, including those outside of Massachusetts, and to materials not covered by the law. This goes against the idea that companies do not need this sort of instruction, and that the only reason to do it is to comply with a rule. Over the years, OTA has heard from several companies that they have instituted TURA-like practices to their non-Massachusetts facilities.

Ray Lizotte has much the same to say about TURA's impacts on two companies where he worked, one of which, (Texas Instruments), was also an environmental leader when TURA began, well-known for having built a state-of-the art water treatment system in Southeast Massachusetts. He clearly states that TURA's process of scrutinizing materials use led to awareness of substantial chemical losses that had not been recognized by this world-class firm. He notes also that the ancillary outcome of building skills is considerable, and that Massachusetts benefits from having a “generation” of staff who “understand the relationship between environmental and business performance”. It is this relationship, this understanding, that TURA seeks.

For Don Alger's Allegro, the various projects that TURA prompted have had significant value, first in saving more than \$1 million in toxics use reduction, and then in helping save a comparable amount through resource conservation. The value of the ISO-14001 registration is not quantified, but is related to the ability to do business internationally. Alger draws a direct connection to TURA planning.

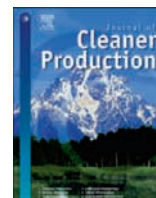
None of these companies were laggards. They were all either industry leaders or well-respected. Yet when TURA came along, they accomplished the basic TUR goal of toxics input reduction by means other than reducing production levels. The planning and tracking and reporting led them to discover options that they then voluntarily implemented. Laden and Gray rightly stated long ago that it is important to subject TURA to close examination, so that we can understand whether or not the Toxics Use Reduction Act is forcing companies to go through motions, wasting time, or whether it really is a tool for reducing chemical risks to people and the environment, and saving companies money. The data from several studies, reviewed above, shows that the act has reduced chemicals use, releases, wastes, and costs. It also seems that this happened through greater efficiency and substitutions, not through plant shutdowns. The stories noted above are just a few examples, but they show us some very good companies had something to learn when they were required to undertake a careful accounting of their use of toxic materials, and their improvement options. The Act did not require that any of these companies invest a single dollar in any chemical substitutions or process changes, but after doing the plan, and sometimes after receiving assistance, these companies chose to do so. Not all companies will respond that way. But if some will, then surely wider application of the prevention strategies used by TURA deserves active consideration.

³⁸ “Toxics Use Reduction: Pro and Con”, at <http://www.piercelaw.edu/risk/vol4/summer/laden&gr.htm>.

³⁹ *The Effect of Providing On-site Technical Assistance*, p. 30.

⁴⁰ For a description of EARS and its benefits, see Nash, Nutt, Maxwell & Ehrenfeld, “Polaroid's environmental accounting and reporting system: Benefits and limitations of a TQEM measurement tool”, *Environmental Quality Management*, Volume 2, Issue 1, Pages 3–15, 1992.

⁴¹ Ohio EPA Pollution Prevention Fact Sheet Number 7, October 1992, *Substitutes for Ozone Layer-Depleting Solvents in the Printed Circuit Board Industry* <http://www.p2pays.org/ref/02/01758.pdf>.



Program assessment at the 20 year mark: experiences of Massachusetts companies and communities with the Toxics Use Reduction Act (TURA) program

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ABSTRACT

The Toxics Use Reduction Act (TURA) model is widely cited as an effective blend of mandatory and voluntary components, and is considered a model nation-wide and internationally. There is ample documentation of the reductions in toxic chemical use achieved by Massachusetts facilities under TURA. The present study was designed to gather other information about the experience of these facilities. Through an online survey and telephone interviews, the study investigated how these facilities are achieving toxics use reduction, how TURA affects internal company dynamics, what benefits and difficulties facilities experience, and how their experiences in the program have changed over time. Survey results indicate that the benefits experienced most frequently by facilities subject to TURA requirements are increased management attention to environmental practices; improved worker health and safety; and financial savings. Most frequently cited obstacles to TUR implementation are technical feasibility problems; financial costs; concerns about product quality; and customer requirements. Survey results also indicate that the TUR planning process is most useful in the first and second planning cycles, although most respondents indicated that they sometimes identify useful TUR options in subsequent planning cycles as well. Over all, the results indicate that facilities are continuing to experience significant benefits from the TURA program, while they also continue to face some challenges. These results provide a snapshot of the experience of Massachusetts facilities 20 years since the inception of the TURA program. They also provide baseline information that will be useful for later evaluations of the effects of statutory changes to TURA adopted in 2006 and implemented in subsequent years. The study also included a preliminary assessment of the experience of Massachusetts municipal agencies, community organizations, small business associations and others that receive assistance from the TURA program.

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1. Introduction

Enacted in 1989, the Massachusetts Toxics Use Reduction Act (TURA) has been in effect for two decades. TURA regulates industrial facilities that use large quantities of chemicals listed on the TURA list of Toxic or Hazardous Substances (MGL c. 211).

Facilities subject to TURA are required to report annually to the state on their use of toxic chemicals; pay an annual fee; and carry out Toxics Use Reduction (TUR) planning every two years. TUR plans must be certified by a TUR Planner trained and certified by the state. Amendments to TURA adopted in 2006 created additional flexibility in the planning process, and provided new options for the program to focus on the substances of highest concern, among other changes. TURA program services include training, grant

programs, technical assistance, demonstration sites, and other activities. These services are provided by three implementing agencies: the Massachusetts Department of Environmental Protection (MassDEP); the Toxics Use Reduction Institute (TURI); and the Office of Technical Assistance and Technology (OTA). The implementing agencies work in concert with an Administrative Council, representing six state agencies; an Advisory Committee, a stakeholder group; and a Science Advisory Board.

The TURA model is widely cited as an effective blend of mandatory and voluntary components, and is considered a model nation-wide and internationally. Recently, it has served directly as a model for initiatives to promote the adoption of safer alternatives to toxic chemicals in the states of New York, California, and Connecticut, and in the Canadian province of Ontario (Meer et al., 2003; Wilson, 2006; Wilson et al., 2008; State of California, 2008; CalEPA, 2008; State of Connecticut, 2010; Ontario Ministry of the Environment, 2008). In this context, it is important to evaluate

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the program's activities and to identify lessons that may be applicable in other jurisdictions.

The effectiveness of the TURA program in reducing the use of toxic chemicals is well documented. The TURA program issues annual reports providing detailed information on toxics use and reductions in the state. These reports are made possible by Massachusetts' unique, publicly searchable database of toxics use information submitted by companies to the state each year. Over the period 1990 to 2005, facilities in a "1990 Core Group" (all sectors and chemicals that were subject to TURA program requirements over the full sixteen-year period) reduced their use of toxic chemicals by 40% and their on-site releases by 91%. Over the period 2000 to 2008, facilities in a "2000 Core Group" reduced toxic chemical use by 20% and on-site releases by 52%¹ (MassDEP 2008, 2010).

The goal of the present study was to gather information on aspects of the program that are not reflected in the state's annual reports on toxics data. The study was designed to generate information on the experiences of Massachusetts companies and communities, in order to identify areas of opportunity and to provide information for other states undertaking similar programs. It was also designed to provide baseline information on positive and negative aspects of the program prior to statutory changes to TURA that were adopted in 2006 and are being implemented in subsequent years.

Through online survey questions and telephone interviews, the study investigated how facilities subject to TURA requirements are achieving toxics use reduction; how TURA program requirements and services affect internal company dynamics; what benefits and challenges facilities experience; and how their experiences in the program have changed over time. The study also included a preliminary assessment of the experience of Massachusetts municipal agencies, community organizations, small business associations and others that receive assistance from the program under its mandate to provide information and assistance to Massachusetts communities.

This article begins with a brief overview of existing literature on the effectiveness of pollution programs in general, and on the experience of the TURA program in particular. It then presents the findings of the survey and interviews that were conducted for this study; explores some of the lessons that may be drawn from these results; and suggests possible directions for future research.

1.1. Literature review

1.1.1. Evaluation of pollution prevention programs

A variety of studies have assessed the effectiveness of government pollution prevention programs. Studies have examined state and federal programs within the US, as well as a variety of programs in other parts of the world. These studies have examined the effectiveness of pollution prevention and cleaner production programs in reducing toxic emissions. They have also assessed the extent to which pollution prevention innovations have spread from one facility to another; the ability of companies to sustain pollution prevention innovations after an assistance program has ended; the ability of demonstration sites to motivate broader change; and the organizational impacts of demonstration projects both within and

outside the demonstration facilities, among other questions (Vidovic and Khanna, 2007; Sarmiento, 2004; Van Berkel, 2004). A 2003 study of state pollution prevention programs in the US, conducted by the US Environmental Protection Agency and the National Pollution Prevention Roundtable, estimated the total amount of pollution prevented by these programs as well as total financial savings resulting from pollution prevention efforts (Spektor and Roy, 2003).

A special issue of the *Journal of Cleaner Production* in 2008 considered opportunities and challenges facing pollution prevention programs in the US. The editors of the issue, in their overview, identify key challenges facing pollution prevention programs going forward. These include diminishing public sector support; competing priorities in the private sector; and challenges in documenting progress (Miller et al., 2008).

1.1.2. Studies of the TURA program

Studies of the TURA program in particular have examined the program's effectiveness in reducing toxics and in addressing worker health and safety; the value of the publicly available TURA data; the program's role in reducing use of specific categories of chemicals, such as carcinogens and asthmagens; and lessons that can be derived from the TURA program for other jurisdictions, among other themes.

A variety of scholarly and advocacy publications related to reforming chemicals policy at the state, national, or international level make reference to the TURA program as a useful model for protecting public health while promoting economic development. For example, physician Samuel Epstein discusses the TURA program as part of a broader exploration of legislative options for reversing the cancer epidemic (Epstein, 2000); and a 2007 publication on "solutions to cancer" showcases the TURA program as a positive example of how policy changes can reduce public exposure to carcinogens (Armstrong et al., 2007).

A program evaluation sponsored by the TURA program and completed in 1997 found that the TURA program had been effective in reducing Massachusetts facilities' use of toxic substances while providing opportunities for facilities to achieve financial benefits. It also identified areas for improvement (see Section 4.9, below) (Becker and Geiser, 1997).

A 2006 study by OTA of the effectiveness of OTA's on-site technical assistance visits found that visited companies reduced their toxics use by an average of 9% more after being visited, than before (Reibstein, 2008).

Roelofs et al. (2000) reviewed published case studies of toxics use reduction by Massachusetts companies, and interviewed TURA program staff, in order to better understand the relationship between TURA program activities and the broader goal of improving worker health and safety. The authors found that "in almost 50 percent of the cases analyzed, improved worker health and safety was cited as a benefit of the toxic use reduction projects." However, they found that worker health and safety was usually not an explicit focus of the TUR efforts, creating the possibility that new hazards could be created or opportunities to protect workers could be missed. They recommended increased efforts to integrate worker protection with pollution prevention efforts.

Campbell and Levenstein (2001) draw upon interviews with Toxics Use Reduction Planners to evaluate the successes and limitations of the TURA program in effecting change within facilities. They identify types of planners, ranging from "active planners" who act as leaders within facilities and effect significant change, to "resistant planners" who do not promote true toxics use reduction. They argue that the successes of the TURA program have been limited by significant variation among companies in the amount of effort devoted to TUR planning, and by a lack of clear quality standards specified by the state for TUR plans.

¹ These figures are production-adjusted. Production-adjusted figures reflect changes in the amount of toxic chemicals used per unit of product. In the period 1990 to 2005, total manufacturing production in Massachusetts increased. The raw (non production-adjusted) toxics use reduction figures for that period, are a 35% reduction in toxic chemical use and a 90% reduction in on-site releases. In the period 2000 to 2008, total manufacturing production in Massachusetts declined. The raw toxics use reduction figures for that period, are a 37% reduction in use and a 62% reduction in on-site releases.

Advocacy organizations have used the TURA data as a way to evaluate the program's performance. For example, in 2001 the Massachusetts Public Interest Research Group (MassPIRG) analyzed the TURA data and argued that insufficient progress was being made in reducing the most highly toxic chemicals, particularly persistent, bioaccumulative toxic (PBT) chemicals. In the same year the Environmental League of Massachusetts analyzed trends in use of carcinogens and found that companies were making progress in reducing use of these chemicals (Champness, 2001).

O'Rourke and Lee (2004) note that TURA embodies several principles that have been proposed as best practice for environmental regulation, including focusing on performance outcomes, using mandatory planning mechanisms, and supporting innovation through technical assistance and peer mentoring. They also identify areas in which the TURA program could be strengthened, including increasing its work with small facilities. They suggest that in the absence of public pressure for more progress, the TURA program "will likely face a plateau of effectiveness." Such a plateau could result when all firms that are willing to innovate have done so, and less-motivated firms simply continue to submit TUR plans without acting on them. They offer several suggestions for ways to move beyond a possible plateau, including empowering the public to put pressure on firms that have not made progress; using TURA data to compare firms with one another and identify leaders and laggards; and using information generated under TURA to inform development of new regulations.

1.1.3. TURA as a model for other jurisdictions

State governments and other jurisdictions have studied the TURA program in detail as part of efforts to replicate the program's successes.

In 2006, University of California researchers wrote a report urging a reform of chemicals policy in California (Wilson, 2006). The report argues that deficiencies in federal regulation are a liability for the state and evaluates several state chemicals policies, including TURA, as potential models for California. The authors note that:

"TURA is unique among U.S. environmental statutes in that it requires firms to report their use of hazardous chemicals rather than their releases of chemical pollutants, and it requires firms to evaluate their operations and plan for process improvements. It is the only statute that includes an institute – to provide ongoing technical assistance, training, and research for Massachusetts businesses in toxics use reduction strategies. Together, these approaches have motivated continual innovation by firms in strategies to reduce their use of hazardous chemicals. ... We believe that California can learn from (and build on) the 16 years of experience by government and industry in Massachusetts under TURA." (Wilson, 2006)

The report also notes limitations of TURA. TURA program requirements do not apply to smaller firms (those that do not meet the relevant chemical reporting thresholds, or have fewer than ten employees). Collectively, firms not captured under TURA could use significant amounts of toxic chemicals. In addition, companies are not required to implement TUR plans, and the state has only a limited ability to motivate implementation. TURA also does not require companies to evaluate the toxicity of, or disclose information about, chemicals in products. The report suggests that California expand and improve upon the TURA model in a number of ways, including establishing a system for evaluating all chemicals, rather than relying on a pre-existing list of toxic chemicals (Wilson, 2006). As of filing year 2008, the TURA list of Toxic or Hazardous Substances included 1422 substances, of which 147 were reported (MassDEP 2010).

Subsequently, the government of California sponsored a series of reports and convened a high-level working group to consider

options for chemicals policy reform in the state. The reports featured detailed consideration of the TURA program as a key model for new initiatives in California (State of California, 2008; CalEPA, 2008; Wilson et al., 2008).

The government of the Canadian province of Ontario has studied the TURA program in detail as part of its effort to replicate the TURA model, including extensive consultation between Ontario government employees and TURA program staff. Among other activities, the Ontario government produced a detailed report on the Massachusetts model (Ontario Ministry of the Environment, 2008).

2. Methods

In 2008, TURI contracted with Abt Associates Inc. to conduct an online survey and telephone interviews with TURA filers and planners. In addition, TURI conducted a preliminary online survey of individuals that have worked with TURI's community program, and contracted with a consultant to conduct telephone interviews with recent recipients of TURI community grants.

2.1. Online survey and telephone interviews with TURA filers

TURA filers are companies that are subject to TURA requirements (reporting, planning, and fee). Companies are subject to TURA requirements if they have ten or more employees,² use more than the TURA threshold amount of one or more listed toxic chemicals, and are in TURA covered sectors. Abt Associates distributed an online survey to all 561 facilities that filed a toxics use report under TURA in 2006.³ Of these facilities, 196 responded to the survey (35%).⁴

The survey was also distributed to all Toxics Use Reduction Planners (TUR Planners) who were registered with the program as of January 2008. There are two types of TUR Planners: Limited Practice Planners, who are certified to work only with one facility; and General Practice Planners, who are certified to work with multiple facilities. Respondents who identified themselves as General Practice Planners had the option to answer a separate set of questions based on the range of their professional experience, without reference to a specific facility. Thirty-six General Practice Planners answered these questions.

Abt Associates conducted in-depth telephone interviews with a subset of 18 of the survey respondents. These interviews provided additional detail to supplement the information gathered through the online survey. Both the survey and telephone interview results were anonymous (identity known to Abt Associates, but not to TURI).

2.2. Online survey and telephone interviews with community organizations

To supplement the survey of TURA filers and planners conducted by Abt Associates, TURI staff conducted a brief online survey for individuals and organizations that have worked with TURI's community outreach program, as well as past recipients of TURI community grants. The survey posed questions about benefits

² The ten-employee threshold can be eliminated in some cases, but this provision has not been implemented to date.

³ The full set of survey questions is available from the author upon request.

⁴ The survey was also distributed to facilities that last filed under TURA in earlier years, going back to 2000. Only nine such facilities responded, so their responses cannot be considered representative of the larger population of facilities that filed in earlier years. These facilities' responses are not included in any of the quantitative results, but this article does reflect some of these facilities' responses to the survey's open-ended questions.

Table 1
Number of employees.

Number of employees	Total survey population	Respondents
>10 and <50	38%	34%
>50 and <100	23%	21%
>100 and <500	32%	31%
>500	7%	8%
Not specified		6%

gained from the TURA program, challenges in implementing toxics use reduction projects, and suggestions about how the TURA program can serve communities most effectively.

The online survey was sent to 350 individuals. Responses were received from 62 individuals. Of these, fourteen responded on behalf of an organization that had received a grant from TURI at some point in the period 1998–2007, while the others provided information on other aspects of TURI's community outreach activities.

TURI also contracted with a consultant to conduct interviews with representatives of organizations that had received a TURI community grant in fiscal year 2006, 2007, or 2008. The interviews included questions about the organization's experience working with TURI, the role of the TURI grant in the development of the organization's agenda and activities, the organization's ability to raise funds prior to and after receipt of a TURI grant, and media recognition of the organization's work. These interviews were conducted with fourteen grant recipients (not necessarily overlapping with the fourteen grant recipients who responded anonymously to the online survey, and who may have received a grant in an earlier year).

3. Results

3.1. TURA filers and planners: Profile of respondents

3.1.1. Number of employees

Just over a third (34%) of respondents were from facilities with 10–50 employees; 21% were from facilities with 50–100 employees; 31% from facilities with 100–500 employees; and 8% from facilities with more than 500 employees. These percentages are similar to those found in the full population of 561 facilities that filed under TURA in 2006, as shown in Table 1.

3.1.2. Years of reporting under TURA

Just over a third of respondents (34%) had been reporting under TURA for five years or less; 18% had been reporting under TURA for six to ten years; and 45% had been reporting for 11–16 years. Again, this breakdown is similar to that of the total population of facilities that filed under TURA in 2006, as shown in Table 2.

3.1.3. Industrial sectors represented

Table 3 compares the industrial sectors represented in the total filing population in 2006 with the breakdown of sectors represented by the survey respondents. The largest percentage of filers in 2006 (17%) were in the chemical manufacturing sector, followed by the fabricated metal manufacturing and computer and electronic manufacturing sectors. It is worth noting that the chemical manufacturing sector accounts for the largest volume of chemical use (64% of total chemical use by volume in 2006) (MassDEP, 2009a).

For most sectors, the percentage of survey respondents was similar to the percentage in the total survey population, with some exceptions. The computer and electronic product manufacturing sector was underrepresented, the plastics and rubber manufacturing

Table 2
Number of years reporting under TURA.

Number of employees	Total survey population	Respondents
1–5 years	27%	34%
6–10 years	16%	18%
11–16 years	50%	45%
Not specified ^a	7%	3%

^a Number of years in the TURA program is not specified for some facilities due to changes in company name or other identifying information.

sector was slightly overrepresented, and facilities classified as “other” were overrepresented in the respondent population.

3.2. How facilities are reducing toxics

The TURA data make it possible to determine the rate at which Massachusetts facilities are reducing their use of toxic chemicals. The survey allowed respondents to augment this information by providing detailed information on how facilities are achieving these reductions. This section presents information provided by respondents on their use of individual TUR techniques, and on focus areas that emerged from respondents' answers to open-ended questions.

3.2.1. TUR techniques

TURA defines six toxics use reduction techniques: improved operations and maintenance; input substitution; recycling, reuse, or extended use of toxics; product reformulation; production unit modernization; and production unit redesign or modification (MGL c. 211). The quantitative portion of the survey asked respondents which of these techniques their facility employed frequently. In addition, respondents had the opportunity to provide open-ended responses describing their toxics use reduction efforts in more detail.

Table 3
Industrial sectors represented.

Sector	Total survey population ^a – percentage (of 561)	Survey respondents – percentage (of 196)
Chemical manufacturing	17%	15%
Fabricated metal product manufacturing	12%	14%
Computer & electronic product manufacturing	12%	3%
Nonmetallic mineral product manufacturing	7%	5%
Paper manufacturing	6%	5%
Utilities	5%	6%
Primary metal manufacturing	4%	2%
Textile mills	4%	4%
Food manufacturing	4%	2%
Plastic & rubber products manufacturing	4%	7%
Miscellaneous manufacturing	3%	4%
Electrical equipment	3%	3%
Personal and laundry services	2%	1%
Petroleum & coal products manufacturing	2%	1%
Transportation equipment manufacturing	2%	1%
Merchant wholesalers, nondurable goods	2%	3%
Other	9%	26%

^a Source: Massachusetts Department of Environmental Protection, 2006 Toxics Use Reduction Information Release (February 2009), p. 20. Available at: <http://www.mass.gov/dep/toxics/priorities/06relfin.pdf>

Table 4
Toxics Use Reduction techniques employed.

TUR Technique	Percentage (of 196 respondents)	Examples ^a
Improved operation & maintenance	63%	Installation of a temperature-controlled storage room to extend the shelf life of raw materials.
Input substitution	46%	Replacement of all uses of n-hexane with safer substances. "It took a long time to find and approve all the new formulations, but the replacement is now complete." Facility was able to stop reporting under TURA as a result.
Recycling, reuse, or extended use of toxics	46%	Implementation of a zero-discharge nickel/chrome recycling system.
Product reformulation	34%	Reformulation initiatives to (a) reduce phenol in resins from 17% to 6%, and (b) reduce use of formaldehyde. As a result, the facility dropped below the TURA reporting threshold for formaldehyde.
Production unit modernization	29%	Creation of "a new vapor etch machine that cut chemical use by 80 percent."
Production unit redesign or modification	28%	Moved parts washing from manual, solvent-based to mechanized, aqueous-based process.
Don't know	7%	

^a Examples are drawn from open-ended responses.

The largest number of respondents (63%) indicated that they have made use of improved operations and maintenance. The next most commonly selected techniques (each selected by 46% of respondents) were input substitution and recycling, reuse or extended use of toxics. Product reformulation, production unit modernization, and production unit redesign or modification were selected by 34%, 29%, and 28% of respondents respectively. These results indicate that facilities are making use of all six of the techniques, although some are used more frequently than others. Table 4 shows the frequency with which each technique is being used, along with an example of each technique as reported in open-ended responses.

Several additional themes emerged in the open-ended responses. Respondents provided detailed information on facilities' work to reduce the use of toxic solvents; efforts to reduce or eliminate the use of lead and other toxic substances targeted by the European Union's Restriction of Hazardous Substances (RoHS); integration between TUR activities and other management systems; and conservation of energy and water, among other themes.

3.2.2. Reducing use of solvents

Several respondents provided examples related to solvent use in cleaning applications. For example, two facilities that have been in the program since its inception have implemented new TUR options in recent years to reduce solvent use. One eliminated its use of methylene chloride even though its use was already below TURA reporting thresholds; the other reduced solvent use by purchasing a closed-loop vapor degreasing system. Table 5 shows examples of reduction or elimination of solvents in cleaning.

Others described efforts to reduce or eliminate solvent use in formulations. For example, one facility adopted a high volume, low pressure (HVLP) spray system, along with low hazardous air pollutant (HAP) coatings. Another respondent explained that the facility develops aqueous coatings instead of solvent-based coatings wherever possible. One barrier is that "many customers have a specific coating already formulated... which may prevent this from happening."

Table 5
Reduction or elimination of toxic solvents in cleaning applications: selected examples.

Sector	Years in TURA	Approach to reducing solvent use
Electronic & electrical equipment & components	5	<i>Elimination of a cleaning step:</i> Facility eliminated the washing of circuit boards, thus eliminating the use of solvents.
Electrical & electronic equipment & components	8	<i>Process change:</i> Facility switched from parts washing using a manual, solvent-based system to a mechanized, water-based process.
Fabricated metal products	8	<i>Process change:</i> Facility eliminated vapor degreasing entirely.
Fabricated metal products	16	<i>Equipment upgrade:</i> A facility that has been in the TURA program since 1990 purchased new closed-loop vapor degreasers in 2001. The purchase allowed the facility to reduce its consumption of trichloroethylene from more than 10 tons to less than 1 ton per year.
Fabricated metal products	16	<i>Reduction of a substance used below TURA threshold:</i> Facility replaced methylene chloride with a safer cleaning chemical. The respondent noted that this reduction was not reflected in the facility's annual reporting because methylene chloride use was already below reportable levels.

In some cases, reformulation requires coordination up and down the supply chain. For example, a facility wishing to reduce its use of a solvent in a purchased product may need to communicate with upstream suppliers in order to obtain a reformulated product. In other cases, a formulator may need to communicate with customers downstream in order to ensure that a reformulated product meets their specifications.

3.2.3. Reduction in lead use

A number of respondents noted that they have used TUR techniques to reduce their use of lead and other hazardous substances in order to comply with the European Union's Restriction of Hazardous Substances (RoHS).

For example, a facility that manufactures audio and video equipment began a lead reduction program in 2001. The effort was motivated by the RoHS requirements, and the facility used TUR planning as a tool to achieve this goal. Among other changes, the facility purchased new wave soldering equipment to replace an older system that relied on lead. The facility planned to eliminate lead-containing products at the end of product life cycles (usually about five years). The respondent commented that an advantage of TURA is that it encourages businesses to make environmental improvements according to their own business plan and schedule.

Facilities whose products are exempt from RoHS or are not sold in the European Union also described their efforts to reduce the use of lead and other hazardous substances. For example, one facility purchased a more efficient solder machine. This change enabled the facility to reduce lead use steadily from nearly 400 pounds in 2003 to just 30 pounds in 2007.

3.2.4. Integration of TUR activities with other management systems

Some respondents emphasized the relationship between their TUR activities and activities under other management systems such as an Environmental Management System (EMS) or Lean Six Sigma.

One respondent explained, “This facility employs Lean Six Sigma techniques in an attempt to continually improve our process safety, quality, energy efficiency, reduced waste generation and to limit the use, handling and exposure to toxic chemicals. We use the TURA process to feed potential projects into this existing process. Several projects are completed annually that reduce chemical usage, reduce chemical exposure, reduce waste generation, improve product quality, improve energy efficiency or improve the overall safety of the facility. Generally the barriers faced in the implementation of these projects are minimal due to the fact that the Lean Six Sigma process and Continuous Improvement is supported at the highest levels within the organization.”

3.2.5. Energy and water conservation

The toxics use reduction planning process can also be used to identify opportunities for conservation of other resources, such as energy and water. A number of respondents described ways in which facilities have been using the TUR planning process to generate options for conserving water and energy.

For example, a facility that has been in the TURA program since its inception installed a steam generator in 2006 in order to reduce natural gas use. This project was included in the facility’s 2006 TUR Plan, and the respondent pointed to it as “feeding into our system from the TURA process.”

Another facility that has been in the TURA program since its inception, and has eliminated or significantly reduced several TURA listed substances, is also working now to reduce its use of water. The facility uses 140 million gallons of cooling water annually. The facility has hired a fluid management contractor to examine options for reducing toxics and cutting costs in general. Any savings achieved through water use reductions are divided with the contractor.

One respondent noted, “One of the primary benefits of being involved with TURA Program has been using the planning tools to achieve other goals outside the program. We have conserved energy, water, and reduced the volume of solid waste generated by our facilities. We have saved money and resources while operating in a positive environmental manner.”

3.2.6. Capital investments

The survey asked respondents whether their facility had made capital expenditures as a result of implementing TUR projects in the period 2000–2006. Capital investments may include investments in equipment, buildings, or other fixed assets.

Of 196 respondents, 77 (39%) indicated that their facility had made one or more TUR-related capital expenditure. These 77 respondents provided detailed information on a total of 125 capital expenditures.

The largest number of these investments was for production equipment. In this category, respondents listed a wide range of examples. These included: purchase or modification of mixing tanks, chemical bath tanks, and acid tanks; replacement of mixer equipment; modifications such as enclosing a mixer or adding a furnace exit curtain; installation of a high volume, low pressure (HVLP) spray system; installation of diameter control equipment; purchase of a new boiler or other new equipment; purchase of a pointing machine; adoption of a reverse osmosis skid system for water purification; and adoption of closed-loop vacuum vapor degreasers. Other capital expenditures selected by a number of respondents were for facility modification; emission control; instruments and controls; and ancillary process equipment (See Table 6).

Most of the capital investments (74%) were under \$100,000. A third of them were under \$10,000. This cost information may be useful in identifying areas in which grants or loans could help small facilities to achieve toxics use reduction.

Table 6
Capital expenditures.

Type of Expenditure	Responses	Percentage (of 77 respondents) ^a	Example
Production equipment	60	78%	Installation of high volume, low pressure (HVLP) spray system
Facility modification	16	21%	Creating a hard piped reuse system
Emission control ^b	12	16%	Redesign of exhaust system
Instruments and controls	12	16%	Improved wastewater control
Ancillary process equipment	11	14%	Automated mixing equipment
Other	7	9%	Investment in piping and pumps R & D test equipment
Product testing equipment	6	8%	
Don't know	1	1%	n/a
Total responses	125	n/a	

^a Percentages do not total 100% because some respondents provided information on multiple expenditures.

^b The activities reported under the category of emissions control do not necessarily meet the definition of toxics use reduction. However, these items indicate that the facility has used the TUR process to consider all the facility’s operations.

3.3. Benefits of TUR planning and implementation

Both in the quantitative portion of the survey and in open-ended responses, respondents described a variety of benefits from TUR planning and implementation of TUR projects. The benefits cited by the largest number of respondents were “increased management attention to environmental practices” (55%), “improved worker health and safety” (51%), and financial savings (41%). The full set of responses to this question is shown in Table 7. In open-ended responses, respondents provided additional insight into these benefits.

3.3.1. Organizational benefits of TURA

The organizational benefits of TUR planning and plan implementation affect every level of the organization, from management to shop floor employees. Regarding increased management attention to environmental practices, one respondent explained that “TURA is a great reason to make sure management and others are involved, and it facilitates routine business discussion.”

Consultation with employees is a required component of the TUR planning process. Respondents described experiences in which employees generated ideas that both protected employee health and improved efficiency.

For example, a facility that has been in the TURA program since 1990 installed a bulk caustic solution tank in 2007. The idea was generated by shop floor employees who worked directly with the caustic solution. Prior to the toxics use reduction project, employees worked directly with 30-gallon drums of caustic solutions. The process was labor intensive and involved exposure of workers to toxic chemicals. Now the entire process is automated. By eliminating the need to handle 2500 or more drums per year, the facility has saved \$70,000 annually in raw material costs.

Respondents also cited benefits related to improved morale. One respondent noted that toxics use reduction had improved morale by making the facility’s cleaning processes more efficient. This was described as a “great morale booster—cleaning is not a desired task.”

3.3.2. Health and environmental benefits

Several respondents described examples of improvements in worker health and safety resulting from TUR implementation. For

Table 7

Benefits experienced as a result of implementing TUR projects in the period 2000–present.

Benefit	Responses	Percentage (of 196 Respondents)
Increased management attention to environmental practices	108	55%
Improved worker health and safety	99	51%
Financial savings	81	41%
Compliance with other state or federal regulations	64	33%
Improvements in production efficiency	57	29%
Improved product marketing	41	21%
Improvements in product quality	33	17%
Improvements in technology and physical infrastructure	30	15%
Compliance with international standards	22	11%
Improved worker–management relations	21	11%
Other	18	9%
Improved community relations	16	8%
Retention of a product line	12	6%

example, one facility switched to hard piping of the facility's wash-water reuse system. TUR, worker safety, and productivity were all incentives for implementing the project. The facility had previously reused wash water by pumping it into drums, which were moved back to the front of the line for reuse. Hard piping and automating the system saved time and labor, and reduced exposures for shop floor workers by reducing the possibility of leaks or spills.

Another respondent described the facility's experience in eliminating cyanide and PCBs, and reducing use of TCE, methylene chloride, anhydrous ammonia, and a VOC lacquer. The respondent noted that eliminating cyanide alone has significantly improved worker health and safety at the facility.

3.3.3. Financial benefits

TURA program requirements are designed to allow facilities maximum possible flexibility in achieving their TUR goals. While facilities are required to complete a TUR plan and to conduct a financial analysis of their TUR options, they are not required to implement any specific TUR option. Thus, when facilities do implement TUR options, they frequently select options that offer direct financial savings as well as health, environmental and other benefits. Eighty-one respondents (41%) indicated that their facility achieved financial savings as a result of implementing TUR options in the period 2000–2006.

For example, a facility that has been in the TURA program for four years installed new cutting presses that allow for tighter patterns, reducing the quantity of scrap fiberglass that is sent out for disposal by about one ton per week. This change reduced operating costs by reducing both raw material and disposal costs, while improving productivity. Through this and other TUR projects, as well as changes in energy use, the facility reduced annual operating costs by more than \$25,000.

3.3.4. Professional benefits for TUR planners

Most general practice planners that responded to the survey indicated that they also work with facilities that are not TURA filers. Of these planners, 83% indicated that their knowledge of TUR is an asset for their work with non-TURA filers.

3.4. Challenges faced in TUR project implementation

The survey gave respondents the opportunity to provide additional information on what challenges or barriers they face as they

make decisions about what TUR projects to implement. As shown in Table 8, the challenges cited by the largest number of respondents were technical feasibility problems (62%); financial costs (55 percent); concerns about product quality (49%) and customer requirements (45%). In their open-ended responses and in the telephone interviews, respondents provided additional detail on concerns about product quality, and the role of customer requirements.

3.4.1. Concerns about product quality

Regarding product quality, one respondent provided the following example: "We tried to use high-grade zinc with low lead content instead of prime western zinc with about 1% lead content in our galvanizing process. The zinc coating quality is not as good using the high-grade zinc. As a matter of fact, the quality was so poor that management decided to go back to the prime western zinc until we can come up with another solution."

3.4.2. Customer requirements

Customer requirements may result from specifications (e.g. military specifications) that are difficult to change; unique functional requirements; or simply a preference for a familiar option. For example, one respondent noted that "The medical industry has a lot of product requirements and exemptions, and getting changes approved is difficult." Another commented that, "Our facility does custom formulations or required formulations for clients; customer decisions often veto substitution options." Another respondent identified customer requirements as "the biggest barrier to phase out lead. Leaded glazes are superior in quality and performance, and customers still want the leaded glaze, although recent stories about lead in toys and paints have helped dull demand." Yet another noted that the facility had had difficulty replacing cadmium because Department of Defense clients specified the inclusion of cadmium in airplane and parachute parts, and disallowed the zinc-tin or zinc-cobalt alloys that were offered as replacements.

3.4.3. Institutional challenges

Some respondents noted that management at their facility places greater emphasis on short-term costs than on long-term benefits, or simply consider TUR to be a low priority. Perceived lack of sufficient benefits was cited as a barrier by 29% of facility respondents and 28% of general practice planners. Nine percent of facility respondents and 28% of general practice planners indicated

Table 8

Barriers to implementing TUR projects in the period 2000–present (facility respondents).

Barrier	Responses	Percentage (of 196 Respondents)
Technical feasibility problems	121	62%
Financial costs too high	107	55%
Concerns about product quality	97	49%
Customer requirements	88	45%
Lack of sufficient expected benefits	56	29%
Project considered too time consuming	37	19%
Project considered low priority for management	18	9%
Lack of support from supply chain partners	16	8%
Regulatory environment	14	7%
Other	13	7%
Lack of organizational support for implementation	13	7%

that TUR projects were given a low priority by management. For some facilities, plant policies and procedures are dictated by parent companies, limiting the facility's ability to take the initiative in reducing toxics.

Other respondents considered other management systems to be more useful than TUR in achieving environmental health and safety goals. Finally, a few respondents simply stated that they see toxics use reduction as antithetical to their company's goals. For example, one respondent stated: "Our company is in the business of selling chemicals. The TURA program essentially reduces our business. A company that survives by selling both toxic and non-toxic chemicals should not have to provide a TURA plan."

3.5. Changes in facilities' experiences over time

One of the goals of the program assessment was to determine how facilities' experiences in the program have changed over time. The early years of the program were characterized by facilities identifying "low-hanging fruit" – opportunities to reduce toxics through simple changes in production systems. These changes often produced financial savings as well. The survey posed questions about how facilities' experiences with TUR planning and other aspects of the program have changed over time.

The survey asked respondents to indicate how often the first, second, and subsequent TUR planning cycles lead to the discovery of new TUR opportunities or options. Respondents were asked about planning years 2000–2006, which pre-date the alternative planning provisions of the 2006 amendments. Thus, responses to this question provide information about the baseline prior to the implementation of the 2006 amendments.

Some respondents indicated that they find that planning is no longer as useful as it was earlier in the program. Others indicated that they do continue to identify new options over time. Seventy percent of respondents "always" or "usually" found new TUR opportunities or options when doing a TUR plan the first time. While a facility's first and second plans are most likely to produce significant insights into the production process, nearly all respondents indicated that they sometimes identify useful TUR options in subsequent planning cycles as well.

Some respondents offered suggestions about how the TURA program could increase the effectiveness of planning and encourage facilities to learn from one another's experiences. One general practice planner recommended shifting the perspective of the planning periodically: "Usually, if we re-metric ... we can find other options that are not readily apparent." Another respondent noted that additional regulatory motivators become increasingly important after the first two planning cycles.

3.6. Value of TURA program services

TURA program services and resources include training sessions, conferences, workshops, compliance assistance, on-site visits, written and online materials, demonstration sites, grant programs, and laboratory and library services. In addition, the program provides an annual 40-h course to train new TUR planners. These services are available to all Massachusetts businesses and individuals, regardless of whether they are subject to TURA program requirements. This section summarizes survey results on the value of these services and resources to TURA filers and planners.

Of the respondents using program services, 90% or more considered the program websites, training sessions, conferences, workshops, and the TUR planner course to be "very" or "somewhat" useful. The program's written resources, compliance assistance, and library and reference services were rated as "very" or "somewhat" useful by more than 80% of the respondents on behalf of

individual facilities, and by 93, 88, and 91% of general practice planners, respectively.

Of those who received site visits, 74% of respondents on behalf of individual facilities and 90% of general practice planners found the visits to be "very" or "somewhat" useful. Cleaner technology demonstration sites and laboratory services were ranked as "very" or "somewhat" useful by over 65% of respondents on behalf of individual facilities, and over 70% of general practice planners. In general, respondents on behalf of individual facilities and general practice planners provided similar assessments of the relative usefulness of each program service, with a slightly higher proportion of general practice planners categorizing each service as useful.

3.7. Community survey results

3.7.1. Benefits and challenges

Survey respondents described economic as well as health and environmental benefits from implementation of community toxics use reduction projects. These include marketing benefits for small businesses, such as landscaping and janitorial services; provision of training to municipal employees and boards; and long-term savings from reducing hazards to water supplies.

Respondents also commented on ways in which the grant program provided them with access to scientists and professionals with specialized expertise, media outlets, and opportunities to leverage additional support. Unique resources offered through the grant program included technical support, training, and materials; education and hands on training that would have not been available otherwise; and assistance with media outreach.

Most grant recipients did not describe major implementation challenges. Some mentioned difficulties associated with carrying out the project in the allotted time, coordinating all the partners and activities involved in the project, or addressing regulatory and institutional barriers.

3.7.2. Project longevity and leveraging of additional support

One of the goals of the community grants is to help begin projects that can continue independently after the grant period has ended. Of the fourteen projects discussed in the online survey, eleven continued after the grant period ended. Only three had received funding prior to the TURI grant.

The telephone interviews gathered additional information on the role of TURI grants in project development and future funding prospects. The fourteen grant recipients participating in the telephone interviews (not necessarily overlapping with the online survey respondents) received, collectively, a total of just over \$190,000 in TURI grant funds. In a number of cases, the TURI grant served as seed money, making it possible for the organization to raise significant additional amounts of funding after receipt of the TURI grant. The interviewees reported a total of \$1,458,000 in non-TURI grants received after receipt of the TURI grant (a leverage factor of 7.5).

For example, the respondent on behalf of the Regional Environmental Council (REC) of Central Massachusetts, a community environmental justice organization, indicated that prior to applying for and receiving a grant from TURI, the organization focused primarily on more traditional environmental issues, such as recycling. A series of grants from TURI helped the organization to develop expertise in toxics and health, areas that are now an important focus of the organization. REC later leveraged this expertise to apply successfully for larger grants from Federal, state, and city sources. The respondent indicated that "The TURI grants helped us to break new ground and develop the confidence needed to get additional funding."

In another example, the Vietnamese-American Institute for Development (Viet-AID), a community development organization, received grants from TURI in fiscal years 2007 and 2008 to educate Vietnamese floor finishers about hazards of, and safer alternatives to, certain floor finishing materials. Earlier outreach efforts had been unsuccessful, but with the additional staff time and resources that were made possible by the TURI grant, Viet-AID was able to educate a large number of floor finishers. Building on the expertise and track record developed under the TURI grant, Viet-AID later applied successfully for U.S. EPA support.

4. Discussion

The survey and interview results are of potential value both for planning within the TURA program, and for other jurisdictions that wish to replicate TURA program elements. This section provides brief comments on some of the themes that emerge from the results presented above.

4.1. Benefits of TUR planning and plan implementation

One question motivating the study was to determine whether the TURA program continues to be useful twenty years after its original adoption. The survey results indicate that facilities are continuing to reap significant benefits from the TUR program, including organizational benefits as well as improved worker health and safety and financial savings.

Comparing the present survey results with those of the program evaluation survey that was conducted a decade earlier can provide additional insight. The 1997 program evaluation found that the most frequently cited benefit of implementing TUR projects was cost savings (67% of respondents), followed by improvements in worker health and safety (66% of respondents). Both of these benefits were near the top of the list in the present survey as well, although the percentage of respondents reporting these benefits was smaller (41% and 51%, respectively). This is consistent with the experience of many facilities in identifying “low-hanging fruit” opportunities for toxics use reduction in the early years of the program. The benefit reported most frequently in the quantitative portion of the present survey, “increased management attention to environmental practices,” which was chosen by 55% of respondents, appeared only in the open-ended responses in the 1997 survey so the percentages cannot be compared.

4.1.1. Organizational benefits

Complying with TURA can affect the internal dynamics within a facility in a variety of ways. One of those ways is increased management attention to environmental practices. The TURA planning requirements are designed to facilitate buy-in from every staffing level, including management. Other activities that can attract management attention include demonstration sites and opportunities for the facility to be honored as a leader.

TURA can also affect internal dynamics through its requirement that the planning process include consultation with employees. This requirement helps to ensure that employees have an opportunity to express concerns and provide suggestions, an opportunity that is not guaranteed by other regulations. The opportunity for employees to weigh in is not guaranteed by any federal statutes. The anecdotal information provided in open-ended survey responses and interviews indicates that some facilities are gaining substantial benefits from the employee consultation element of the planning process, achieving financial savings and improvements in health and safety as a result of employee-generated ideas. There may be scope for other facilities to learn from these successes in order to make the best possible use of this plan element.

4.2. Value of TURA program services

Some of the activities that respondents cited as most useful have been a focus of TURA program work. For example, reduction of lead use has been a focus of TURA program activities at both TURI and OTA. Among other activities, TURI has worked with Massachusetts businesses to create a consortium of facilities working to build and test prototypes of lead-free electronic circuit boards. Many respondents cited lead reduction as a key benefit of the TURA program for their facility.

Another example is the program’s work to facilitate communication up and down the supply chain as a means of facilitating toxics use reduction for specific industry sectors. Supply chain communication has been particularly important for the work by manufacturers of electrical and electronic equipment to comply with RoHS requirements, in particular the reduction or elimination of lead.

4.3. Challenges faced in implementing TUR projects

The design of the TURA program, with its focus on voluntary implementation of TUR options, makes it possible for facilities to make business decisions about the most technically and financially viable options. Those options that are less viable from a technical or financial standpoint are set aside in favor of those that are most advantageous to the facility. Thus, even under ideal circumstances, some options will be rejected due to technical or financial barriers. However, the TURA program endeavors to help facilities overcome as many such barriers as possible. Thus, for example, the technical barriers cited by respondents indicate opportunities for assistance through research and technical support.

It is notable that while 41% of respondents cited financial savings as a benefit of TUR plan implementation, 55% cited financial costs as a barrier. These responses are not contradictory: in some cases, cost is the deciding factor against a project. This is consistent with facilities also gaining significant financial benefits from TUR implementation in some cases.

4.4. Opportunities for greater integration with other management systems

The survey results indicate that a number of respondents were interested in increased integration between TUR planning and other management tools. In the process of implementing the 2006 amendments, the TURA program has worked to integrate TUR principles into the broader environmental management systems (EMS) methodology. Going forward, it may also be useful to work toward the integration of TURA principles into Lean Six Sigma processes and other, similar management systems. It may also be useful to build the Global Reporting Initiative criteria into TURA reporting; these criteria are used increasingly by U.S. EPA and other state pollution prevention programs (U.S. EPA 2010).

4.5. Opportunities associated with alternative resource conservation planning

The 2006 amendments to TURA make it possible for facilities to conduct alternative resource conservation planning as an alternative to toxics use reduction planning under some circumstances. The survey focused on facilities’ activities prior to these amendments going into effect. However, the survey responses indicate that even prior to the 2006 amendments, some facilities were using the TUR planning process to identify options for energy and water conservation, in addition to reducing toxics.

Going forward, with the implementation of the 2006 amendments, the TURA program has the opportunity to encourage and facilitate adoption of new energy- and water-saving techniques. The experiences of facilities that have already undertaken some activities of this kind indicate opportunities for progress by other facilities. Skills and capacity built through existing TURA program activities have helped to lay the groundwork for further progress in this area.

4.6. Opportunities to increase the usefulness of TUR planning

Most respondents indicated that the usefulness of the TUR planning process decreases with repeated planning cycles, although some useful TUR options continue to be discovered with repeated planning cycles. It is worth noting, however, that some facilities have found ways to make the planning process useful every time it is conducted, and some respondents offered specific suggestions about ways to ensure continued usefulness of the planning process. In this context, there are potential opportunities to help planners and facilities to ensure that the planning process is useful every time. This could include encouraging facilities to begin the planning process earlier in the year, and providing guidance on options for shifting the perspective of the planning process in each cycle.

4.7. Technological change and the role of TUR planning

In some instances, additional toxics use reduction occurs over time because new options become available due to the development of new materials and technologies. With repeated planning cycles, facilities have an opportunity to re-visit their use of toxic substances regularly and to take advantage of new alternatives as they become available.

The case of solvent reduction, substitution, and elimination provides a good case in point. Some of the facilities that have reported reductions in solvent use in the period 2000 to 2006 have been in the program for many years. Some had difficulty reducing their use of toxic solvents earlier in the program, but were able to do more in recent years due to technological advances.

Some facilities shifted from solvent-based systems to safer aqueous systems in the mid 1990s, while others found it difficult to make this shift. For facilities that have difficulty switching to an aqueous system, an alternative or intermediate solution is to move to a closed-loop system that minimizes potential exposures. Closed-loop vapor degreasing systems became available in the late 1990s; thus, some facilities that have reported reduction in solvent use in recent years have done so thanks to this new technology.

4.8. Role of capital investments in toxics use reduction

The survey results indicate that facilities are continuing to choose to make capital investments in toxics use reduction techniques. In all cases, facilities made a business decision in favor of these capital investments; the TURA program does not require facilities to make these investments.

It is interesting to note that most of the capital investments (74%) were under \$100,000, and a third of them were under \$10,000. These results indicate that facilities continue to identify toxics use reduction options that can be implemented with a relatively small up-front capital investment.

4.9. Improvements over time: progress since 1997

As noted in the introduction, the 1997 program evaluation identified a number of areas for improvement in the TURA program. These included addressing barriers related to product quality and

customer requirements; rewarding firms that have made progress in TUR and focusing assistance on those that have been less successful; working with smaller quantity toxics users to ensure they make progress in tandem with larger firms; applying the principles of TUR planning to areas other than use of toxic chemicals, such as water and energy use; and analyzing health and environmental effects of toxics in consumer products during use and disposal.

It is valuable to consider which of these recommendations have been pursued and where the remaining gaps may lie, as context for interpreting the other material presented in this article.

Many, though not all, of the 1997 recommendations have been followed.

- The program has addressed barriers related to product quality and customer requirements for specific industry sectors through a wide variety of activities, including demonstration sites, on-site technical assistance, university research, and supply chain initiatives. These activities are ongoing with variations to address industry needs that change over time.
- The program has continued to reward firms that make progress in TUR by showcasing their work in public events, publishing case studies, and other activities. The program has, however, done less to focus assistance on those companies that have underperformed.
- The 2006 amendments to TURA have addressed some of the recommendations directly. Under these amendments, facilities may use the toxics use reduction planning process to plan for conservation of other resources such as water and energy. In addition, the amendments create a higher hazard substance designation which makes it possible for the program to work with smaller firms in some cases. There continues to be additional scope for work with smaller firms, as many of them are still not covered by TURA.
- The recommendation that TURA work to assess the effects of toxic chemicals in products has been fulfilled to some extent in the TURA program's work on alternatives assessment; its grants to community organizations and university researchers; and individual research projects funded by outside agencies. However, there continues to be ample opportunity to better address the problem of toxic chemicals in products used in Massachusetts. One possible forum for addressing chemicals in products is for the TURA Administrative Council to coordinate action on this issue among multiple Massachusetts agencies.

5. Directions for future research

One weakness of the present study was that many respondents lacked institutional memory, making it difficult for them to answer some of the questions, especially those related to changes in costs or savings over time. Many respondents lacked detailed information on costs or savings associated with TUR implementation over a period of several years, and could comment only on expenditures or savings within the past year. This made it difficult to draw robust quantitative conclusions about costs and savings over time. In the future, it will be useful to request financial information from facilities at shorter intervals.

Under the 2006 amendments to TURA, facilities have the option to do alternative resource conservation planning or develop an environmental management system (EMS) in place of regular TUR planning, or to incorporate TUR into an existing EMS. This option was created in order to ensure that repeated cycles of TUR planning continue to be useful for facilities. It will be important to survey facilities in future years to determine whether there are changes in

the rate at which facilities indicate that second and subsequent TUR planning cycles are useful.

The 2006 amendments also make it possible for the TURA program to designate “higher hazard substances.” Facilities are subject to TURA reporting, planning, and fee requirements if they use more than 1000 pounds per year of a higher hazard substance. As of February 2010, four substances have been designated in this status; the program has the statutory authority to designate up to ten per year. This new provision means that beginning in reporting year 2009, new and smaller facilities will be subject to TURA program requirements. It will be important to assess the experiences of these new facilities entering the program, capturing their experiences early on and tracking changes over time.

It may also be of interest to take a closer look at the role of Toxics Use Reduction Planners in driving toxics use reduction at Massachusetts facilities. A future study could assess the significance of the planner certification program in the success of the TURA program, and could provide insights to other states considering creating such a program.

Unlike the 1997 evaluation of the TURA program, this study also includes some preliminary information on the experience of community organizations that have received grants or other assistance from the program. There is ample scope for further study of these organizations’ activities, their effects on health and the environment in Massachusetts, and their experiences working with state agencies through the TURA program.

6. Conclusions

The results of the survey and interviews conducted with Massachusetts facilities indicate that facilities are continuing to experience benefits from the TURA program, including improved worker protection and financial savings as well as organizational benefits. Facilities also continue to face challenges, ranging from technical feasibility problems to limitations deriving from customer specifications. In combination with past studies of the TURA program, the present study adds to a comprehensive understanding of the program’s effects on Massachusetts companies, and provides baseline information about the experience of TURA filers prior to the implementation of the 2006 amendments to TURA. It also provides useful information on the benefits of TURA program grants to community organizations. Results indicate that relatively small grants, combined with active support from TURA staff members, can make it possible for these organizations to build substantial projects and leverage significant additional support.

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Appendix

The following sample respondent profiles are based on online survey results as well as telephone interviews.

Sample respondent #1

The respondent’s facility has been in the TURA program for eleven years.

In the online survey, the respondent noted that the facility has been able to stop reporting for two chemicals because of TUR project implementation. A variety of TUR planning elements were flagged as “very useful,” including soliciting TUR ideas from employees. The respondent noted that other facilities outside Massachusetts have employed TUR techniques. The respondent also indicated that every TUR planning cycle has revealed areas of opportunity, and that Cleaner Technology Demonstration Sites sponsored by the TURA program have helped the facility to generate new ideas.

In the period 2000–2006 the facility made TUR-related capital expenditures in the range of \$250,001–\$500,000, and reduced annual operating costs by \$100,001–\$250,000 through TUR implementation in this same period. The capital expenditures included new production equipment (e.g., moving from 150 to 50 gallon acid bath tanks) and corresponding controls. However, the respondent noted that the savings in chemical costs, filing fees, and waste and wastewater disposal costs have “more than made up for” these expenditures in terms of annual savings.

The respondent indicated that with each TUR plan, staff members generate and undertake some new project. Recently they experimented with a new product to prolong solution life. An ion exchange project they attempted failed, but the respondent was glad TURA helped to generate the idea and said they learned something even with the failure. Most recently, filtration to help freshen the acid bath resulted in a 7–10% reduction in nitric acid use.

Sample respondent #2

The respondent’s facility has been in the TURA program for three years. The respondent indicated in the online survey that all TUR elements were “very useful,” and cited improved worker health and safety and financial savings benefits. The respondent noted that at this facility, an employee feedback form is distributed every three months to solicit TUR suggestions. Winners are declared for the best improvement ideas, and several successful projects have been proposed in this manner.

As an example of a TUR project, the respondent explained that in the facility’s reclamation process, a series of chemical baths are used to strip a variety of coatings, including copper, from wafers. Previously, some of these baths would “boil over” with the reactions. Employees designed a new bath shape to save money, prevent spills, and reduce exposures to the chemicals.

Sample respondent #3

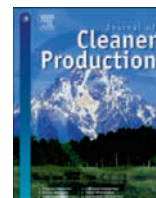
The respondent's facility has between 100 and 500 employees, and has been in the TURA program for 16 years. The respondent indicated in the online survey that the facility has eliminated use of two toxic chemicals through implementation of TUR projects; that the facility implemented TUR projects in plan years 2004 and 06; and that the facility experienced worker health and safety and financial savings benefits. The respondent reported total capital expenditures of \$500,001–\$1,000,000 over the period 2000–2006.

The facility found that there were many improvements it could make in the 1990's, but the respondent indicated that it has become more difficult to implement TUR over time. Even with annual planning meetings, the facility has more difficulty finding changes to make.

The respondent stated that a major benefit of TUR has been the removal of the facility from the "spotlight" of environmental regulators. Reporting to TURA has become easier since the facility has reduced its number of reportable chemicals from four to one.

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Safer alternatives assessment: the Massachusetts process as a model for state governments

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ABSTRACT

In 2006 the Massachusetts Toxics Use Reduction Institute conducted a study to determine if states could identify safer alternatives to five chemicals of concern. The chemicals investigated included di (2-ethylhexyl) phthalate (DEHP), formaldehyde, hexavalent chromium, lead and perchloroethylene. First, the Institute developed a methodology for assessing alternatives to these five chemicals that allowed it to quickly determine priority uses and alternatives to assess and to research the pertinent decision criteria, which included performance, technical, financial environmental and human health parameters. The methodology included important feedback from stakeholders in the state, which helped to focus and enhance the value of the work. Second, the Institute implemented the methodology over a ten month period. Based on the activities conducted by the Institute, safer alternatives were identified for each of the priority uses associated with the five chemicals studied. This report summarizes the methodology employed and provides examples of the results for one of the five chemicals, namely DEHP. The experience of the Institute and the information contained in this report indicates that alternatives assessment was a useful approach to organizing and evaluating information about chemicals and alternatives.

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1. Introduction

There is growing concern among consumers about the presence of toxic chemicals in the products they use. Studies showing these chemicals' persistence in the environment and potentially harmful effects on humans exposed to them are becoming a common place item in the news. Retailers, anxious to maintain their consumer base, are taking a harder look at the products they are willing to sell in their stores. Manufacturers are concerned about providing safer product formulations that will create a sustainable market share and help them to avoid potential future liabilities and costs. Public health and environmental advocacy groups are diligently working to raise public awareness and understanding of the risks associated with toxic chemicals, an activity which in turn puts more pressure on the retailers and manufacturers.

The tightening pressure to remove toxic chemicals from products has understandably come to the attention of municipal, state and federal governments, who are responsible for protecting their

constituents and the environment they inhabit while continuing to promote a more productive economy.

In July 2005, the Commonwealth of Massachusetts requested that the Toxics Use Reduction Institute perform an alternatives assessment for five chemicals identified by a coalition of public health, labor and environment advocacy groups. The chosen chemicals included lead, formaldehyde, perchloroethylene, hexavalent chromium, and di(2-ethylhexyl) phthalate (DEHP). For each chemical, the Institute was charged with identifying significant uses in manufacturing, consumer products, and other applications; reviewing health and environmental effects; and evaluating possible alternatives.

Because the study had to be conducted within a very short time frame (approximately 10 months) for a limited budget the Institute needed to quickly focus its work on the highest priority chemicals and applications. Likewise, for each use studied, the Institute chose a subset of possible alternatives for analysis. The Institute analyzed a total of sixteen different use categories and approximately one hundred different alternatives. Examples presented throughout this article are associated with one of the five chemicals studied, DEHP.

The Institute conducted its research in a phased manner, using the methodology described herein. This report presents the streamlined approach used by the Institute; a method that can be

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adapted for use by other governments and companies interested in quickly identifying safer alternatives to chemicals of high concern.

2. Phase I – understanding the concerns associated with the chemical being studied

To fully assess whether an alternative was indeed both technically and economically feasible for its intended use as well as being safer, the characteristics of that chemical was first identified.

2.1. Profile inherent hazard and exposure of the chemical of concern

Information about potential human health and environmental impacts associated with the use or exposure to the chemicals of concern can be found in a number of sources: public databases, peer-reviewed scientific journals, reference materials, industry trade group and advocacy group resources. The objective was to provide background information on each chemical of concern, highlight the associated environmental, health and safety issues, and provide a baseline against which alternatives may be compared.

The Institute has a long-standing history of focusing its work on the inherent hazards associated with toxic chemicals. However, the US federal government and most companies and trade associations have historically considered “risk” when setting policy about the use of chemicals. Risk assessments include an evaluation of the exposure potential associated with the use of a chemical as well as its inherent hazard. Potential human health and environmental hazards are typically inherent to a chemical and are not influenced by the use or exposure potential associated with the chemical. Table 1 presents the pertinent inherent hazard information associated with DEHP.

The potential for human exposure to a chemical of concern is directly influenced by the manufacturing process and use for specific applications. Physical characteristics of the chemical and the product or material in which it is incorporated influence the potential for exposure to the chemical of concern. For DEHP, the

Table 2

Physical characteristics of DEHP influencing exposure potential.

Physical characteristic	DEHP data	Primary sources of information
Water solubility (mg/L)	0.0025	HSDB, 2009
Vapor pressure (mmHg)	1.4×10^{-6}	HSDB, 2009
Octanol–water partition coefficient (K_{ow})	7.6	HSDB, 2009
Flashpoint	215	HSDB, 2009
Migration potential	Possible migration from matrix in lipid soluble	Health Canada, 2002

physical characteristics and characteristics that could lead to exposure are summarized in Table 2.

The Institute used exposure potential information to help determine the priority of specific uses of each chemical, but also to gain more insight into how alternatives compared to the chemicals of concern for specific uses.

2.2. Identify function, uses and use categories

Uses of chemicals range from manufacturing processes to services to consumer products. The first task was to identify the suite of uses for the chemicals of concern. Uses may include use in manufacturing operations (e.g., chemical production), use in non-manufacturing operations (e.g., services such as dry-cleaning), as well as incorporation in consumer and industrial products.

The Institute utilized the following sources when gathering this information:

- Major suppliers of the chemical;
- Major derivatives, components and/or end products that incorporate the chemical or use the chemical as a feedstock, and their manufacturers;
- Major distributors, retailers, or customers of the end product;
- Functionality requirements of chemical or component or end-product users; and

Table 1

Inherent hazard characteristics of DEHP.

Chemical characteristic	DEHP data	Primary sources of data
Environmental criteria		
Persistence	<ul style="list-style-type: none"> • 140 days in sediment • 15 days in water • 30 days in soil • 0.75 days in air 	EPA PBT Profiler, 2010
Bioaccumulation	BCF = 310	EPA PBT Profiler, 2010
Chronic aquatic (fish) toxicity (ChV)	No effect at 0.0025 mg/L	EPA PBT profiler, 2010
Human Health criteria		
Carcinogen	<ul style="list-style-type: none"> • NTP B2 (Reasonably anticipated to be a human carcinogen) • IARC 3 (Not classifiable as to its carcinogenicity to humans) 	<ul style="list-style-type: none"> • National Toxicology Program Report on Carcinogens, Eleventh Edition, 2010 • International Agency for Research on Cancer, 2010
Reproductive toxicity	No adverse affect level = 3.7 mg/kg bw/d	NTP, 2005
Lethal dose (LD50)	<ul style="list-style-type: none"> • 25–34 g/kg (oral, rat) • 10 g/kg (dermal, guinea pig) • 25 g/kg (dermal, rabbit) 	HSDB, 2009
Irritation	<ul style="list-style-type: none"> • Dermal • Ocular • Respiratory (mucous membranes) 	HSDB, 2009
Metabolite of concern	Mono(2-ethylhexyl)phthalate (MEHP) classified as a reproductive toxicant	CDC, 2005
Reference dose	0.02 mg/kg/day	HSDB, 2009
Target organs	<ul style="list-style-type: none"> • Eyes • Respiratory system • Central nervous system • Liver • Reproductive system • Gastrointestinal tract 	NIOSH Pocket Guide to Chemical Hazards, 2005

Table 3
DEHP uses and stakeholder discussion.

Uses/applications	Stakeholder discussion
<i>Consumer products</i>	
Toys	Permanently banned in EU; Potentially vulnerable population exposed; DEHP not currently used in toys in the US because of consumer relations; concern with imported products
Sheet/film (e.g. food packaging)	FDA limits use of DEHP in packaging that touches food
Vinyl shower curtain	Not recommended for study because other applications with similar manufacturing process will be evaluated
Vinyl wall covering	High consumer exposure potential; large usage; ubiquitous
Car undercoating	Alternatives available
Footwear	Alternatives available; further research to determine manufacturing in MA and US and potential consumer exposure.
Upholstery	High consumer exposure potential; large usage; ubiquitous
<i>Medical devices</i>	
Plastic sheet materials (e.g. bags)	High usage; potentially vulnerable population exposed; many alternatives possible; Serious health issue; High concern to many stakeholders
Tubing (e.g. IV tubing)	High usage; potentially vulnerable population exposed; many alternatives possible; serious health issue; High concern to many stakeholders
<i>Industrial/commercial uses</i>	
Resilient flooring (also residential use)	Used in MA; high occupational exposure potential; alternatives available on the market
Roofing	Most roofers do not want or use products containing DEHP; alternatives available
Aluminum foil coating/laminating	Alternatives available
Paper coating	Alternatives available
Extrudable PVC molds/profiles	Used in MA; 1% of total DEHP use; not identified as priority
Electronic component parts	Used in MA; less than 1% of total DEHP use; not identified as priority
Wire/cable coating compounds	Used in MA; DEHP has been greatly reduced in MA due to use of alternative plasticizers

- Concerns of relevant stakeholders, including businesses, industry associations, environmental, public health and labor organizations.

2.3. Stakeholder engagement

The prioritization process was informed by the experiences, concerns and knowledge of a group of stakeholders who were gathered together by the Institute early in the process. Engaging stakeholders is key to attaining a more transparent and participatory process for providing useful information to assist environmentally responsible decision making. A critical aspect is to appropriately involve relevant parties in the assessment process (Thabrew et al., 2009) The stakeholder engagement process became a vital component of the success of this process, in that the feedback of the various stakeholders helped to quickly identify priority uses of the five chemicals studied based on the criteria identified above.

Stakeholders who were invited in to the conversation included representatives from companies using and manufacturing the chemicals of concern and their alternatives, industry trade organizations, labor organizations, environmental and public health advocacy organizations, academic experts and policy makers in Massachusetts. The focus was clearly limited to the impact of chemicals used in Massachusetts, and therefore national trade associations were not included as relevant stakeholders in the early process. They were, however, offered the opportunity to review and comment on Institute research and provide additional information as the assessment process progressed.

As an example, the variety of uses identified as being of priority to the various stakeholders for the plasticizer DEHP is presented in Table 3.

2.4. Develop a preliminary prioritization of chemical uses for further evaluation

For each chemical of concern, the range of associated uses is wide and varied. Therefore it was necessary to narrow the scope to focus our evaluation on uses that are a priority. The Institute prioritized uses of the chemicals of concern using the following criteria:

- Total quantity of chemical used in manufacturing and business operations in the state (the Massachusetts Toxics Use Reduction Act requires that companies using toxic chemicals report those uses. This information is available on the Institute's website,¹ and was used for this purpose)
- Potential availability of alternatives (based on preliminary research and feedback from stakeholders)
- Environmental, occupational, and public health exposure potential. This included consideration of the mobility of the chemical for a particular use and whether the chemical was used in a product in a way that could lead to user exposure.
- Potential value of the alternatives assessment results to state businesses and citizens.

The priority uses identified for DEHP, based on these criteria and the feedback of our stakeholders and research conducted, are summarized in Table 4.

For the remainder of this article, only the alternative assessment results for the resilient flooring application will be presented.

3. Phase II – alternatives identification and prioritization

This phase of the process involved more extensive research to identify possible existing or emerging alternatives to the chemicals of concern for the specific applications being studied. The knowledge of stakeholders was used to help facilitate this process. Alternatives were only identified for the priority uses determined in the previous section.

3.1. Identify alternatives for priority uses only

Alternatives to the chemicals of concern potentially include drop-in chemical substitutes, material substitutes, changes to manufacturing operations, changes to component/product design, or other technological solutions. The Institute considered all possibilities as it researched potential safer alternatives to the five chemicals being studied. Appropriate industry-specific performance requirements for each use were necessary criteria in

¹ www.turi.org.

Table 4
DEHP list of priority uses.

Use	Criteria applied to determine as priority
Medical sheet/bag devices in neonatal care	Potential public exposure; Many device manufacturers in Massachusetts; Many alternatives available
Medical tubing devices in neonatal care	Potential public exposure; Many device manufacturers in Massachusetts; Many alternatives available
Resilient flooring	Largest DEHP manufacturer in Massachusetts; Potential occupational and public exposure; Many alternatives available
Vinyl wall coverings	Potential occupational and public exposure; Many alternatives available

determining if an alternative was technically feasible. Each alternative's characteristic was evaluated relative to those technological criteria to determine if it represented a reasonable alternative to the chemical of concern for the specific use.

For resilient flooring the Institute focused on the use of DEHP to soften and provide resiliency to poly vinyl chloride (PVC) residential flooring applications. When considering alternatives for this application, both alternative plasticizers and alternative materials that do not require plasticizers were considered. The Institute used information from stakeholders, industry experts and literature research to identify the potential alternatives summarized in Table 5.

3.2. Pre-screen alternatives

The Institute conducted a pre-screening step to eliminate from further study any chemical alternatives that would pose a high risk to the environment or human health. All identified chemical alternatives were screened based on the following criteria:

- PBT (persistent, bioaccumulative toxin)
- Carcinogen
- Present on Massachusetts More Hazardous Chemical list

If an alternative met any of the pre-screening criteria, it was eliminated from further consideration as an appropriate alternative. It is important to note that, when no data associated with one or more of the pre-screening parameters were available the chemical was not screened out based on that parameter.

Table 5
Available alternatives to DEHP in resilient flooring.

Alternative category	Potential alternative
Phthalate-based plasticizers	<ul style="list-style-type: none"> • DINP (di isononyl phthalate) • DIDP (di isodecyl phthalate) • DEHT (di(2-ethylhexyl)terephthalate) • BBP (butyl benzyl phthalate) • DHP (di isohexyl phthalate) • BOP (butyl, 2-ethylhexyl phthalate) • DBP (dibutyl phthalate) • DIHP (di (isohexyl)phthalate)
Other plasticizers	<ul style="list-style-type: none"> • DEHA (di(ethylhexyl) adipate) • DEHPA (di(2-ethylhexyl) phosphate) • TCP (tricresyl phosphate) • ATBC (o-acetyl tributyl citrate) • DBS (dibutyl sebacate) • TEGDB (triethylene glycol dibenzoate) • DGD (dipropylene glycol dibenzoate) • DEGDB (diethylene glycol dibenzoate) • 97A (hexanadecioic acid, di-C7-9-branched and linear alkyl esters) • TXIB (butane ester 2,2,4-trimethyl 1,3-pentanediol di isobutyrate)
Materials	<ul style="list-style-type: none"> • Natural Linoleum • Cork • Polyolefin • Polyethylene/limestone blend • Rubber

3.2.1. Persistence, bioaccumulation and toxicity

Developing data on persistence, bioaccumulation potential and toxicity are especially important from an environmental assessment standpoint. In order to present more comprehensive data, the Institute utilized the US EPA PBT Profiler software for those chemicals for which there was no currently available persistence, bioaccumulation or toxicity data (U.S. EPA PBT, 2010). The PBT Profiler evaluation was conducted by a subset of the assessment team, consisting of chemists and chemical engineers trained to appropriately interpret the data, in order to assure consistent use and interpretation of the results of this tool. Other publicly available scientific-based and peer-reviewed estimation tools that were identified and tested over the course of this study were also used to augment the available information about each of the chemical substitutes evaluated.

- Persistence: The US EPA PBT Profiler defines very persistent chemicals in terms of their half life in specific media (U.S. EPA PBT, 2010). If any one of the environmental media half lives was exceeded, the chemical was considered to be persistent for this study.
- Bioaccumulation: As defined in the PBT Profiler, the US EPA considers a chemical very bioaccumulative if it has a bio-concentration factor (BCF) greater than 5000 (or $\log K_{ow}$ greater than 5) (U.S. EPA PBT, 2010).
- Aquatic toxicity: According to the PBT Profiler, chronic aquatic toxicity values less than 0.1 mg/L indicate that a chemical was of high concern (U.S. EPA PBT, 2010). The parameter used to evaluate for freshwater fish species toxicity was based on 30-day exposure duration, with the endpoint for evaluation expressed in ChV (mg/L). In many cases data for aquatic toxicity was not available. In this case the chemical was not screened out based on toxicity, and was only screened out as a PBT if the criteria for both P and B were exceeded.

3.2.2. Carcinogenicity

For the purposes of this study, a chemical was screened out if it was identified as a carcinogen under one of the following classifications:

- US EPA Classifications (USEPA, 1986):
 - Group A: Known Human Carcinogen
 - Group B1: Probable Human Carcinogen (Limited human evidence)
 - Group B2: Probable Human Carcinogen (Sufficient evidence in animals)
- IARC Classifications (IARC, 2000):
 - Group 1: Known Human Carcinogen
 - Group 2A: Probable Human Carcinogen

3.2.3. Chemicals present on specific lists

The Institute used the TUR Science Advisory Board's list of More Hazardous Chemicals (Mass TURI, 1999) as an additional pre-screening list for its alternatives assessment process. In this list,

“hazard” includes inherent toxicity, potential for exposure through dispersal in the work place (based on the physico-chemical properties of the chemicals, e.g., vapor pressure) and indicators of safety of use (e.g., flammability). Potential for exposure and indicators of safety do not include site-specific conditions. Chemicals found on the list were eliminated from consideration as a viable chemical alternative.

3.2.4. Alternatives screened out from further consideration

As part of the initial screening effort to determine alternatives to eliminate, several plasticizer alternatives were identified as having persistence, bioaccumulative or toxic values that exceeded the screening criteria with one of the other PBT criteria approaching a level of concern. Hence they were not screened out as PBTs, but were flagged as being of concern because they approach the associated PBT screening levels. However, because there were numerous plasticizer alternatives identified for this use that did not approach levels of concern, none of these questionable alternatives were considered vital to the goals of the study, and were not evaluated further. The chemicals that were screened out for further analysis included:

- DIHP (di (isoheptyl) phthalate) – Failed due to sediment persistence and aquatic toxicity
- 97A (hexanadedioic acid, di-C7-9-branched and linear alkyl esters) – Failed due to sediment persistence and aquatic toxicity
- TXIB (butane ester 2,2,4-trimethyl 1,3-pentanediol di isobutyrate) – Failed due to sediment persistence and aquatic toxicity (also exhibits high bioaccumulation, though it does not exceed the screening level)

No materials were screened out at this point in the assessment, though several potential alternatives initially identified were eliminated from further consideration because they did not meet the resiliency criterion (*i.e.*, able to return to their original form after compacting) established as part of the study. These materials included concrete, terrazzo, concrete and recycled glass blend, wood and bamboo.

3.3. Prioritize alternatives for further evaluation

The purpose of the prioritization effort was to focus the Institute’s assessments on the most feasible alternatives for each specific priority use. Our intention at this stage was to do a high level evaluation of the potential alternatives to identify any factors leading to immediate screening out of the chemical or informing the prioritization of the alternative as a potentially feasible alternative to one of the five chemicals. The Institute considered the following:

- *Performance*: Performance criteria specific to the use of the chemical/material, which could include items such as maintenance and durability as well as specific performance requirements. The potential for future performance enhancements was considered.
- *Availability*: Number of suppliers/manufacturers that commercially provide the alternative. In addition, information about the volume of the alternative produced was considered (*i.e.*, was the alternative available only in very small quantities and therefore less feasible).
- *Manufacturing location*: Products or materials manufactured in Massachusetts received a higher prioritization for evaluation as this may have a greater impact on the Massachusetts economy.

- *Cost*: Current costs associated with the alternative compared to that of the chemical of concern. The potential for future cost reductions (*e.g.*, economies of scale due to higher volume production) was considered. If available, other significant costs such as raw material costs, storage and handling costs and disposal costs were also considered.
- *Environmental, health, and safety*: Known environmental, health and safety risks or benefits as compared to that of the chemical of concern. Frequently there was a paucity of data about alternatives, which was noted and addressed in the assessment phase.
- *Global market effect*: Information about pending or existing global restrictions that might materially affect the ability of an industry to market its products internationally was considered.
- *Other*: Other use specific criteria were used as appropriate. For example, in some instances multiple similar alternatives exist for a particular use. In this case one alternative that was representative of that type was chosen for further study.

Table 6 presents the final list of alternatives considered for resilient flooring applications.

4. Phase III – alternatives assessment

Risk assessments use many categories of information including scientific, technological, and legal information. These types of information are potentially helpful in identifying and reducing the risks of hazardous chemicals (Koch and Ashford, 2006). Similarly, the alternatives assessment methodology used for this study includes the collection and analysis of many different types of information.

4.1. Types of alternatives to be considered

The Institute organized and evaluated environmental, technical, financial and human health data obtained for each alternative to assess its feasibility as a substitute for the chemical and use. The main types of alternatives that were considered included chemical, mixture and material alternatives as well as process alternatives.

4.1.1. Evaluating chemical alternatives

In this study, a chemical was considered to be any element, chemical compound or mixture of elements and/or compounds. Chemicals are the constituents of materials. A chemical “mixture,” also known as a chemical “preparation,” includes multiple chemicals.

A chemical alternative represents the simplest case, where the chemical being studied can be directly substituted with another chemical that satisfies the functional requirements for the particular use. In this instance, the evaluation was relatively straightforward; information could be obtained, verified and presented in a way that maximizes usefulness of the information for those interested in designing products using alternative chemicals.

Table 6
Priority alternatives for resilient flooring.

Priority alternative plasticizers	Priority alternative materials
DEHT	Natural linoleum
DINP	Cork
DGD	Polyolefin
DEHA	

4.1.2. Evaluating mixtures

Often the chemicals being evaluated are used in formulations of multiple chemicals. In this case, each of the chemical constituents of the mixture had to be considered in the assessment, in a manner similar to that used for individual chemicals (as above). The Institute obtained environmental and human health information about each of the chemical constituents, and performance and cost information for the overall formulation when doing the assessment. When information on the weight percent of constituents in the mixture was available from a manufacturer's materials safety data sheet (MSDS) that information was used.

The Institute focused on the primary constituents of each formulation being evaluated. Specifically, constituents present in amounts exceeding 1% were included in the review. When formulation breakdowns were presented on associated MSDSs with ranges, the Institute assumed the average weight percentage of the range presented. This was the only time that a weighting factor was included in our assessment of alternatives. As the EH&S factors associated with the constituents of a mixture were determined, their relative significance to the overall EH&S characteristic of the mixture was determined based on the weight percent within the mixture.

The actual approach to evaluating the EH&S impact of a mixture differed depending on whether the chemicals in the mixture cause similar or different health effects. If the health effects are similar (e.g., two constituents are CNS depressants), their weight percentages were added and the overall impacts of the combined chemicals were assessed. If the health effects were different (e.g., one chemical was a CNS depressant, while another was a respiratory irritant), the effects were evaluated separately based on the weight percentages of each constituent (Craig et al., 1999).

4.1.3. Evaluating material alternatives

A material is defined as the basic matter (as metal, wood, plastic, fiber) from which the whole or the greater part of something physical (as a machine, tool, building, fabric) is made. In some cases the chemical being studied was used to impart particular qualities in a material. For instance, DEHP is used in PVC to make this otherwise rigid plastic flexible. Rather than find other ways to make the material (PVC) less rigid, opportunities to find alternative materials that are inherently more flexible were available that precluded the need for this particular chemical additive.

When evaluating material alternatives performance and cost considerations are still important. However the impact of a material on environmental or human health may not be as readily assessed as it can be for chemical substitutes. For materials, life cycle considerations may become more important. For this study the Institute looked both at EH&S impacts when appropriate and at life cycle issues that based on our research appear to be of most significance relative to the material being replaced. It is important to note that this was not a comprehensive life cycle assessment. Rather, when our research indicated that there may be important positive or negative impacts at a particular point in a material's life cycle these were mentioned qualitatively relative to the material being substituted.

4.1.4. Evaluating process alternatives

Process alternatives are those that employ a different technology, process or approach to achieve the objective or function of the original product or process. For example, when considering alternatives to perchloroethylene in vapor degreasing, one approach might be to change the upstream process to use lubricants that either don't require cleaning, or are easier to remove using water-based surfactants. The feasibility of this type of

alternative can be assessed, but it is very difficult to compare the EH&S impacts quantitatively. These types of alternatives were therefore included in the study where appropriate, and their feasibility assessed qualitatively. When our research indicated that there are important positive or negative attributes or impacts relative to the substance being substituted, these were mentioned.

4.2. Criteria considered for alternatives

The alternatives assessment phase included comparison of health and environmental effects, technical feasibility, and financial feasibility for the prioritized alternatives for each studied use to the chemicals of concern. It is important to note that this study was not designed to assess the relative safety of one alternative over the other. Rather, alternatives were compared to the study chemical as a baseline.

4.2.1. Health and environmental effects

The Institute evaluated a subset of environment, health and safety (EH&S) endpoints. The Institute did not perform a detailed toxicological review for each alternative. Rather, the study relied on information obtained from authoritative bodies, emphasizing the most recent validated data or data that has been referenced by a US government agency. Where this type of information was not available, or where more recent studies called into question the results previously published by authoritative bodies, supplementary information was noted. In cases in which it was necessary to evaluate chemicals in mixtures, the assessment considered each of the chemical constituents, excluding those making up 1% or less by mass of the mixture.

The Institute used the following protocol when evaluating environmental and human health data:

- All data must represent current science and be derived from peer-reviewed and publicly available sources. Our primary sources of this data were those available from the National Library of Medicine's Hazardous Substances Data Bank (HSDB, 2009)
- For human health, data based on human epidemiological studies were used preferentially. Data based on tests of non-human sources were used if human epidemiological data was not available. If neither human epidemiological data nor data based on non-human sources was available, data derived from models were used; and
- If modeled data was used, the Institute used models approved by the US EPA.

When presenting data for any of these categories, the Institute relied on information obtained from authoritative bodies,² with the most recent validated data presented first. When faced with multiple or conflicting data, the Institute preferentially used data that has been referenced by a US governmental agency such as EPA, CDC and OSHA. Examples of data included in the health and environmental effects assessment include aquatic toxicity, water quality, persistence, bioaccumulation, environmental mobility, degradation products, lethal dose, worker exposure limits, metabolites of concern, carcinogenicity, mutagenicity, endocrine disruption, reproductive toxicity, corrosivity, reactivity, vapor pressure, and potential for dermal adsorption.

² Authoritative bodies include the US Environmental Protection Agency, the Occupational Safety and Health Administration, the National Toxicology Program, the International Agency on Research of Cancer, National Institute of Health, and the Center for Disease Control, etc.

4.2.2. Technical feasibility

The study identified and assessed application-specific performance requirements that must be met for each feasible alternative. The performance information that the Institute was able to obtain varied considerably among uses. For some uses, information was obtained from published studies or directly from technical experts or several users of the alternatives. For other uses, the Institute relied on information provided by product manufacturers. Examples of parameters considered for technical feasibility included: product longevity, performance standards (e.g. UL, ASTM, or ISO standards), physical characteristics (e.g. processability, density, or color), and quality requirements (e.g. durability, maintenance requirements).

4.2.3. Financial feasibility

Data sources for financial information included manufacturers, stakeholders, the Chemical Economics Handbook and other standard reference sources (Bizzari et al., 2003). In many cases, particularly for emerging alternatives, no quantitative cost information was available. In other cases, sufficient cost information existed to conclude that the alternative was either more or less costly than the current chemical use. The Institute recognized as part of its assessment that cost comparisons are snapshots in time, and may also be of limited relevance for emerging technologies and technologies that are gaining in popularity, since learning curves, economies of scale, and other factors can reduce costs over time. Examples of parameters considered for financial feasibility included: purchase price, commercial availability, capital costs for equipment associated with adopting the alternative, operating costs, and manufacturing costs.

4.2.4. User experience data associated with alternatives

While conducting the technical/performance assessment, the Institute identified any industry-specific performance requirements that must be met for each feasible alternative. The primary source of this information was industry/user experience with the chemicals and their substitutes. Institute staff contacted and interviewed representatives from manufacturers, trade associations and customers who use the chemical or its derivatives to gather pertinent information.

4.2.5. Life cycle implications of alternative materials

Considering the life cycle of a material can provide a quantitative basis for assessing potential alternatives with respect to the impact adopting alternatives might have on the overall environmental performance of the system (Azapagic and Clift, 1998). Because of the limitations placed on this study (specifically the limited amount of time available to conduct the study) as well as the overall goal, which was merely to determine if safer alternatives could be identified, the Institute made the decision to not engage in a comprehensive life cycle assessment of material alternatives. The Institute did, however, look for readily available information on key life cycle considerations (such as waste disposal limitations, energy usage required during manufacture, impact on product recyclability or reuse potential) that might have affected the feasibility of the alternative. This information was presented in the final report only when more than one source corroborated the data, and when it was deemed to materially impact the overall assessment of one alternative's feasibility.

4.3. Summary of criteria for assessing resilient flooring alternatives

Table 7 summarizes the criteria used to assess plasticizer alternatives to DEHP. Table 8 summarizes the criteria used to assess material alternatives to PVC modified with DEHP.

5. Results and discussion

DEHP used in PVC for resilient flooring applications provides an excellent example of the results of the assessment process. Both chemical and material alternatives were identified and assessed for this use of DEHP (as was done for all priority uses of each of the five chemicals of concern studied).

5.1. Summary of results for alternative chemicals

Based on our evaluation of the four plasticizer alternatives to DEHP for resilient flooring applications, and using the primary criteria that impacted the ability of manufacturer's to adopt safer alternatives, a matrix was created that compares the alternatives to DEHP, as shown in Table 9.

Table 7
DEHP plasticizer alternative assessment criteria.

Category	Assessment criteria
Performance	The following performance criteria are important when substituting plasticizers in flooring and wall covering operations: <ul style="list-style-type: none"> • Lower plasticizer volatility, measured by plasticizer's vapor pressure, increases a product's expected lifetime. Ideally, the volatility of a substitute plasticizer should be equal to or lower than DEHP. • Compatibility measures how well a plasticizer is suited to PVC. Plasticizers with low compatibility are known to migrate out of plastic over the life of a product. • Molecular weight is a good indication of tensile elongation. Higher molecular weight plasticizers tend to result in longer product life • Compounding and calendaring processability compared to DEHP. These processes are most common when manufacturing flexible PVC. Alternatives should ideally process as well as or better than DEHP.
Financial	Cost data from industry sources in March 2006, based on a hardness rating of 70 Shore A. Cost estimates use plasticizer substitution factors to determine the relative amount of plasticizer, compared to DEHP, needed to obtain a particular level of hardness. For example, a factor of 1.1 indicates to achieve similar hardness; 1.1 times the amount of DEHP used is required.
Environmental Health and Safety	<ul style="list-style-type: none"> • Critical criteria were associated with the initial screen (i.e., no PBT, Class 1 or 2 carcinogens or TURA SAB more hazardous chemicals). No chemicals that exceeded these criteria were put forward for further assessment. • If a plasticizer exhibits PBT values that approach levels of concern, as identified by the EPA in its PBT Profiler methodology, it will be considered less favorably in the assessment phase. • Additional parameters that are considered when assessing plasticizer alternatives have been identified based on the characteristics of DEHP and specific concerns relative to the likelihood of an effect occurring. These additional health criteria include: water solubility, octanol–water partition coefficient (a measure of hydrophobicity), organic carbon partition coefficient (sediment affinity indicator), lethal dose value (using the oral rat value as the benchmark), immediately dangerous to life and health (IDLH) value, permissible exposure limit, reference dose, carcinogen classification, toxicity (EU R-phrase or present on the California Proposition 65 list), and vapor pressure.

Table 8
DEHP/PVC alternative material assessment criteria.

Life cycle phase	Environment and Human Health Issues	Positive aspects of DEHP/PVC
Raw materials	<ul style="list-style-type: none"> Extraction and refining of petroleum based feedstocks. Ethylene feedstock is non-renewable Few suppliers offer recycled content A minority of DEHP/PVC is manufactured from chlorine made using the mercury cell process 	<ul style="list-style-type: none"> Some vinyl sheet manufacturers use up to 25% post-industrial recycled DEHP/PVC and reclaimed wood fibers in product.
Manufacture	<ul style="list-style-type: none"> Human health impacts of PVC precursor chemicals Energy use impacts: greenhouse gas, particulate, other Potential worker exposure to DEHP during manufacture 	<ul style="list-style-type: none"> Post-industrial vinyl scrap is recyclable
Installation	<ul style="list-style-type: none"> Volatile organic compounds emitted from styrene butadiene floor adhesives 	<ul style="list-style-type: none"> Adhesives typically water-based, safer than older solvent-based types
Use and maintenance	<ul style="list-style-type: none"> DEHP exposure, though this is expected to be low due to the low vapor pressure VOC emissions (rate depends on product type) Most varieties require routine stripping and waxing, which may have associated VOC emissions 	<ul style="list-style-type: none"> Waxing and cleaning with mild detergent
End of life	<ul style="list-style-type: none"> Potential for chlorine derivative (dioxin and furan) emissions from improper combustion (accidental fire, backyard burning) Chlorine derivatives may be found in fly ash of properly controlled incinerators Not compostable Lack of recycling infrastructure to recycle DEHP/PVC flooring 	<ul style="list-style-type: none"> Recyclable

In this table you can find a summary of the data used to assess how the alternatives compare to DEHP for this specific use. In addition, to simplify the comparison summary, only the most pertinent criteria are shown in the table. The alternatives were assessed for each criterion as being similar to (=), better than (+) or worse than (–) DEHP for this application. A “?” symbol is shown to indicate that sufficient information was not available to make this kind of assessment.

5.2. Summary of results for alternative materials

Material alternatives were also considered as replacements for the DEHP/PVC blend used as resilient flooring in residential, industrial and commercial settings. Based on our evaluation of the various material alternatives to DEHP amended PVC for resilient flooring applications, and using the primary criteria that impacted the ability of manufacturer's to adopt safer alternatives, a matrix was created that compares the alternatives to DEHP/PVC, as shown in Table 10.

Table 9
Summary of plasticizer alternatives assessment for resilient flooring.

Assessment criteria	DEHP (Reference)	Comparison relative to DEHP				
		DEHT	DINP	DGD	DEHA	
Technical/Performance criteria	Volatility	1.4×10^{-6} mm Hg	–	+	=	+
	Compounding	Good	?	=	=	=
	Tensile elongation (life of product)	MW 390	=	=	=	=
	PVC compatibility	Good	=	=	=	–
	Loss of plasticizer (Manufacture, Use)	Acceptable (M, U)	=	= (M); – (U)	=	–
Cost	Cost/lb applied	\$0.70 (March 2006)	=	=	=	=
Environmental criteria	Persistence	Sediment (140 days)	=	=	=	+
	Bioaccumulation	BCF = 310	+ (BCF = 25)	+ (BCF = 3.2)	+ (BCF = 190)	+ (BCF = 61)
	Aquatic (Fish) toxicity	>0.0025 mg/L	= (>0.015 mg/L)	= (>0.14 mg/L)	= (0.55 mg/L)	+ (>100 mg/L)
Human health criteria	Carcinogen	EPA B2, IARC 3	?	= (indicated in rodents)	?	?
	Reproductive toxicity	Yes (Prop 65, EU; NOAEL = 3.7–100 mg/kg bw/d)	+	+	+	= (potential fetotoxicity)
	Occ. exposure to emissions (mfg)	Yes	=	=	?	–
	LD50	34 g/kg	?	+	+	–
	Irritation	Yes (Dermal, Ocular, Respiratory)	= (D,O); + (R)	+	=	+ (D); = (O,R)

In this example you can see that the criteria focused on were associated more qualitatively with life cycle considerations than quantitative data.

5.3. Discussion

While the work of the Institute indicated that alternatives assessment can be done efficiently, resulting in valuable information to promote the adoption of safer alternatives in specific applications, it is clear that this work is limited in scope and can be built upon to create a more universally applicable methodology. To this end, the Institute gathered representatives from a number of states in 2008 to discuss the need for shared resources and a common language with respect to assessing the availability of safer alternatives for chemicals of concern. The state representatives decided to work collaboratively to create a protocol for conducting safer alternatives assessments. The intent was to create a flexible and adaptive set of steps that form the shared understanding of what constitutes a safer alternative to a chemical of

Table 10
Summary of plasticizer alternatives assessment for resilient flooring.

Assessment criteria		DEHP/PVC reference	Comparison of materials to DEHP/PVC		
			Linoleum	Cork	Polyolefin
Performance criteria	Color/pattern choices	Large	=	–	=
	Ease of maintenance	Easy	=	=	=
	Recyclable	Yes	–	–	=
Cost	Purchase and installation cost	\$2–\$10/ft ²	=	=	=
	Expected lifespan of material	25+ years	+	+	+
Environmental criteria	Derived from sustainable material	No	+	+	=
	Use environmentally preferred materials for installation	Possible	=	+	=
	Energy use/GHG emissions (mfg)	Reference	+	?	=
	Biodegradable/compostable	No	+	+	=
Human health criteria	Emissions of VOCs during Manufacture (M), Installation (I), or Use (U)	Yes (M, I, U)	=	=	= (M, I); + (U)

concern. The goal was not to dictate precisely how to conduct the assessment, but rather to lay out basic steps generally agreed upon at that meeting, and to provide a set of resources to draw from when a unique alternatives assessment is performed.

The states have been working together since that time to create the common protocol, which includes the elements described in this paper as well as additional steps that are essential to a comprehensive protocol for alternatives assessments. Specifically, the identification and prioritization of chemicals of concern needs to be considered. For the Institute, this step was completed by the coalition of advocacy groups and the state legislature. But the process of identifying and prioritizing chemicals of concern is an important step in the process that is being defined within the collaborative work of the states.

Another important next step that is needed to facilitate the ability of governments to utilize alternatives assessments to inform their chemicals policy is to create a searchable and comprehensive database of chemicals that provides information on the human health and environmental effects associated with the chemicals, along with the performance and cost criteria that affect the feasibility of a chemical as an alternative to the chemicals of concern. This work is currently being considered by a coalition of US states, as well as by other organizations worldwide.

The US Environmental Protection Agency is now creating Chemical Action Plans for chemicals that it identifies as being of high concern. These plans will encompass many of the activities of the alternatives assessment methodology presented herein. Indeed, one of the first chemical classes to be addressed under this new program is phthalates.

Finally, it is important that policy makers and technical assistance providers discover innovative ways to promote the adoption of safer alternatives. These incentives may range from regulatory restrictions on the use of specific chemicals of high concern for specific uses (such as the Safer Children's Products Act in Maine, which will identify and limit the use of chemicals of high concern in children's products), to creating tax incentives for companies to switch from the use of identified chemicals of concern to "safer" chemicals. One of the challenges in this area is in fact the definition of "safer" in this context. Currently, and as presented in this methodology, a "safer" chemical is a chemical that is not considered to be "worse" than a chemical of concern based on an assessment of the environmental and human health and safety criteria established for the chemical of concern.

6. Conclusions

The detailed information provided by the Institute at the conclusion of the work was designed to serve as a valuable resource

for anyone interested in understanding the alternatives to the five chemicals that were examined. The alternatives assessment was designed to be useful to policy makers, industry, public health and environmental professionals and advocates, and other stakeholders. In every case, at least one alternative was identified that was commercially available, was likely to meet the technical requirements of many users, and was likely to have reduced environmental and occupational health and safety impacts compared with the chemical of concern.

The active involvement of all stakeholders was key to the success of this project. Their expertise, willingness to collaborate and share perspectives, and review of the report were invaluable. The involvement of a wide range of stakeholders throughout the project resulted in a more accurate assessment, more valuable results, and increased understanding of the issues, challenges and perspectives among stakeholders. Stakeholder contributions to this project also revealed in detail the substantial investment firms have made in developing safer products.

Many promising alternatives were identified during this study. Some of these will require further work to determine their practicality and applicability for specific applications. Such work will speed up the adoption of these alternatives, and could include detailed discussions with vendors and users, independent laboratory testing of technologies, pilot-scale industrial installations, supply chain workgroups and demonstration sites. The Institute has had success using these approaches for industrial toxics use reduction, and believes that there are many parallels for small businesses and consumer products.

The Institute's experience with this study has also yielded important lessons about the methodology of alternatives assessment. The experience of the Institute and the information contained in this report indicate that alternatives assessment was a useful approach to organizing and evaluating information about chemicals and alternatives.

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Estimated chemical usage by manufacturers in Connecticut

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ABSTRACT

Background: There is little available data on chemical use patterns by companies, with few federal requirements for reporting. This results in difficulties for targeting toxics for possible substitution, assisting employers with complying with newer international regulations, and decreased ability to estimate health and environmental impacts.

Methods: Massachusetts chemical use data for manufacturers required under the Toxics Use Reduction Act (TURA) was acquired, with corresponding information on industrial sector classification and employment levels by sector for both Massachusetts (MA) and Connecticut (CT). The MA chemical data was adjusted based on the ratio of employment levels by sector for CT compared to MA to give estimates of chemical usage by sector in CT.

Results: It was estimated that there was over 660 million pounds of chemicals used in CT, with over 300 million pounds each of carcinogens and reproductive hazards (categories overlap). The most common chemicals estimated to be used were styrene monomer (266 million lbs.), sodium hydroxide (60 million lbs.), and methanol (50 million lbs.). The industrial sub-sectors estimated with the highest chemical usage were chemical manufacturing, plastics and rubber products manufacturing, and fabricated metal product manufacturing.

Conclusion: There is extensive chemical use in CT manufacturing, but little direct information on actual use patterns.

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1. Background

The US EPA is responsible for assessing exposure and health risks of industrial chemicals in commercial use under the U.S. Toxic Substance Control Act (TSCA). Unfortunately, TSCA has been heavily criticized for its failure to significantly diminish the chemical impact on human health and the environment, including no requirement for a minimum required set of exposure, hazard and health data (Wilson and Schwarzman, 2009; Denison, 2009; Wilson, 2008; Wilson et al., 2006; GAO, 2005; Schwarzman and Wilson, 2009). In the early 1980s, several initiatives at the federal level and at the state level (e.g. Massachusetts Toxic Use Reduction Act) were implemented to better characterize and understand chemical use patterns within industry (Laden and Gray, 1993).

At the federal level, the National Institute of Occupational Safety and Health (NIOSH) conducted the National Occupational Exposure Survey (NOES) to collect information on occupational exposures to chemical, physical and biological agents (NIOSH, www.cdc.gov/noes) (Sundin and Frazier, 1989; Boiano and Hull, 2001). Although

some of the NOES data is currently available to utilize, it has not been updated since 1990, and it does not provide complete chemical usage data by company since it was a sampled survey rather than an inventory. Other federal databases, such as the Toxic Release Inventory (TRI) data, is limited to only very large quantities of stored chemicals (Horvath et al., 1995). Companies that produce more than 25,000 pounds or handle more than 10,000 pounds of a chemical selected by TRI must report. As a result, there is insufficient data available on patterns of chemical use by company, industry sector, and occupational categories in the United States.

At the state level, Massachusetts has collected high quality data on chemical usage for manufacturing facilities through its Toxic Use Reduction Act (TURA) (Mayer et al., 2002). TURA requires reporting on over 1400 chemicals, although only about 250 have been used and reported in practice. Since there is no current system to identify chemicals of concern in Connecticut, and Connecticut has industry patterns somewhat comparable to Massachusetts, the Massachusetts TURA data is used in this study to estimate chemical usage in Connecticut. The data from this model will begin to assist state agencies to better understand chemical use patterns among Connecticut industries, and to provide guidance on how the state may initiate programs and services to promote safer alternatives to toxic chemicals.

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2. Methods

Under TURA, companies are required to report all of the chemical substances on the federal TRI under Section 313, as well as substances on the federal Comprehensive Environmental Response and Compensation Liability Act (CERCLA), except for delisted chemicals. A Massachusetts TURA (Toxics Use Reduction Act) database of chemical usage organized by company was obtained from the Toxic Use Reduction Institute, including Standard Industrial Classification (SIC) codes of reporting companies. These reports were broken into manufactured amount, processed amount, and “amount otherwise used” to determine the total chemical quantity used. Total chemical use was organized by the chemical name and facility/industry. SIC codes were converted into NAICS codes using the code translator at www.naics.com. NAICS is the modern six-digit industry identification system of coding used by OSHA, which allows greater coding flexibility over the four-digit structure of the SIC system. If old SIC codes could be converted into more than one new NAICS code, databases and websites that provide the current NAICS code such as www.manta.com were utilized to overcome translational problems and acquire the proper NAICS code. Employment by NAICS industry codes for Connecticut (CT) and Massachusetts (MA) was based on Bureau of Labor Statistics data for 2006. The proportion of the CT workforce in relation to MA workforce was calculated by dividing employee numbers using the first 3-digits of NAICS industry sector. This proportion was then applied to the chemical use data for each manufacturing sector in MA to estimate the probable chemical use by sector in CT. There are a number of other approaches that could potentially be used for extrapolating from MA data, such as overall population fraction or number of companies. We felt that since manufacturing sectors often share the same processes and chemicals, that production levels tend to be proportionate to employment, and that MA and CT have roughly similar economies, that the proportion of workers in CT compared to MA by sector would be the most accurate way of estimation for specific chemical use.

3. Chemical groups

Chemical estimates in CT were totaled and organized into seven ‘Chemical Group’ categories as defined by TURI including reproductive toxins, carcinogens, common solvent, “more hazardous” chemicals, “Persistent, Bioaccumulative, and Toxic (PBT), metals, and organochlorines (TURI, 1999). Reproductive toxins are chemicals defined as reproductive toxins listed by Physicians for Social Responsibility. Carcinogens are taken from the TRI Public Data Release OSHA Carcinogen list (EPA, 1999). The Common Solvents

category was developed by TURI and the TURI Surface Cleaning Lab and includes solvents commonly used in industry that are able to dissolve or disperse substances. The “More Hazardous” chemicals category was developed by the TURA Science Advisory Board and published in the report *Categorization of the Toxics Use Reduction List of Toxic and Hazardous Substances*. PBT are chemicals that appear on the *Draft EPA PBT Chemical list (EPA, 1998)*. Metals are any TURA chemical that is a metal (not including zinc which was removed due to an alteration in reporting requirements). Organochlorines are carbon chemicals containing chlorine.

4. Results

There was an estimated total of 675 million pounds of reportable chemicals used in manufacturing in CT based upon the MA reporting figures. The most common specific chemicals are noted below.

Chemicals were put in categories, as noted above (Fig. 1); categories frequently overlap, and so add to more than the above total. Chemicals categorized as *reproductive toxins* totaled to 314 million pounds, with the most common reproductive toxins being styrene monomer, glycol ethers, toluene, epichlorohydrin, lead compounds, and diethyl hexyl PHT, all with over 1 million pounds of estimated usage. Reproductive toxins include 22 chemicals on the TURI list. Carcinogens have extensive overlap with reproductive toxins since they have similar mechanisms of action. *Carcinogens* totaled 304 million pounds, with the most estimated use for styrene monomer, followed by sulfuric acid, formaldehyde, dichloromethane, diethyl hexyl PHT, and lead compounds, all with over 1 million pounds. There are 47 carcinogens on the TURI Carcinogen list. *Common solvents* accounted for an estimated 112 million pounds, led by ethanol, glycol ethers, and toluene, each with over 10 million pounds. There are 26 chemicals on the TURI “Common Solvents” list. “*More hazardous*” chemicals, covering 40 chemicals in the TURI list, totaled 48 million pounds, led by sulfuric acid, formaldehyde, chlorine, epichlorohydrin, and lead compounds, all with over 1 million pounds. *PBT*’s, 28 chemicals from TURI, totaled 21 million pounds, led by zinc and compounds, lead compounds, diethyl hexyl PHT, and copper compounds. *Metals*, comprising 27 chemicals from the TURI category, totaled 20 million pounds, led by zinc, antimony, lead (2.5 million lbs), and copper compounds. *Organochlorines*, with 26 TURI chemicals, totaled 8 million pounds, led by dichloromethane and epichlorohydrin.

The industry sub-sector that is estimated to use the most chemicals in Connecticut is Chemical Manufacturing (325000) at an estimated 600 million pounds (Fig. 2). The Chemical Manufacturing sub-sector is defined by NAICS as companies

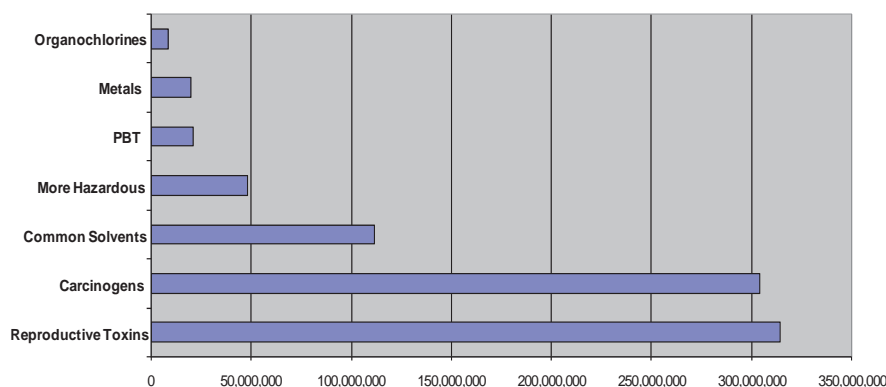


Fig. 1. Chemical usage by chemical group, pounds, estimated for CT.

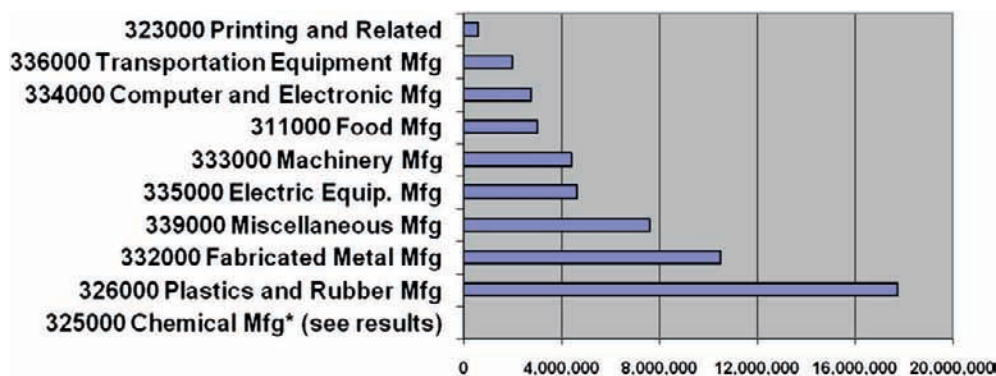


Fig. 2. Chemical usage by industry sector (NAICS code), pounds, estimated for CT.

transforming organic and inorganic raw materials by a chemical process to create a product. Companies in the Plastics and Rubber Products Manufacturing (326000) sub-sector make goods by processing plastic materials and raw rubber, and accounted for an estimated 17 million pounds. Industries in the Fabricated Metal Product Manufacturing sub-sector (332000) were estimated to use over 10 million pounds of chemicals in CT. These industries transform metal into intermediate or end products, other than machinery, computers, electronics, and metal furniture. Important fabricated metal processes are forging, stamping, bending, forming, and machining used to shape individual pieces of metal; and other processes, such as welding and assembling, used to join together separate parts.

5. Most commonly used chemicals

5.1. Styrene

Styrene monomer (Fig. 3), with a total use of 266 million pounds, is estimated as the highest volume chemical in Connecticut. It is primarily used to make plastics and rubber, and is used in insulation, fiberglass, plastic pipes, automobile parts, shoes, drinking cups and other food containers, and carpet backing.

The International Agency for Research on Cancer (IARC) has concluded that styrene is a possible human carcinogen, and the US EPA defines it as “a suspected toxin to the gastrointestinal, kidney, and respiratory systems” (ATSDR, 2007a).

5.2. Sodium hydroxide

The amount of sodium hydroxide used in CT is estimated at nearly 60 million pounds. Sodium hydroxide (also known as caustic soda or lye) is used to manufacture soaps, rayon, paper, explosives, dyestuffs, and petroleum products. It is also used in processing cotton fabric, laundering and bleaching, metal cleaning and processing, oxide coating, electroplating, and electrolytic extracting. Sodium Hydroxide is a corrosive chemical and contact can severely irritate and burn the skin, eyes and respiratory system (ATSDR, 2002).

5.3. Methanol

It is estimated that about 50 million pounds of methanol is used in CT. It is a basic building block for numerous chemicals which are used in the construction, housing, or automotive industries. Varnishes, shellacs, paints, windshield washer fluid, antifreeze,

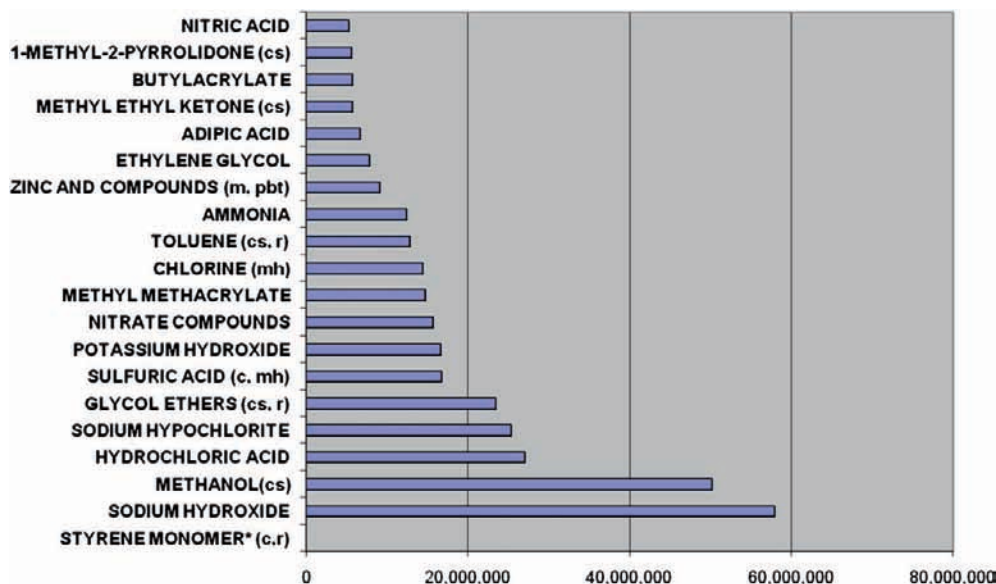


Fig. 3. Most commonly used chemicals in manufacturing, pounds, estimated for CT. Key: c, carcinogen; cs, common solvent; mh, more hazardous list; pbt, persistent, bio-accumulative, toxic; r, reproductive hazard; m, metal. *Styrene monomer was too large for graph: 266 million pounds.

adhesives, and deicers are some of the consumer products that contain methanol. Methanol is very acutely toxic in humans. The U.S. EPA has concluded that methanol is likely to be carcinogenic to humans by all routes of exposure although the mode of action for cancer is unknown. (EPA, 2009).

5.4. Hydrochloric acid

Approximately 25 million pounds of hydrochloric acid is estimated to be used by manufacturers in CT. Hydrochloric acid is used to produce chlorides, fertilizers and dyes in many different industries including electroplating and rubber. It is corrosive to the respiratory organs, eyes, skin, and intestines. (ATSDR, 2007b).

5.5. Sodium hypochlorite

Sodium hypochlorite use is an estimated 25 million pounds in CT per year. Sodium hypochlorite (bleach) is used for bleaching and disinfecting. Significant amounts of sodium hypochlorite is used in agriculture, chemical industries, paint and lime industries, food industries, glass industries, paper industries, pharmaceutical industries, synthetics industries and waste disposal industries. Sodium hypochlorite is corrosive to the eyes, skin, respiratory and gastrointestinal tissues and can be fatal (ATSDR, 2002).

5.6. Glycol ethers

The model estimated that CT uses over 20 million pounds of glycol ethers. Glycol ethers are used as solvents and as an ingredient in cleaning compounds, liquid soaps, and cosmetics. Acute (short-term) exposure to high levels of the glycol ethers in humans results in narcosis, pulmonary edema, and severe liver and kidney damage, and intoxication similar to the effects of alcohol. Chronic (long-term) exposure to the glycol ethers in humans may result in neurological and blood effects, including fatigue, nausea, tremor, and anemia (a shortage of red blood cells). Some glycol ethers have been shown to be a reproductive toxin in laboratory animals where low-level exposure glycol ethers caused birth defects and damaged sperm and testicles (EPA, 2000).

5.7. Sulfuric acid

Over 15 million pounds of sulfuric acid is estimated to be used in CT. Sulfuric acid is a clear, colorless, oily liquid that is very corrosive. It is used in the manufacture of fertilizers, explosives, other acids, and glue; in the purification of petroleum; in the pickling of metal; and in lead-acid batteries (used in most vehicles). The International Agency for Research on Cancer (IARC) has determined that occupational exposure to strong inorganic acid mists containing sulfuric acid is carcinogenic to humans (ATSDR, 1998).

5.8. Potassium hydroxide

CT is estimated to use over 15 million pounds of potassium hydroxide, which is a white crystal, lump, rod or pellet which may be concentrated in a water solution. It is used in many industries such as liquid and soft soaps, fertilizers, and electroplating to make other chemicals. The chemical is extremely corrosive. It can cause serious skin and eye irritation and burns, which may lead to permanent eye damage. Breathing the chemical can irritate the nose, throat, and lungs causing coughing, wheezing and/or shortness of breath, and sores in the nose (NJDHSS, 1995).

5.9. Nitrate compounds

It is estimated that over 15 million pounds of nitrate compounds are used in CT. Nitrate Compounds are used at paper mills, chemical, lighting and large equipment manufacturers. These compounds are a suspected cause of cardiovascular outcomes such as increased blood pressure and irregular heartbeat. They may also affect the immune system (Maine, 2010).

5.10. Methyl methacrylate

Nearly 15 million pounds of methyl methacrylate is estimated to be used in CT. Methyl methacrylate is a colorless liquid with a sharp, fruity odor. It is used to make resins, plastics, and plastic dentures. Methyl methacrylate can irritate the eyes, skin, nose, and throat. It can damage the lungs causing coughing and/or shortness of breath. Higher exposures can cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency, with severe shortness of breath. High exposure can cause dizziness, irritability, difficulty with concentration and reduced memory. It may cause a skin allergy. It may damage the nervous system causing numbness and weakness in hands and feet. It may affect the liver and kidney. There is limited evidence that it is a cancer hazard (NJDHSS, 1996).

6. Discussion

There is no current comprehensive state tracking of chemical use by industry sector in Connecticut. We found that there is an estimated 663 million pounds of chemical use in CT manufacturing, underscoring the need for better tracking mechanisms.

It should be underscored that these are estimates for CT based upon MA reporting data, adjusted by workforce/manufacturing sub-sector, and not actual reporting for CT. As such, there are a number of possible inaccuracies in the data. The profile of chemical use in Connecticut may differ from MA companies with the same NAICS code, particularly if one large company dominates in either state. If one company uses a very high amount of a unique chemical, such as a chemical manufacturing plant that focuses on a particular product line in MA, the same sub-sector may focus on an entirely different product in CT. If a company in CT uses a unique chemical in high amounts, this will not be reflected in the MA data and therefore not in our estimates. However, since there is so little data currently available on actual use patterns by industry in CT, these estimates give us at least some idea of the likely magnitude, distribution, and chemicals of concern. Data is still being analyzed, and we will be comparing this data to other existing sources of data.

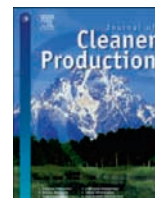
A comparison with TRI Tier 1 release data (the amount of chemicals released into the environment) for manufacturing by sub-sector was performed to assess whether the method of applying a proportion based upon employment for estimating chemical usage in this paper is valid, since this data was available for both CT and MA. There was a high correlation between the amounts by sub-sector ($r = 0.81$, $p = 0.01$) predicted by our model compared to the actual CT data, indicating that the estimate of the distribution across sectors was good. The overall estimate for CT chemical releases based on the MA data (adjusted by size of workforce for CT) was 17 million pounds, compared to 40 million pounds for the actual CT amounts. This under-estimate could indicate errors from the calculation method or may be due to tangible differences such as that MA has recorded large decreases in chemical use over the life of TURA while CT has not had an equivalent program. It should be noted additionally that our estimates are for stored and used chemicals which may have different patterns than for emissions.

It is acknowledged that estimating chemical usage in Connecticut based on Massachusetts data is a poor substitute for actual data, with a number of assumptions and known inaccuracies such as chemical industry patterns that may differ dramatically depending on product line and the omission of sector uses that may be present in CT that are not present in MA. The need to do such a study underlines the serious policy inadequacies in current law and voluntary reporting. Given the known hazards of many chemicals, the known lack of complete research and standards on most chemicals, and the clearly very high use of chemicals based on this analysis, it is important to find a way to improve our knowledge of chemical usage patterns in the U.S. (since almost all other states share the lack of information characteristic of CT).

There are several potential uses for our estimates of chemical use in CT. Results may be used to establish classes of chemicals of concern, prioritize chemicals for safer alternative assessments or green chemistry research, provide a basis for possible additional chemical reporting or surveys or CT workplaces that would be much more focused (and therefore less costly), and compile a list of industry sectors in CT with likely high chemical use, thus allowing targeted safer alternative education. A newly created Chemical Innovation Institute at the University of Connecticut Health Center (HB 5126 passed by the Connecticut General Assembly) will be attempting to pursue a number of these uses. This should prove helpful in planning for the impact of international regulations such as REACH on Connecticut exports, and also help in targeting safer alternatives to reduce both occupational and environmental impact.

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Voluntary Pollution Prevention Programs in New Zealand – An evaluation of practice versus design features

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ABSTRACT

Coordinated voluntary approaches to Pollution Prevention are widely practiced in many western-style economies. However, little empirical research has been undertaken into the extent to which these approaches match best practice pollution prevention approaches. In this paper nine programs employed by five regional and district councils in New Zealand are evaluated against nine 'Best Practice' design features. All five councils' pollution prevention programs contained some of the best practice design features in their program's design. Perhaps not surprisingly the older programs rank highest out of the five. However, all programs have the potential to develop towards containing all of the 'best practice' design features, with most emphasis needed on the credibility of program monitoring. From an ongoing research perspective, and also from an overall PP program performance point of view, the biggest challenge remains the extent and depth that the programs apply each of the design features. As presented they are extremely generic. While generic design features provide for flexibility in implementation, often seen as a positive, they can also be a recipe for 'tokenism', something that future researchers and program managers need to be aware of. We also sought to determine if these programs were contributing to sustainable management in New Zealand. Findings in this respect were equivocal. This finding in part is due to the lack of specificity around targets, monitoring and reporting, items needing further attention from managers and researchers.

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1. Introduction

Voluntary Pollution Prevention Programs (PPPs) are generally used in the policy mix to support regulation or to explore new policy areas. Substantial evidence suggests the relationship between voluntary approaches and regulation is reciprocal; voluntary approaches provide flexibility and cost effectiveness (Borkey et al., 1999). Best practice design features in a range of these voluntary PPPs were identified in Chittock and Hugheys' (2011) review of systems operating in Australia, Canada, Japan, the United Kingdom, and the United States. They identified nine key 'best practice' features, which in header form are summarised as:

- Adequate and consistent funding
- Collaborative relationship with industry

- Single sector program focus
- Setting credible goals
- Info-regulation and resources available
- Threat of credible enforcement
- Regular and credible monitoring
- Visible participant benefits
- Transparent provision of program results.

But, despite identification of guidelines, or design features, for improving practice there remains limited evidence on the effectiveness of voluntary approaches, or on the uptake of best practice approaches.

In New Zealand the Resource Management Act 1991 (RMA) is considered the cornerstone of the country's legislative approaches to environmental management, including pollution prevention. When the research described in this paper began in 2006 four regional councils (the top tier of local government and responsible for air and water quality amongst a range of other issues) and one city council (the second tier of local government and responsible for land use and the provision of most services including domestic water supply) in New Zealand were known to have initiated voluntary approaches focused on pollution prevention. With the

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number of publicly funded programs and expenditure, levied through rates, growing there is an increasing need to determine whether these programs are adopting best practice design principles.

In this paper we investigate the extent to which New Zealand councils' voluntary pollution prevention programs are developed in accordance with international 'best practice' design features, are supported by appropriate policy mechanisms and are an effective instrument for improved environmental management.

2. Methods

Comparative to most of the countries reviewed in Chittock and Hughey (2011), voluntary approaches in New Zealand are relatively young. The research reported here is the first known survey or analysis of council pollution prevention programs, although Brown and Stone (2007) do provide useful policy and related context to this evaluation, and Narayanaswamy and Stone (2007) report on business and industry initiatives in Australia and New Zealand, but not from the program perspective reported here.

We employed a mixed methods approach to achieve the three aims of this paper. This approach incorporated:

- reviews of councils' statutory policies and plans, i.e., the first aim of this paper;
- a questionnaire administered to program managers in the five councils. The questionnaire was structured around five key areas: program evolution; type of program; policy and regulation; program structure; and performance measures – it comprised of 18 questions which were a mixture of yes/no and more open-ended questions. These questions, in sum, contributed to evaluation of the design features employed and to program contribution to environmental management objectives, i.e., the second and third aims of the paper. Where insufficient information was provided to enable a judgement to be made we resorted to the informal personal interviews and discussions to elicit appropriate responses; and
- ongoing informal personal interviews and discussions with the personnel of the five councils with pollution prevention programs. These interviews and discussions occurred either over the telephone, by email or via face-to-face discussions at national meetings, and contributed qualitatively to all three aims of the paper.

Four of the councils studied are regional authorities and from the north to the south of New Zealand were:

- Northland Regional Council (NRC), the northern most regional authority, with the longest coastline of all regions,
- Auckland Regional Council (ARC), the most densely populated authority with the country's largest city (Auckland) within its boundary,
- Greater Wellington Regional Council (GWRC), centrally located at the bottom of the North Island, and containing a very diverse mix of land use types,
- Canterbury Regional Council (CRC), the largest council by land area with New Zealand's second largest city (Christchurch) within its boundary, and located in the South Island.

The fifth council, North Shore City Council (NSCC), is a territorial authority and is the fourth largest city in New Zealand, located inside the regional boundary of the Auckland Regional Council.

3. Results

3.1. Evaluation of council policy mechanisms

In New Zealand regional councils and district councils are respectively required to produce a Regional Policy Statement (RPS) or a District Plan (DP), mandated under the Resource Management Act of 1991. One similarity among all RPSs reviewed was mention of education or information provisions based around the improvement of surface water or storm water quality and hazardous substance storage. Table 1 lists the Pollution Prevention relevant features mentioned in the RPSs or district plan.

Cleaner Production is a consistent element mentioned in all four RPSs, alongside specific guidelines and Codes of Practice (CoP(s)) in the development of environmental education strategies for industry. "Cleaner production means applying a strategy to your business to make the most efficient use of resources including raw materials, water, energy, time and money whilst preventing pollution and minimizing your impact on the environment. To maintain their effectiveness, cleaner production strategies are regularly re-evaluated" (Ministry for the Environment).

All four regional councils have documented their commitment in their recent Long Term Council Community Plans (LTCCP), produced under the Local Government Act 2002, to actively include and support voluntary approaches or programs. All the relevant sections of the regional authorities' RPSs reviewed include the use of Cleaner Production principles.

The methods listed in Auckland's RPS (ARPS) (Auckland Regional Council, 1999) are very prescriptive and specifically list practices or physical systems that must be used by industry and sites to meet policy requirements. Methods specifically mention the implementation of an "Industrial and Trade Pollution Program to avoid, remedy, or mitigate the adverse effects of discharges from industrial and trade activities" (Auckland Regional Council, 1999). The other three regional councils' RPSs use a broader supporting methodology for describing their industry education provision. A broader approach in a council document potentially allows for interpretation by council personnel in the implementation and development of a voluntary industry approach. This is where the use of the words 'Industrial and Trade Pollution Program' by ARC leave no doubt as to what should be developed.

The district plan of NSCC provides less information than the RPS documents, but the district plans must give effect to RPS requirements and support them. District Plan functions, amongst others, are to control the use of land and natural and physical resources, to a lesser degree than those of a regional authority RPS. The NSCC District Plan includes the specification of guidelines for the operation and management of hazardous substance facilities. No detail on how to implement or develop this is provided; this lack of detail is comparable to the majority of the RPSs' reviewed.

3.2. New Zealand Councils' Voluntary Pollution Prevention Programs

A questionnaire was distributed at a national meeting of council program managers, an email version was also sent to all personnel involved following the meeting. A follow-up email was sent one month after questionnaires were distributed along with phone calls to check on progress and answer any questions related to the questionnaire. This occurred over a six-month period. While most councils returned the questionnaires within four weeks, one took six months. Greater Wellington Regional Council was the only council to not return the questionnaire. The relevant material and review of their findings relied on personal discussions with the program leader and their website for research material. Senior

Table 1
 Voluntary Approach mechanisms in regional and local environmental policy documents (Empty cells indicate no relevant information was found.) – definitions of ‘method’ and ‘policy’ given in column 1 are consistent with the Resource Management Act 1991 – see <http://www.qualityplanning.org.nz/definitions/index.php> – accessed 12 February 2010.

Policy areas	Northland Regional Council Regional Policy Statement	Auckland Regional Council Regional Policy Statement	Wellington Regional Council Regional Policy Statement	Canterbury Regional Council Regional Policy Statement	North Shore City Council District Plan
Principles (main or leading ideas)	Cleaner production	Cleaner production and education	Cleaner production Anticipatory and flexible approaches are 2 of 13 guiding principles of GWRPS	Cleaner production	
Methods (a specific course of action to implement a policy specified in a plan, and includes rules and other regulatory methods, and non-regulatory actions)	Implementation includes: education, industry based CoP or guidelines, provision of information and environmental standards	Prescriptive and specific CoP, guidelines and education program Industrial and Trade Pollution Program	Where necessary develop standards, guidelines and CoP in co-operation with industry Education and information provision to change behavior	Use of CoP, environmental education, advocacy	Specifying guidelines and best operational practices and promoting excellence in managerial practices
Policies (a general course of action taken by the local authority to achieve an objective)	Policies promote best management practices		The complementary use of voluntary approaches is a stand-alone option for supporting industry	Information provision to change people's perceptions, attitudes and behavior Better management practices Education and information provision alongside regulatory methods	Education program for business in conjunction with ARC Education in conjunction with rules
Regulation (imposed by government and given effect through a rule in a plan)		EMP to meet permitted activity status Voluntary EOP is considered to satisfy regulation conditions	Complement to regulation when consent required Balanced approach	Education and information provision alongside regulatory methods	

program personnel from Greater Wellington Regional Council reviewed this analysis to confirm its accuracy.

Returned questionnaires were evaluated against the ‘best practice’ design features identified in Chittock and Hughey (2011). The council's pollution prevention program design features were identified as each questionnaire was reviewed. When a design feature was not able to be identified from the questionnaire alternative inquiry mechanisms were used. These included further review of council websites, reports, policy documents and publications before finally contacting program personnel and asking them explicitly about the design feature. The following five sections each deal with an individual case council, with results reported in the following order: a general introduction to the program and its development; progressive comments on each of the nine design features; and, a final comment where appropriate on general contribution of the program to environmental management in the region or district.

3.2.1. Northland Regional Council – Pollution Prevention/Cleaner Production

The Northland Regional Council voluntary program began in 2006. It developed from statements in the RPS (Northland Regional Council, 1999) and Regional Water and Soil Plan (RWSP)(Northland Regional Council, 2004) that mandate waste minimization work with industry, thus leading to the appointment of a Cleaner Production/Pollution Prevention Officer (CP/PPO). The program is classified as a public voluntary program, with a relatively informal approach used in its implementation with industry.

The CP/PP program is fully ratepayer funded, with no direct cost to the site. Business participants welcome the ‘free’ funding concept, but can find it hard to believe; first, that the council will not initially penalize them for environmental issues found on their sites and, second, for identifying possible areas where they may be able to find efficiencies and reduce costs.

The program is classified as a public voluntary program, with a relatively informal approach used in its implementation with industry. Overall it attempts to be collaborative.

Cleaner Production was the initial focus of the CP/PPO, however their first two sector groups (vehicle washing and auto dismantlers/scrap dealers) had a pure Pollution Prevention (PP) focus (i.e., they had an almost total focus on prevention of water pollution). The third group, boat-building, allowed the use of a broader Cleaner Production (CP) and PP inclusive approach. Due to the scale and nature of the boat-building industry with a full manufacturing process, greater scope for resource efficiencies through CP was possible. Efficiencies were created through optimising processes and developing a continuous improvement culture. The PP/CP program approaches all known sites within an industry group, the program will continue to develop and is flexible in its approach allowing it to adjust to the industry sector worked with to achieve the desired environmental outcomes.

The objective of NRC's program is the promotion of environmental awareness combined with the acceptance and adoption of pollution prevention techniques. Measurement of the program against this objective is empirical in nature with witnessed changes to site practices and behaviour gauging the success of the program.

Program promotion is through direct contact with individual sites or industry groups and information available on NRC's website (www.nrc.govt.nz) and the networking of the CP/PPO. The program also interacts with agencies, such as Enterprise Northland, who promote and encourage sustainable economic development in partnership with central government, local industry, business and local councils. Successful case studies will be written up and used in future to publicize the program further to the business and industry groups, this may help to allay some business fears of working with

a regulatory authority. Behavioural change is a large part of the process with initial points of contact being addressed to business or site management. Their direct involvement depends on the size of the business approached and management's enthusiasm for the program, in some cases responsibility may be designated to operational management level personnel.

The Pollution Prevention Program has enforcement links. These can be utilized within the Regional Council structure for businesses reluctant to comply with recommended PP measures that relate to current regional rules and relevant legislation.

Sites that are slow to respond are followed up on; those that resolve their site issues are thanked with a letter and used as role models for others in the industry.

To date the only potential direct benefits to program participants are the resource efficiencies through the CP component of the program but this has not been applicable to all three industry groups covered. Indirect benefit for a participant occurs through the reduced potential for enforcement action and monetary fines by working co-operatively with the CP/PPO. It has been reported by the NRC CP/PPO that greater success has been had with industrial participants when a pollution prevention perspective is used with more of a potential enforcement focus on environmental issues, as opposed to a CP perspective with an "I can help you save money by reducing waste" focus.

The program is not reported on in council annual reports.

3.2.2. Auckland Regional Council (ARC) – Industrial Pollution Prevention Program

ARC's urban pollution control program began in the mid 1970s. The program then was purely responsive to incidents of pollution reported by the public and other agencies. The first proactive pollution control program of visiting and auditing industrial sites occurred in the mid 1980s in the Manukau Harbour catchment. The proactive auditing component was continued following the implementation of the RMA and undertaken by ARC's Pollution Control Team who developed an urban pollution control system called the 'Industrial Pollution Prevention Program (IP3).

There is no initial cost to a business site for the voluntary program, however if a site has been visited previously and/or significant pollution is found ARC may seek to recover costs if appropriate. Costs can include officer time, mileage, sample analysis fees and any other material expenses.

The IP3 program is designed to work proactively and co-operatively with businesses with a firm-but-fair policy underpinned by statutory enforcement tools. Evolution of the purely voluntary program has changed with the introduction of the Proposed Auckland Regional Plan: Air, Land and Water (Auckland Regional Council, 2005), potentially requiring all moderate and high-risk industrial or trade process sites to have an Environmental Management Plan (EMP). A guide and template provides the basis for sites to create and implement their own EMP.

Over the last decade a number of different types of interventions have been implemented from:

- Targeting industry sectors with high pollution risk
- Working with business communities located near sensitive catchments
- Proactive and voluntary initiatives
 - From guidance in the form of an industry sector letter
 - On-site audits
 - Catchment or sector-based workshops.

The primary objectives of IP3 are to protect and improve land and water quality from industrial and trade activities through

targeted pollution audits or assessments to ensure compliance with the RMA by:

- Identifying and stopping any actual pollutant discharges to land and/or water
- Identifying and eliminating, or putting in place site management controls, to address potential discharges, and
- Ensuring industrial site operators are prepared to deal with accidental discharges through the preparation of emergency spill response plans.

Assessments of high-risk industry sectors were compliance based; other lower risk industry groups had proactive visits providing information and discussing pollution prevention opportunities. Education material provided to industrial sites includes the Environmental Operations Plan (EOP) and industry specific fact sheets designed in conjunction with the industry groups.

Sites with identified issues are followed up on to make sure the issues are resolved; sites that require consents are followed up by programmed compliance monitoring visits.

Internal measurements for gauging program success include the number of sites assessed by the Industrial Trade Processes (ITP) team and the number of consents participating sites require and apply for. A key objective of ARC's voluntary program is to identify if resource consent is required. It needs to be noted that the ITP team are also responsible for processing and monitoring consents for the discharge of contaminants onto or into land from industrial or trade processes.

Auckland RC views reduced risk of pollution incidents, associated clean up and enforcement costs as indirect financial benefits to a program participant.

Within the LTCCP (2006–2016) (Auckland Regional Council) one publicized form of measuring the program's success is the annual reduction of repeat pollution incidents from industrial or trade premises.

Overall, there is no long-term measurement of the EOP program's effectiveness with regard to improving environmental performance.

3.2.3. North Shore City Council – Pollution Prevention

Pollution prevention work has been undertaken by North Shore City Council (NSCC) since 2001, the main focus being on issues related to the identification and prevention of surface water pollution to the storm water system. Included in this work is the 'blitz' program which targets industrial, commercial or catchment based areas.

This work is ratepayer funded and generally carried out in the form of selected industrial and commercial area or catchment 'blitzes'.

NSCC staff utilize the "private agreements" type of voluntary approach when working with a site; this is established by 'direct bargaining' over specific issues identified.

The selection of a blitz area is based on historical pollution incidents, location of high-risk businesses and the sensitivity of the receiving environment (e.g., surface water) – the program is multi sector.

There is little in the way of explicit action in terms of setting credible targets.

'Blitzes' aim to "identify sources of actual or potential pollution on-site and ensure that companies and individuals are complying with New Zealand's environmental legislation" (Pollution Prevention). The program focuses on the manager of a site and encourages action to be taken. An initial site visit is made with a follow-up site visit if necessary to ensure compliance.

All sites visited receive a letter thanking them for their participation and covering any issues that were identified during the blitz (Chittock, 2008).

The council uses the media to advise and warn businesses they are planning a 'blitz' and also to provide feedback to the community once the blitz has been completed.

The benefit of NSCC's program to the business is a reduction in risk of an illegal discharge and potential fines.

Public reporting of the program achievements is mentioned in two of the last four annual reports (Pollution Prevention). Like most councils' annual reports, both regional and territorial, only high level project information is reported on.

In August 2007 the NSCC reviewed its proactive pollution prevention programs, including the 'blitz' approach to ascertain the effectiveness of different methods for encouraging behavioural change. The focus groups included industry sites the NSCC pollution prevention team had visited, those they had sent information to and a control group with no solicited council contact. The objectives of this review included determining business attitudes and knowledge of their environmental responsibilities and the assessment of current interactions between businesses and pollution prevention staff and identifying barriers for businesses in implementing pollution prevention measures.

Findings from the focus group evaluation showed that NSCC was sending out too much general information; businesses are only interested in what is directly relevant to them and the implications for their business. The two groups who had contact with pollution prevention staff appeared to have higher levels of awareness about environmentally responsible business behaviour, specifically spill kits, not washing to drains and safe storage and disposal of hazardous wastes. The third group had reasonable awareness levels, particularly those members of a trade association; however most saw the issues as common sense.

The focus groups concluded the future direction of the NSCC program should be to:

- Work further with industry groups and associations,
- Develop a green grading system for rating business compliance,
- Publicize offenders and good performers,
- Provide workshops for businesses in environmentally risky industry sectors.

Subsequent recommendations that came from the focus group research have been included in future planning considerations of NSCC:

- Blitz type programs will continue but will target more high-risk industry sectors, with industry specific information,
- Publicize compliant businesses and make examples of non-compliant, and communicate financial benefits of being compliant (costs of spills, fines)
- Work with other council departments so that a variety of issues are covered when visiting a business, not just pollution prevention (e.g., waste minimization, energy and water consumption and trade waste)
- Have greater follow-up with sites visited to check action is actually done, provide further information or take enforcement action (North Shore City Council, 2007).

3.2.4. Greater Wellington Regional Council (GWRC) – Take Charge

The 'Take Charge' program was established in 2001; the principal objective was to assist businesses to identify and address their environmental problems, and provide the foundations for them to

go beyond compliance if they choose. This could be achieved via recycling, cleaner production, management systems and other environmental initiatives.

Funding for the Take Charge program has varied, even though the program is fully ratepayer funded. Budgets have never been fully utilized with three of the seven years reported spending less than 50% of their allocated budget. GWRC is the only council researched to publicly provide individual program budgets in their annual reports.

Environmental Protection Officers (EPOs) implement the 'Take Charge' voluntary program and work collaboratively with sites to implement practical solutions to identified issues and to improve overall environmental performance (Greater Wellington Regional Council).

Take Charge is a generic voluntary program. Initially the approach of the program was to focus on one or two industry groups and approach all the businesses within these industries. The program then changed to include the catchment approach in conjunction with an industry approach, with the catchment approach seemingly used to a greater extent today.

Audits identify actual or potential environmental pollution of a significant nature; however formal steps may be taken to effect an improvement.

This program included information workshops, a guideline, checklists and standard resource consent conditions for council staff, contractors, consultants and developers (Greater Wellington Regional Council).

'Take Charge' uses a 'carrot and stick' approach. This is consistent with the objectives of the Environment Division's Strategic Plan 2002–2010, where divisional priorities for the Environmental Regulations Department include:

- A hard line on compliance, using a fair and reasonable (but non-nonsense) approach and;
- Increased emphasis on pollution prevention (Greater Wellington Regional Council).

In the 2005–2006 year changes were made to site resources for EPOs, this included the implementation of a new 'Take Charge' audit form; this was developed to remove the delay between the site audit and the formal report being delivered to the site. Audit reports can be issued on the spot, giving recipients an instant record of their performance and reminder of actions required. During 2005 revisits were conducted for service stations and motor vehicle workshops where significant issues were identified from previous years (Greater Wellington Regional Council). GWRC personnel have analyzed their program and found that to get committed action by participants to change site practices a minimum of three visits is required.

GWRC are considering introducing a certificate of support or acknowledgement, for participating businesses.

The parameters for measuring the impact of the program are set each year in the annual plan and reported on in the annual report. In the last four years' Pollution Control Annual Reports, the industry groups targeted and the numbers of actual site audits conducted have been recorded. Information on catchment based approaches and why areas are selected are summarized along with other projects undertaken under pollution prevention initiatives. All Annual Environmental Incident Reports and Pollution Control Reports from 1998 onwards are available online (Greater Wellington Regional Council).

Over time the program began to explore more integrated approaches to environmental management. For example, the environmental protection team contributed to an environmental management guideline prepared by Vector, a network utility

operator, for contractors to use when installing power cables and undertaking maintenance. This included proposing pollution control measures and presenting them to Vector's contract managers (Greater Wellington Regional Council). During this same period a guideline for developers and contractors to use when designing and developing subdivisions on steeper sites was published. This activity was causing increased siltation of many watercourses in areas under development pressure in the region.

3.2.5. Canterbury Regional Council (CRC) – Pollution Prevention Guide

In 2002 CRC implemented a voluntary program called the Pollution Prevention Guide (PPG). The PPG is described as; "An Environmental Guide for Business describing appropriate site management of hazardous substances and solid and hazardous waste" (Canterbury Regional Council). In February 2005, following a diesel spill in a local river, the program employed Pollution Prevention Officers (PPO) to promote and implement the PPG to industrial and business sites in Canterbury.

The PPG program is fully ratepayer funded with no costs to sites for staff time or resources provided. It is proposed to run until at least 2016 as stated in the LTCCP (Canterbury Regional Council).

In most cases management, or in smaller businesses the owners, are contacted to discuss participating in the PPG program. Approaches at this level allow ownership to be taken by management and if implementation of the program is passed to relevant staff, the PPOs know that any inaction can be redirected back to management for resolution. A strong collaborative approach is thus being fostered.

The CRC voluntary program approaches and works with individual sites, industry groups and associations to promote and gain access to potential program participants. Referrals from existing sites that already use the program is another method used. Implementing this strategy means that potentially all sites within a sector are contacted, maintaining a level playing field and program credibility. Not all sites approached or worked with in the program hold resource consents. The program is clearly generic.

The PPG is a modular document in the form of a basic environmental management system or plan, designed to improve environmental practices and prevent pollution. It is intended to show a business has documented evidence of its site activities and procedures and reduced the risk of causing harm to the environment.

The PPO provides a written site assessment of the issues with an agreed resolution timeframe for site personnel to work to; this allows measurement of a participant's achievement.

The development of the program from a purely written resource for industry, to having staff to work with sites in its implementation, has seen the PPG develop into a voluntary program.

The PPG program is designed to raise awareness and improve the environmental practices of sites and compliance requirements. If a site implementing the PPG program is found to contravene a CRC rule during a site assessment and the site chooses to not rectify the issue, then enforcement will be notified. Leniency is provided first, the site is made aware of why the activity is an issue and given the opportunity to voluntarily comply and rectify the issue.

Implementation of the program involves at least two site visits, one to introduce and assess the site and at least one follow-up visit to check on implementation progress and issue resolution. All issues found are ranked into categories of risk posed to the environment and risk of breaching rules or regulation.

Follow-up visits are planned after a two-year period to see how the site is performing. Contact with sites is maintained by sending out holiday shutdown procedures to all participants twice a year, along with requests for six-month progress reports from all sites.

Consented sites that return four consecutive six-month reports are entitled to have their compliance monitoring visits reduced; this reduces participating sites' costs as these are paid for by the consent holder. Other benefits include the promotion of program participants through case studies on the CRC website and in local newspapers and CRC publications. Participants required to obtain spill kits from site assessments are entitled to a discount from participating spill material providers.

The stated objective of the PPG program is; "Providing advice on preventing pollution from industrial and commercial sites, to protect the environment." The PPG program is measured on; "the number of business sites that receive a site assessment and guidance on pollution prevention each year" (Canterbury Regional Council). In the first two years neither target has been met due to staff recruitment taking longer than expected, and the higher than anticipated number of issues found on sites visited (Canterbury Regional Council).

Future plans for the program include industrial catchment based approaches around urban waterways with water quality issues.

3.3. Program evaluation compared to 'best practice' design features

Table 2 provides a summary comparison of the New Zealand local voluntary programs against the 'best practice' design features. The five reviewed councils' programs all have a common element of protecting water quality. This is achieved through the provision of information and/or resources to industry to raise awareness of compliance requirements as stated in regional and district rules. Funding for all regional or district councils is derived from ratepayers, the provision for funding council led programs can vary as budgets can be changed to accommodate other areas that have greater environmental or public impact.

Adequate and consistent funding – the five council funded programs appear to have adequate levels and longevity of funding to remain operational, although GWRC has had instances where budgets were under spent. ARC's IP3 program is the only one to state it may recover costs if warranted by the magnitude of issues found during a site assessment. Council funding for all programs can be subject to change, when issues of regional significance arise there can be some precedence placed on these and if funds are required then some budget 'trimming' can occur.

Collaborative relationship with industry – most councils mentioned the development of sound relationships with industry or the business sector. The NSCC 'blitz' approach means that relationships are more informal and one-on-one rather than with a sector association or group. Northland RC is developing its industry relationships informally also, but endeavors to work with all known sites within a sector. The remaining councils' programs have been running longer allowing more time to approach and work with industry and supporting organizations, e.g., GRWC and ARC have Codes of Practice and/or guidelines in place for various sectors.

Single sector program focus – all council programs are generic in their design although ARC is instigating a change to a sector specific approach as stated in their LTCCP 2006–2016. The NRC program is semiformal and like NSCC is not supported by a documented generic guide, this approach allows the CP/PPO to tailor a program to each sector targeted. Greater Wellington RC and CRC have a generic management system guideline; staff implementing the program can provide information relevant to that site during or following a site visit. The NSCC model is broad and based solely on a catchment basis and all sites within that area are visited.

Setting credible targets – the three programs that have been running longest (ARC, GWRC & CRC) set completion targets and/or

Table 2
Evaluation of New Zealand Voluntary Programs against 'best practice' design features.

Design Features	Northland Regional Council	Auckland Regional Council	North Shore City Council	Greater Wellington Regional Council	Canterbury Regional Council
Adequate and consistent funding	Program developing, funding adequate	Adequately funded. Part funded by cost recovery from repeat participants or sites with significant pollution issues. Projected to remain for the next 8 years	Adequately funded	Fluctuated early on and funding under utilized some years. Projected to remain constant for next 8 years	Relatively consistent. Projected to remain for the next 8 years
Collaborative relationship with industry	Yes, developing and approach also includes the community	Yes, industry relationships developed. CoPs and guidelines developed collaboratively	Developing, utilize ARC information	Yes, liaison with industry sectors producing specific industry guidelines	Yes, increasing liaison with industry sectors, fact sheet development
Single sector program focus	No, generic approach at present	Under development, moving into sector focus from generic approach. EMP is an adaptable template for sites to use	No, pollution prevention focus, catchment blitz approach	Initially an industry specific approach taken, with a generic guideline	Generic program used to work with all known sites within an industry sector
Setting credible targets (for sites that are visited)	Empirical in nature currently, measured by CP/PPO during revisits	Yes, site has issues recorded and timelines for them to be achieved in	No, only one visit made with random rechecks occasionally	Yes, site has issues recorded and timelines for them to be achieved in	Yes, site has issues recorded and timelines for them to be achieved in
Info-regulation and resources available	Industry discussion group meetings, case studies under development	Yes, EOP and CoPs developed and industry guidelines and fact sheets	Some industry information sheets available also utilize ARC information	Industry information sheets available and guidelines	Fact sheets for some industry groups. Generic workshops held with 2 sectors
Threat of credible enforcement	Enforcement links, authority is an enforcement agency. PP approach with enforcement focus used	A firm-but-fair policy, enforcement under pins the program	Not perceived as strong on compliance or enforcement	Linked to enforcement, PCOs have powers of enforcement	Linked to enforcement, authority is an enforcement agency
Regular and credible monitoring	Monitoring does occur but the frequency is not mentioned. Progress is empirical through witnessed site changes	Sites are followed up on to ensure issues are resolved. Revisits can occur from reported incidents	No, only one visit made with random rechecks occasionally	Yes, sites with significant issues revisited to monitor progress	Yes, majority of sites revisited within two months and 2 site reports requested annually.
Visible participant benefits	Only indirect through CP initiatives and reduced risk of fines	Indirect through reduced clean up and enforcement costs	Indirect through reduced risk of discharge and potential enforcement costs	Indirect through reduced liability, potential cost savings from CP initiatives. Certificate of participation being considered currently	Yes, potential for reduced monitoring costs for consented sites. Discounts on spill materials. Waste minimization incentives. Indirect through reduced risk of fines
Transparent provision of program results	Not recognised as a reported activity within council annual reports	Program not fully reported on in annual reports. Internal reports based on number of sites assessed and number of consents applied for	Sporadically reported in Annual Reports, some detail provided of the main projects and achievements	Annual plan sets the number of industry groups to be worked with, including the reduction of pollution incidents compared to baseline target, Annual Pollution Control Reports summarize actual work undertaken	Yes, actual sites visited versus proposed. Resolution of issues not reported on, generally only major report targets are monitored in brief

dates for resolving issues on industrial or business sites according to risk posed in agreement with site personnel. Neither the NRC or NSCC program mentions the setting of targets for a site to achieve objectives or resolve issues. The NRC program revisits sites that require further assistance to resolve issues, while NSCC randomly revisits sites to see if they have implemented changes to site practices.

Info-regulation and resources available – all the programs have resources or information available for participants, although the depth of information and number of resources available varies greatly. Auckland RC and GWRC have developed CoPs and/or guidelines with industry; CRC, NRC and NSCC are developing their resources as their programs evolve and develop with further industry sectors. As a territorial authority within the Auckland region NSCC utilizes the resources and guidelines developed by ARC.

Threat of credible enforcement – all councils have some level of enforcement within their structures, the only variance is in the credibility and threat of council enforcement operations. Greater Wellington RC staff have powers of enforcement, so when the voluntary approach does not work, enforcement can be carried out by the same staff member. A firm-but-fair approach is undertaken by ARC, giving the participants time to implement change and resolve issues, a similar approach was reported in both NRC and CRC programs. The 'blitz' program review carried out by NSCC, highlighted that enforcement was not perceived as strong or consistent among the business or industrial sectors, NSCC has its own enforcement capability and can also call on the ARC at a higher level.

Regular and credible monitoring – most programs followed up on program participants, however regularity varies between councils, with random revisits by NSCC, to programmed revisits and planned follow-up mechanisms for ensuring issues are resolved by CRC. The significance of the environmental issues found by ARC and GWRC were the key motivators for monitoring a site's progress. Sites that require and hold consents within ARC's program are monitored repeatedly under regulation to ensure conditions are maintained. NRC provided further staff assistance and monitoring to sites that were changing practices and reducing their environmental liability.

Visible participant benefits – most had indirect benefits relating to the reduced potential for fines or enforcement action. Most programs allow some leniency for a site to resolve an environmental issue. Production or process efficiencies through CP initiatives are available from the NRC, GWRC and CRC programs. There is the potential for reduced compliance costs for consented sites in the CRC program, along with subsidies for purchasing spill management materials. Promoting competitive advantage is planned in differing forms from GWRC with the certification of participants and the advertising of businesses completing the NSCC and CRC programs.

Transparent provision of program results – only three of the programs report publicly. In part this is due to the vast council program structures and number of reportable objectives. Generally only the main outcomes that the council perceives as a priority are reported on. The NSCC program has some reporting provided but not consistently or of any true indication of what is being undertaken or achieved. The CRC program only focuses on the number of sites visited, with the first year providing some detail on the issues found and resolved. GWRC produce an annual report on incidents and prosecutions in the Wellington area, within this a detailed review is provided on what the 'Take Charge' program has achieved. As the GWRC program becomes further established the reports have developed to provide more detail and program information.

4. Conclusions

The wealth of global research literature on voluntary approaches to pollution prevention programs shows they have merit, but they need certain design features and implementation structures to be successful (Chittock and Hughey, 2011). The objective of this research was to compare five New Zealand regional and local authorities' pollution prevention programs to the best practice design standard. Analysis shows they all have varying degrees of 'best practice' design features in place.

Auckland RC's program was the only one that may recover costs. United States research shows that this approach created a 'barrier' for industry and reduced the uptake of the program (Funk, 2002). Funding is one area that all council led programs can have difficulties with, having proposed funding for expansion or implementation of industry work declined can occur and is beyond the control of program personnel.

All councils to varying degrees had or are developing collaborative relationships with industry groups. This needs to be continued by all, especially the newer programs, to help them get established. Industry in the United States ranked collaboration with regulatory agencies as the main reason for participating in voluntary programs (United States Environmental Protection Agency, 2005).

None of New Zealand's programs are industry specific; a generic approach has been taken by all. There is flexibility and adaptation available in the local programs through the use of Codes of Practice(s), guidelines and fact sheets. ARC has started to move into sector specific programs (Auckland Regional Council, 1999). Australian research found that the best way to maximize results for voluntary programs is to include appropriate industry initiatives and design features (Gunningham and Sinclair, 2002). Canada used a template from the motor industry to develop a new program for the metal finishing and print and graphics groups, and the United States had industry established programs that collaborated with the EPA (United States Environmental Protection Agency, 2007).

Most New Zealand programs appear to set credible targets – this is a vital area all councils need to manage carefully to equitably monitor the progress of participating sites. The more recent programs need to develop this area to improve monitoring and reporting of sites, thus helping to maintain the credibility of the pollution prevention programs. All the reviewed countries did this to some degree but with no consistent process established. These conclusions are consistent with Peters and Turner (2004) who showed that the establishment of baseline data allowed accurate assessment and measurement of any site improvements made.

All councils have some form of resource or information they can supply a site with, although the newer council programs need further initiatives in this area. The NSCC focus group highlighted this in the findings – industry gets bombarded with information from councils, and they are only interested in what is directly relevant to them and the implications for their business (Rabe, 1999).

All councils have enforcement options available, although the findings of the NSCC focus groups found that industry representatives perceive council regulation and enforcement practices as weak and inconsistent. We perceive that this may not be an opinion isolated to this council, but more research is required to test this perception. Despite this view it is also clear that 'a hard line' should not be taken with every case, a period of leniency was offered by most councils and appears a good enticement and transition for businesses to join programs. Research from Oregon reinforces this view – enforcement dispensation was provided as long as program participants corrected problems that arose and subsequently

maintained an overall high level of environmental performance (Funk, 2002).

Program monitoring varies greatly in New Zealand. There is no universal set of indicators thus making comparative reporting and assessment, even within council, very challenging if not impossible. The credibility of all programs' monitoring is thus an area that all councils need to address, perhaps supported by the relevant central government agencies. This not only distorts reports on the programs' achievements, but also has the potential to damage the industry relationships that have been established. Research from both Japan (Sugiyama and Imura, 1999) and Canada (OECD, 2003) reinforced this conclusion.

All five New Zealand pollution prevention programs reported some participant benefit, the majority via indirect measures, such as lower potential for a fineable offence to occur, or clean up cost. However, Northland's CP component can provide a participant with process or operational savings, but this is not always possible with some industry groups (auto dismantlers and scrap dealers). Greater Wellington RC is investigating a 'green' certificate system and Canterbury RC have discounts available for spill kit purchases and reduced monitoring costs for consented sites. The New South Wales VEA provides industry with reduced insurance costs - this is an area that all council programs could explore further to provide further enticement for industry to participate (Pollution Control Consultancy and Design).

Greater Wellington RC provides the highest level of program results of all councils, producing a separate 'Pollution Control Annual Report' where the 'Take Charge' initiatives created, or catchments and sites worked with, are publicly recorded. Openly reporting program initiatives helps provide transparency. Research from Japan found that reports of industry agreements are sometimes kept confidential, as some agreements' effectiveness were questioned due to inadequate monitoring by authorities and infrequent submissions of emission reports by industry as agreed upon (Sugiyama and Imura, 1999). The credibility of New Zealand's pollution prevention programs need to be maintained as all are publicly funded and reporting transparency must be emphasized.

All five councils' pollution prevention programs contained some of the best practice design features in their program's design. The older programs from ARC and GWRC rank highest out of the five. Auckland RC is the only council to specifically include the use of an Industrial and Trade Pollution Program to meet policy requirements as well as looking to implement a specific industry focused program. However, all programs have the potential to develop towards containing all of the 'best practice' design features, with most emphasis needed on the credibility of program monitoring. From an ongoing research perspective, and also from an overall PP program performance point of view, the biggest challenge remains the extent and depth that the programs apply each of the design features. As presented here, and in their earliest form in Borkey et al. (1999), they are extremely generic. While generic design features provide for flexibility in implementation, often seen as a positive, they can also be a recipe for 'tokenism', something that future researchers and program managers need to be aware of.

We also sought to determine if these programs were contributing to sustainable management in New Zealand. Findings in this respect were equivocal. This finding in part is due to the lack of specificity around targets, monitoring and reporting, items already identified as needing further attention.

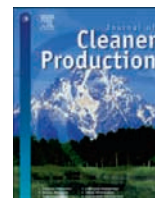
Overall then this research has highlighted that to date the small size of New Zealand and the high level of interaction between council personnel has seen programs develop largely in unison. This may not always be the case with future pollution prevention programs implemented by other councils. Based on this research the following recommendations should be focused on:

- A national framework for local council authorities to design voluntary environmental programs, including pollution prevention programs should be implemented. This ideally should be guided by input from the five councils currently implementing these programs.
- Inclusion of the 'best practice' design framework within regional and district policy documents but with improved specificity around some of the design features, particularly in terms of target setting, monitoring and reporting.

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A review of international practice in the design of voluntary Pollution Prevention Programs

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ABSTRACT

Voluntary approaches to industry-wide pollution prevention programs have gained a global impetus. Despite this impetus relatively little research has been undertaken into identifying key features of successful programs. This research identified these features by reviewing selected programs in five countries, Australia, Canada, Japan, the United Kingdom and the United States. Nine key features have been identified, namely: Adequate and consistent funding; Collaborative relationship with industry; Single sector program focus; Setting credible goals; Info-regulation and resources available; Threat of credible enforcement; Regular and credible monitoring; Visible participant benefits; and, Transparent provision of program results. The research complements other work and while showing a high level of similarity in the features, provided also for the inclusion of two further design features, namely 'adequate and consistent funding', and developing a maintaining a 'collaborative relationship with industry'. It is suggested that the nine design features alone, while important, are insufficient and that further research is required to identify these other supporting factors.

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1. Introduction

Choice of government policy to help manage pollution is generally dictated by national context, including political structure and economic considerations. Pollution management thus involves regulatory and economic instruments, and increasingly voluntary agreements within and between industry and public authorities (Williams, 1997). The trend in many industrialized countries is thus away from a solely 'command and control' policy approach, to a more integrated approach including such voluntary approaches. These approaches have been used for over 50 years with countries like Canada, Japan, the United Kingdom, Australia and the United States having implemented both regulatory and voluntary approaches.

Voluntary environmental approaches frequently include collaborative arrangements between individual businesses, industry associations and regulatory agencies or central governments, with the industry participants committed in either formal or non-formal ways. The spectrum of voluntary approaches includes industry-initiated and developed guidelines for pollution prevention, codes of practice, or cleaner production principles, through to international organizational standards (e.g., ISO). These approaches range from solely industry instigated and privately led, to

combined public and private arrangements, to wholly private voluntary agreements that are independently audited. The geographical boundaries of voluntary approaches also vary greatly, from international, national, regional, to local initiatives.

Borkey et al. (1999) identify four main 'voluntary approach' program types with varying degrees of research undertaken into their use and effectiveness:

- Public Voluntary Programs – these involve commitments set by an environmental authority that invites individual firms to participate on a voluntary basis.
- Negotiated Agreements or Bilateral Agreements – these involve public authorities and industry developing bargains that generally occur at a national level, but individual agreements are also possible.
- Unilateral Commitments – these are set by industry, individually or collectively, without an overseeing authority trying to establish standards or rules for self regulation.
- Private Agreements – these agreements are reached through direct bargaining between polluters and one or more affected parties and can involve the establishment of environmental management programs and/or the installation of pollution abatement devices.

Research has highlighted a risk that voluntary approaches between regulators and industry may set soft targets, where the

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objectives are the same as a 'business as usual' scenario, or where industry knows that more ambitious environmental targets will not be enforced (Borkey et al., 1999). There is limited evidence on the effectiveness of voluntary approaches. They are generally used in the policy mix as a support to regulation or to explore new policy areas. Substantial evidence suggests the relationship between voluntary collaborative approaches and regulation is reciprocal; voluntary approaches provide flexibility and cost effectiveness (Borkey et al., 1999).

There is no preferred form of voluntary approach and no single approach is likely to work in all circumstances or industries (Gunningham and Sinclair, 2002). Borkey et al. (1999) researched strengths and weaknesses and established a list of implementation recommendations. These recommendations included: clearly defined targets, credible regulatory threats, and support from credible and reliable monitoring as features to be included in the design or structure of a voluntary approach. The extent to which these recommendations match international (assumedly) best practice has been given little attention. The principal objective of this research therefore is to review the broader international literature to determine 'best practice' design for voluntary pollution prevention approaches.

Five 'highly developed' countries were selected for review. Country selection was based on the following considerations, but also on the availability of relevant information: Japan is a pioneer of voluntary agreements; the United Kingdom has a multi decade tradition of cleaner production approaches; Australia is a 'westernised' Southern Hemisphere nation with a 'concern' for the environment; the United States is a non signatory to the Kyoto Protocol, is the world's largest greenhouse gas emitter but also has a long 'cleaner production' history; and, Canada which neighbours the United States is a Kyoto signatory and provides a useful contrast.

The main focus of this international review is to determine the design features or principles of these countries' voluntary approaches/program. The ultimate aim is to develop a 'best practice' set of design features or principles for voluntary environmental programs.

2. Literature review

2.1. Japan

Japan is one of the earliest known adopters of voluntary approach programs with pollution prevention related memos traced back to 1952 (Welch and Hibriki, 2002). There have been around 40,000 'Pollution Control Agreements' (PCA) implemented since 1964 (Sugiyama and Imura, 1999). Generally, voluntary agreements were developed between local government and industry to suit local environmental conditions.

Historically Japan had a strong reliance on centralised national legislation using 'command and control' regulation, with high levels of intervention, this allowing programs to be driven by government bodies or local authorities. But, in the late 1950s and early 1960s there was rapid industrial growth and the laws offered inadequate environmental protection at a local level. More recent reports show that regulatory instruments are effective and widely used to implement environmental policy in Japan, with media-specific nationwide environmental quality standards in place for air, soil, noise, surface waters and groundwater (OECD, 2002a).

According to Welch and Hibriki (2002) Japan's policies contradict the economic and regulatory agreements of western countries, where voluntary approaches are typically non statutory and created outside established legislative channels. Welch and Hibriki (2002) attribute this to cultural differences, Japanese culture places great importance on Japanese people maintaining their public

profile. In terms of voluntary agreements with local government, industry management personnel made sure they adhered to the negotiated terms for fear of tarnishing their image.

Yokohama City negotiated the first modern voluntary program in 1964 with a company building a coal fired thermal power plant near the city. At this time most voluntary approaches were implemented during the planning and construction phases and placed conditions on operation, using best available technology and setting emission levels (Tsutsumi, 2001). Yokohama City's negotiated agreement set more stringent emission levels than national law at the time; in some cases PCAs were precursors to future regulation rather than complementary (Welch and Hibriki, 2002).

Sugiyama and Imura (1999) stated that PCAs benefited local government by being relatively quick to implement strict voluntary measures and design approaches to meet relevant local environmental issues. The business benefited by developing a good relationship and image with the local government and community. The community also benefited by having input into local industrial development and environmental protection.

Due to inadequate monitoring Sugiyama and Imura (1999) questioned the environmental effectiveness of these agreements. Tsutsumi (2001) found that reporting information was not always publicised, even though it was stated in voluntary agreements, and reporting timeframes were also inconsistent. There is also a lack of public transparency, with reports remaining confidential between local authorities and business (Welch and Hibriki, 2002). The 2002 Organization for Economic Cooperation and Development (OECD) Environmental Performance review of Japan (OECD, 2002a) found only 12% of negotiated agreements have public input, with no regulatory requirement for government to monitor or enforce agreements and penalise non-complying voluntary participants.

In the 1990s Japan focused more on global environmental issues with its agreements and industry wanted less government intervention. Voluntary programs emerged from within industry and were labelled Voluntary Action Plans. A plan set up by Japan's Federation of Economic Organizations in 1991 called 'Keidanren' is one of these industry initiatives. This type of approach has been classified by Sugiyama and Imura (1999) as a unilateral commitment.

The Keidanren plan promoted voluntary methods to achieve environmental conservation and recommended concrete measures be used. Participants are voluntary, a wide range of industries participate, quantitative targets are set and the plan and process are reviewed annually and publicised.

Preliminary findings by Sugiyama and Imura (1999) stated that the targets were non-ambitious, industry's self review is questionable, lacks transparency and there is no penalty for not achieving set targets. There is a moral issue that the program is run by industry for industry and could be influenced by economic measures rather than consumer and market environment concerns. The Keidanren plan focussed mainly on large businesses with opportunity for free riding by small and medium sized companies.

2.2. Canada

Canadian environmental policy has been described as one of the most decentralized forms in the western world (Rabe, 1999). The Waste Management Act of 1982 (WMA) was a key regulatory tool for the control, monitoring and reduction of industrial discharges.

The WMA was mainly reactive, focusing on end-of-pipe treatment solutions and inhibited provincial authorities implementing proactive programs. Instead local authorities had to rely on organizations voluntarily adopting adequate environmental policies to achieve regulation requirements. Stakeholders including employees, lending institutes, suppliers and consumers pushed organizations for

improved environmental performance, many responded by implementing environmental management systems (Hagarty, 1999).

The Canadian Environmental Protection Act (CEPA) 1988 involved a shift from control and management to the prevention of pollution. Voluntary initiatives occurred at federal and provincial levels and focussed on targets to reduce chemicals or hazardous by-products from production processes.

In Ontario in 1991 a provincial government pollution prevention strategy was implemented in partnership with the metal finishing and printing and graphics sectors. Due to serious pollution issues emphasis was on voluntary control at source rather than enforcement at end-of-pipe. A memorandum of understanding (MOU) was developed and signed off between industry and federal and provincial governments. Government funded the project co-ordinator, with an industry specific program developed.

The program was introduced to metal finishing companies through a workshop in late 1992. Volunteers were invited to work with government to develop a pollution prevention program. This included establishing draft guidelines, auditing and training packages; the outcome is a pilot program specifically for the metal finishing industry. Program evolution incorporates a Pollution Prevention Resource Centre that provides research findings, information clearing and industry expertise. Industry expertise encompasses site assessments, access to cost effective technology evaluation, development and demonstration. Subsidies are also available for metal finishing participants to undertake other industry related programs. After two years participants' sites are reassessed and another two year MOU is signed off with progress reports on participants' actions compiled. However, any program or site shortcomings are only documented without being rectified.

The Accelerated Reduction/Elimination of Toxics (ARET) program was the first formal government issued voluntary "challenge" agreement. It was designed to complement government regulation and other policy instruments at the time. It ran from 1994 to 2000 and aimed to reduce or eliminate releases of 117 toxic substances potentially impacting on human health and the environment. A multi stakeholder committee developed the ARET program (government, industry and non-governmental organizations). Central government funded 90% with the remaining 10% from Industry Canada. However, government staff time and input was considered to be inadequate during the program's lifetime (OECD, 2003).

A 2003 OECD report (OECD, 2003) evaluated the ARET program and identified four principles that future voluntary Canadian programs should follow:

- Effectiveness – Environmental Performance Agreements must achieve measurable environmental results;
- Credibility – the public must have confidence in the approach and in the parties' capacity to deliver on their commitments;
- Transparency/Accountability – all parties to an Environmental Performance Agreement must be publicly accountable for the commitments they make and for the performance against the commitments; and
- Efficiency – Environmental Performance Agreements should be no more expensive to the parties than alternatives for environmental results.

In the late 1990s the Canadian government realized the need to expand existing command and control mechanisms of environmental regulation to include voluntary or cooperative programs. Environment Canada (Government Department) realized that for environmental agreements to be successful, set objectives were needed with a supporting framework for industry and regulatory authorities to follow. In March 2000 the CEPA was strengthened.

New powers increased government requirements for pollution prevention planning, including the preparation of environmental emergency plans and environmental management systems. Canada's decentralized policy framework still contained doubt about the federal government's ability to implement and enforce legislation and standards (OECD, 2004).

In 1998 the federal government, nine provinces and two territories signed the Canada-wide Accord on Environmental Harmonisation. It was designed to improve cooperation, environmental protection, national effectiveness and clarity in environmental management issues. An intergovernmental forum (Canadian Council of Ministers of the Environment (CCME)) was created for co-ordinating policy.

In August 2000, Environment Canada published a discussion paper on environmental performance agreements. This laid out conditions under which all levels of government would enter into an agreement with an enterprise or industry sector (Environment Canada, 2001). The policy framework covers four areas:

- Environmental Performance Agreements;
- Core design criteria for agreements;
- Environment Canada's role in support of this policy; and
- Circumstances in which Environment Canada will consider entering into the agreements.

In July 2004 the Government of Ontario (Commission for Environmental Cooperation, 2004) proposed a Framework for Ontario's Environmental Leaders Program (aligned with the national framework). The proposal objective was to launch an "integrated approach to environmental compliance assurance" in partnership with industry, to establish Ontario as a leading environmental authority.

Benefits of these types of voluntary approaches have been: a specific focus on industry environmental issues, greater access to industry members and potential incentives for participating industry to move beyond environmental compliance. This is being achieved using a consistent format for federal, provincial, territorial or municipal authorities when implementing voluntary approach programs (Commission for Environmental Cooperation, 2004).

Canadian experience suggests that in some cases voluntary approaches can be effective provided they include clearly defined targets, with third party auditing and further action if targets are not achieved (OECD, 2004). The implementation of this policy may provide clearer results on the effectiveness of future voluntary approaches; to date it is difficult to distinguish if impacts are due to regulatory changes or operational practices.

2.3. United States of America

The core US environmental policy was established in the 1960s and 1970s, with the major statutes focussed on end-of-pipe remediation and pollution control issues. Environmental issues were and currently are regulated by single-medium approaches, with the enacted policies based around air, land or water. Zarker and Kerr (2008) state that command and control style regulation is still needed, but this approach is running into the law of diminishing returns.

The Nixon administration created the Environmental Protection Agency (EPA) in 1970, with a national approach to environmental management (OECD, 2005). Alternatives to the regulatory approach were discussed in 1976 with source reduction listed in approaches to reducing and managing solid waste.

The Commission for Environmental Cooperation (2004) suggested that the federal Pollution Prevention Act of 1990 provided a basic foundation for the adoption of pollution prevention (P2). An

important feature is that it is almost entirely voluntary and focuses on industry reaching regulatory compliance. The EPA is responsible for implementing pollution reduction strategies, their funding and reporting results.

Funding of state and federal pollution prevention groups and programs has never exceeded \$6 million annually (Zarker and Kerr, 2008), this represents less than 1% of state regulatory programs allocation (Commission for Environmental Cooperation, 2004). Some states implement fee funded programs to supplement federal funding; these programs have mixed results and generally remained under funded. Changes in government also affected the levels of funding for P2 programs and groups.

Throughout the early 1990s changes occurred at several levels of state authorities, with pollution prevention requirements included in industry permits and by some limited multi media monitoring approaches. A general lack of cohesion between agencies meant infrequent monitoring of facilities and permit holders. The Government Performance and Results Act (1993) addressed this, with a “managing for results” approach. An active role by state authorities initiated policy in response to regional issues and urged greater federal leadership on global environmental issues (OECD, 2005).

In late 1990 the EPA launched the public voluntary 33/50 program, targeting 17 chemicals; participating companies were committed to reducing their usage, discharge and disposal rates to 33% of 1988 levels by 1992 and 50% of 1988 levels by 1995. Pollution prevention techniques were the main emphasis of this federal instigated voluntary approach. The goal of the 33/50 programs was achieved one year ahead of schedule; this was primarily achieved by the efforts of the program participants (Borkey et al., 1999). Factors that led to this success are:

- The EPA organised regional pollution prevention workshops and conferences, promoting collaboration and partnership among industry representatives, government, academia and public interest groups.
- Successful participating companies achieving pollution reductions were publicised in the EPA's media releases, documents and newsletters.
- Industry specific guidance, reference manuals and bibliographic reports were provided.
- 80% of participants set measurable goals to reach the target, others tied goals to production changes, with others making general commitments without numerical targets.

Some state and local governments established programs and beyond-compliance plans in an Environmental Management System (EMS) context. An example was Oregon's Green Permits program for facilities developing beyond-compliance performance plans. Targets and goals were set for exceeding regulatory compliance and reducing environmental impacts; at higher levels this also includes non-regulated pollutants and sustainable development practices. An applicant submitted a \$5,000 deposit with their permit application, with the agency administering budgets for the developing, reviewing and monitoring of the permits three-year term.

Design features of this program include a single point of contact within the state agency, enforcement dispensation – with a focus on correcting issues, consolidated reporting for all facility operations, quicker planning processes and extended permit terms with lower monitoring requirements (Funk, 2002). The program focused on recognition, technical assistance and collaborative problem solving with industry and included community involvement. Due to federal funding cuts in May 2003 the program was wound down.

In 2000 the EPA established the National Environmental Performance Track whereby participants pledged to beyond-compliance performance improvements and had an operating EMS. EPA and state regulator recognition and increased collaboration were primary program benefits (Zarker and Kerr, 2008). The highest motivating factor for a site joining Performance Track was developing a collaborative relationship with the EPA or state authorities; state buy-in of the whole process ranked highly; as did wanting to advertise membership to the local community and authorities. Regulatory incentives were not a key reason for many joining it (USEPA, 2005). Forty-seven states currently have facilities participating in the program, with 470 member sites (as at August 2006) that have set 1500 environmental commitments (USEPA, 2007).

Mazurek (1999) reported that the effectiveness of voluntary approaches in the United States would require legislative remedy, unless their effects were to remain marginal. Implementation problems led to lower than expected results through poor evaluation methods, lack of data and weak monitoring; these issues may have caused the EPA at this time to overstate the effectiveness of programs. Mazurek (1999) found the main benefit of voluntary programs was the promoted interaction between industry, regulators and stakeholders.

Legislative issues still provide an obstacle for voluntary programs in the United States, a major issue is federal statutes contain no specific authorisation for the use of voluntary approaches in lieu of regulatory requirements. Significant progress has been achieved, however greater public recognition of the benefits combined with additional funding is required to bring pollution prevention and performance-based regulation into mainstream national environmental management (Zarker and Kerr, 2008). These conclusions are reinforced by Miller et al. (2008) who found there is no federal mandate to report Pollution Prevention results data, even though state-wide progress is occurring.

The key considerations for developing voluntary programs are senior management commitment and transparency through public reporting. Approaches to this include auditing, performance measures, enhanced public/private monitoring networks and strong enforcement measures (Zarker and Kerr, 2008).

2.4. Australia

For at least the last three decades industry and its environmental impact, especially pollution, has been addressed by regulation in Australia, with a degree of success. However, Gunningham (2004) describes command and control as a ‘blunt tool’ that has picked ‘the low hanging fruit’. Policy makers recognize these limitations and that regulation is only part of the policy solution in a rapidly changing and increasingly complex interdependent world (Gunningham, 2004). There is a need for a broader mix of measures to maintain and increase these improvements.

Environmental management in Australia is described now as a partnership approach, with a mix of regulatory, economic and voluntary instruments, all relatively transparent. Voluntary measures and agreements exist between government, industry and community groups and play a central part in the environmental management process. The OECD 1998 Environmental Performance Review (Gunningham, 2004) stated that the Australian government could improve the effectiveness and efficiency of environmental management by setting environmental standards. These standards were being defined in the National Environment Protection Measures, at the time of the writing the OECD report.

Environmental Protection Authorities (EPA) operate in some states, this single agency responsible for the integrated management of the natural resource base. The Environment Protection Act

1970 was the first in the world to provide such an integrated framework for managing the environment (OECD, 1998).

There is a move towards the use of collaboratively developed industry guidelines or codes of practice at state government level for certain industries, eventually replacing licensing (OECD, 1998). These have led to multiple voluntary programs implemented throughout Australia, at national to local levels, and from within industry.

A federal program developed in 1993 and implemented in 1997, Cities for Climate Protection (CCP) Australia, was designed to reduce greenhouse gas emissions. The key factors that contributed to the success of the program are:

- the level of commitment by local government to make it work,
- support by the performance-based programs of the International Councils for Local Environmental Initiatives,
- actions implemented were practical and affordable,
- the continuous and consistent funding by the Australian government for eight consecutive years (Campbell, 2005).

This program was based around a formal commitment made by the council participant, leading to the implementation of five 'milestones'. The 'milestone' process first measured the status quo, set reduction targets and implemented action plans, followed by results monitoring and review.

From the beginning of the 1990s Victoria's EPA became an early promoter of Cleaner Production (Van Berkel, 1999). In addition, New South Wales' State Protection of the Environment Operations Act 1997 provided for voluntary environmental audits (VEA) in industry (PCCD, 2010). Businesses contract and fund environmental consultants to undertake audits which result in 'protected documents'. The key audit benefit is that results cannot be used in enforcement or prosecution actions against the business or owner but instead are used in the identification of environmental risk, development of pollution reduction programs and cost-benefits through reduced insurance premiums.

Gunningham and Sinclair (2002) looked at a number of factors within voluntary approaches (unilateral commitments and public voluntary programs) in the Australian mining and forestry sectors, concluding that clearly defined targets are desirable to make a voluntary program effective. Mature agreements may run the risk of losing credibility and those in the early stages of development should begin with good faith agreements, allowing participants to feel their way rather than be put off by unrealistic and unachievable targets.

Participants should publicize or announce the performance indicators and timetables they are aiming to achieve for program accountability and transparency. Workable performance indicators need establishing during target setting to provide independent verification that results are actually being achieved (Gunningham and Sinclair, 2002). To maintain credibility an auditing process should be operated by either an in house team, selected from outside the program team or an external third party.

A key finding from Gunningham and Sinclair's (2002) study is that generic programs might be less effective than industry specific programs. Implementation of industry specific programs maximised the chances of success as context appropriate initiatives and design features can be included. Gunningham and Sinclair (2002) consider that voluntary programs can exist in the policy mix, provided there is alignment within private and public interests, effective regulatory monitoring and enforcement practices in place.

Early voluntary approaches achieved modest success due to industry playing a central role in target setting, uncertainty over regulatory threats, non-enforceable commitments, poor monitoring and lack of transparency. Current programs tend to have

more specific targets set by government over and above business as usual achievements (Gunningham, 2004). To date literature surrounding voluntary instruments in Australia has focused on perceived process improvements, not on environmental outcomes. The influence of voluntary approaches was not as strong in practice as the literature suggest it should be; other factors such as pressure from parent companies or clients, public pressure and economics all had equal if not greater effect on environmental performance (Annandale et al., 2004).

2.5. United Kingdom

Environmental legislation in the United Kingdom dates back to the early 1860s with regulated air emissions from the caustic soda industry (West Sussex). With introduction of the Environmental Protection Act in 1990, along with Integrated Pollution Control and Duty of Care legislation, both voluntary and mandatory initiatives have increased in use in the United Kingdom. Both have developed simultaneously because formal EMS standards were created around the same time (Dahlström et al., 2003). The British Standard 7750, a specification for EMS was introduced in 1992, followed by the European Union's Eco-Management and Audit Scheme (EMAS) in 1993 and the establishment of the International Organization of Standardisation (ISO) 14001 in 1996.

The Pollution Prevention and Control Act (1999) supercedes the 1990 legislation and made the 1996 European Union directive on Integrated Pollution Prevention and Control (IPPC) into law. From 2001 to 2007 the IPPC system has been phased in, maintaining the previous principles but going beyond the traditional focus on emissions by promoting energy efficiency and waste prevention (OECD, 2002b).

Overall there are far fewer voluntary agreements in the United Kingdom than other comparably sized and environmentally performing European Union countries, with most having limited effect through not being legally binding (OECD, 2002b).

Some firms have opted for voluntary initiatives to minimize or avoid regulatory costs. These cost reductions are flexible in how industry meets stated environmental targets and can be negotiated down to a lower level. There have been cases where voluntary measures were taken but regulatory costs were imposed anyway, resulting in some distrust of voluntary approaches by industry. Another reason for firms opting for voluntary environmental performance initiatives is for product differentiation, signaled to consumers through product labeling (OECD, 2002b).

The Department of the Environment (as it was known then) launched the Environmental Technology Best Practice Program (ETBPP) in 1994 (ETBPP, 1999). It provided small and medium sized enterprises (SME) with a free environmental helpline, half-day site assessments, technical and management publications and regional seminars. In the late 1990s SMEs, organizations with fewer than 250 employees, were the fastest growing segment of the business population in the United Kingdom (ETBPP, 1999). The ETBPP provided one on one contact with specialist counselors who undertook half-day site assessments and by June 1997 the ETBPP achieved its objectives of improving environmental performance and reducing energy usage. A greater proportion of visited sites took action by implementing the advice given by a specialist counselor, compared to those solely using the helpline facility (ETBPP, 1999).

A voluntary waste minimization and environmental performance program targeting SMEs in East Anglia found that the outcomes of voluntary initiatives were influenced by size, type of industrial sector involved, market structure and prevailing corporate and general policy culture. SMEs were reluctant to embrace environmental policy and considered environmental issues to be

nonessential (Peters and Turner, 2004). The program ran regular meetings among participants, allowing for the transferring of ideas and practices among sites along with encouragement among participants. Senior level management support and in cases championing of the project, helped to foster a culture of change on industrial sites. Having an appropriately experienced and credible waste minimization consultant helped to engage industry. The establishment of baseline data allowed an accurate assessment and measurement of the levels of improvement made.

Peters and Turner (2004) found that two important factors in successfully establishing the waste minimization voluntary programs were, creating relationships with key players in a region to enable and influence further contacts, and ensuring adequate funding was available for the lifetime of the project.

Finally, research commissioned by the English Regions Network on selected sustainable development tools found that negotiated agreements combined with clear penalties were likely to be the most effective voluntary approach with industry (CAG Consultants, 2003). A list of desirable features was identified by CAG Consultants (CAG Consultants, 2003) for the United Kingdom and Europe for negotiated agreements:

1. Clearly defined targets, activities or standards to be met by signatories, with dates for achievement.
2. Stakeholder involvement in agreeing the targets, activities or standards.
3. Independent assessment of 'business as usual' baselines, to inform the setting of more challenging targets.
4. Regular monitoring.
5. Publicly available information on the agreement and the performance of signatories.
6. Regular reviews and updating of action plans.
And if the agreement is with industry
7. Minimize the risk to industry of damaging their competitive position.

While research in the United Kingdom on voluntary approaches is less than in other countries, the base findings demonstrate similarities with the other countries' reviewed. European Union influence on some United Kingdom policy has provided a positive shift from the cost–benefit analysis instrument to the establishment of explicit media-specific objectives and strategic planning (OECD, 2002b).

3. Design features of voluntary approaches

3.1. Best practice framework

The voluntary programs/agreements with industry reviewed in the five case countries had widely diverse characteristics. Apart from the broadly encompassing evaluation of Miller et al. (2008) for the United States, research in other countries is largely program specific. In order to identify broadly common and complementary themes therefore, we have attempted to identify the most recent and major findings from each of the case countries' reviewed. From this exercise we have identified nine 'best practice' design features and the levels to which these are incorporated or considered in the reviewed countries (Table 1). The key components of these nine features are next summarised and important inter-country comparative lessons are drawn.

3.1.1. Adequate and consistent funding

This is a necessary requirement as shown in the United States programs, with funding cuts reducing program terms thus affecting the relationships developed. Fee funded programs had mixed

results and create a 'barrier' or excuse for industry to not participate. The United Kingdom and Australia show good results from adequate government funding from either national or local level. Even with adequate funding as in Canada there also needs to be staff committed to effectively promoting and running the program.

3.1.2. Collaborative relationship with industry

The development of sound relationships between industry and regulatory or program agencies was evident in most of the countries reviewed. In the United States Performance Track program a collaborative relationship with the EPA was the highest motivating factor (USEPA, 2005). Collaboration provides credibility and trust early in program development for the promoting agency to those industry members who are not motivated to automatically join. Literature reviewed from the United Kingdom indicated that SMEs viewed environmental issues as nonessential and developed a program to focus on this group. Research from the United Kingdom also showed that renegeing on promises of reduced compliance costs by participating in a voluntary agreement resulted in industry distrust.

3.1.3. Single sector program focus

Most country programs' were specifically designed for a single site or industry sector. Gunningham and Sinclair (2002) found the best way to maximize program results is to include an industry issue so appropriate initiatives and features can be included in program design. Ontario's (Canada) Environmental Leader Program adds value to industry by seeing tangible results from the program, and by being industry specific allows direct comparisons among participants. Having program personnel involved that were familiar with the sectors' processes and practices achieved credibility. Program staff were aware of relevant local environmental issues and knowledgeable of legislative issues.

3.1.4. Setting credible targets

This was a factor in most countries researched, i.e., an independent assessment established a baseline. All programs need to have credible targets supported by the participant with milestones set through the life of the program. This allows participants at all levels of improvement to be measured including those that go beyond compliance. There appears to be no consistent target setting process used for voluntary programs. Australia's 'good faith' initial agreements are a practical answer to get participants involved and collaborating on the program's design, however timeframes are needed for regular review and evolution of the targets set.

3.1.5. Info-regulation and resources available

In order to assist industry uptake all countries' programs provided some form of resource for industry, from technical publications to using best available technology, to the evaluation of technology. The United Kingdom programs set up local meetings to facilitate the sharing of ideas and encourage others, while in Australia industry Codes of Practice were established. Providing resources shows commitment to industry that the agencies involved were dedicated to ensuring the program worked and can also disseminate information or practices within an industry sector, as long as technological or competitive advantage is not lost.

3.1.6. Threat of credible enforcement

Most countries' programs supported or had some form of enforcement threat incorporated into their design. Most agencies implementing voluntary programs also have an enforcement arm within their structure. Having a period of enforcement leniency appears to be a useful enticement for a business to come forward

Table 1
Voluntary programs design features. (Note that empty cells indicate no literature was found on this topic area during the review.)

Feature	Japan	Canada	United States of America	Australia	United Kingdom
Adequate and consistent funding		Government funding is provided Subsidies provided for industry participant to join related programs Inadequate levels of funding and staff provided	Full government funding, but stated levels not reached Inconsistent funding through political party changes Also participant funded	Continuous and consistent funding	Adequate funding is required Authorities provide free environmental help
Collaborative relationship with industry	Industry and Regulator relationship developed Not always transparency between all parties Large industry focus only	Relationships and partnerships developed with motivated industry groups Collaborative design of program	Collaborative relationship development between industry and regulator Industry support and collaboration	Accountability and Transparency by participants of their performance	Relationships with senior level management to champion program internally Promises of reduced compliance costs reneged, resulting in distrust of VAs.
Single sector program focus	Site specific programs developed for local environmental issues	Industry specific program established using existing program principles Framework for industry and regulator to follow	Industry established voluntary programs EPA provides industry specific guidance	Site specific independent audits Industry specific voluntary programs to maximize results	Specialized counselors conducting site assessments maximized results SMEs developed programs
Setting credible targets	Push for concrete measures and quantitative targets Low targets are set by industry internally SME industry free riding possible	Program piloted, guidelines established and auditing and training packages for industry participants Objectives set	Some programs set targets against a baseline year with timeframes, others set soft targets No consistent method used across sites Beyond-compliance goals set	Credibility by clearly defined targets for mature agreements Baseline measured from status quo Workable sets of performance indicators set at target setting stage	Independent assessment establishing baseline targets Clearly defined targets with dates for achievement Stakeholder support for targets
Info-regulation and resources available	Best available technology to used	Resource Centre established to support industry participants (site assessments, technology evaluation, industry expertise used)	A single point of contact for participant for all regulatory matters Technical assistance provided for sites by agency	Program identifies the environmental risk of the participants' site practices Apply practical and affordable actions	Technical publications and regional seminars for participants Regular local meetings for participants
Threat of credible enforcement	No regulatory requirement to monitor or enforce agreements with no penalties for non-performers	Supportive policy and regulatory framework with consequences (Regulatory backstop only for chemicals of greatest risk)	Enforcement leniency provided if a high level of environmental performance maintained and issues resolved	Participant is immune to enforcement or prosecution while in program Need for effective enforcement	Clear penalty and enforcement structure in place
Regular and credible monitoring	Lack of adequate and consistent monitoring of program participants	Sites reassessed, with MOU signed for 2 years Reports of participant progress compiled, no rectification of site or program shortcomings	Cohesion between regulatory agencies, allowing frequent monitoring of sites	A robust and independent system to collect, report, collate and analyze data Need for effective monitoring practices	Regular monitoring Regular reviews and updates of action plans
Visible participant benefits	A wide range of industry included – level playing field Industry shows good image to community	Access and subsidies to other industry related programs No more expensive than alternatives for environmental regulation	Regulatory agency publicly recognizes participants achievements Regulatory process benefits for participants	Financial benefits for participants (reduced insurance costs)	Minimize damaging industries competitive advantage Product differentiation by labeling Minimizing regulatory compliance costs
Transparent provision of program results	Lack of transparency in relation to results of agreements	All parties must be transparent and accountable for program and commitments	Transparency with surrounding stakeholder community	Accountability and transparency of program aims and achievements made public	Transparency and accountability of participants performance compared to targets

and participate, and provides opportunity to rectify a process issue rather than have action taken and fines imposed, and then still require remedial action. Voluntary programs in most countries complement other command and control measures.

3.1.7. Regular and credible monitoring

To maintain program credibility, and the sites involved, most programs showed the need for regular monitoring. Australia uses an independent system to collect and report program results, thus helping to remove bias. Both Canada and Japans' programs showed a poor level of monitoring and if issues were found, nothing was done. This was found to destroy the relationships between program personnel and other program participants.

3.1.8. Visible participant benefits

A range of visible benefits to program participants were provided from the regulatory agency, e.g., insurance companies reducing site costs, or the regulator providing quicker processing

for future permits. While the monetary value may not be large they provide some tangible benefits for participants contributing within a voluntary program.

3.1.9. Transparent provision of program results

All programs demonstrated some transparency, with almost all stating it was already in the program design and it needed to be consistent and reliable. Transparency indicates to stakeholders that programs are being implemented and what results are being attained. Transparency is also important given that many programs involve some public resource input.

3.2. Comparison of design features of voluntary approaches

Table 2 compares these nine design features to those of Borkey et al. (1999). While both sets have a majority of comparable or complementary features there are some significant and important differences. Two of the Borkey et al. (1999) recommendations:

Table 2
Comparison of recommended design features for voluntary approaches.

Borkey et al. (1999)	This research
Clearly defined targets Targets should be clearly defined, transparent and quantitative, with interim objectives to highlight difficulties during implementation stages.	Adequate and consistent funding Sufficient funding available to match programme targets, on an ongoing basis. Setting credible targets As for Borkey et al. (1999) but add the need for broad stakeholder credibility, especially between the industry and the public agency concerned.
Characterization of a business as usual scenario Before setting targets, estimates of a business as usual trend should be established in order to provide a baseline scenario.	Single sector focus Making such assessments on a single business or industrial sector basis is likely to add credibility to the evaluation.
Credible regulatory threats Made at negotiation stage, a threat of regulation by public authorities provides companies with incentives to go beyond the business as usual trend.	Threat of credible enforcement AND Collaborative relationship with industry With many such approaches being negotiated it is important to reflect on collaborative strength
Credible and reliable monitoring Provisions for monitoring and reporting are essential for keeping track of performance improvements; they are key to avoiding failing to meet targets. In certain contexts independent organizations for monitoring may be used.	Regular and credible monitoring
Third party participation Environmental performance should be made public and transparent, third party involvement increase validity of VA's, also provides industry with additional incentives to respect their commitments.	Transparent provision of program results
Penalties for non compliance Sanctions for non-complying firms should be set; this can be achieved by either making binding commitments or linkages between VA's commitments and regulatory requirements.	Collaborative relationship with industry AND Threat of credible enforcement
Information oriented provisions In order to maximize the informational soft effects of VA's, support for activities in technical assistance, technical workshops, edition of best practice guides should be promoted.	Info-regulation and resources available
Provisions reducing the risk for competition distortions – In the case of collective VAs, safeguards against adverse effects on competition could be provided by notification of new VAs to antitrust authorities.	Visible participant benefits Transparent provision of program results

Table 3
'Best Practice' design features for voluntary pollution prevention programs.

Design feature	Overall justification
Adequate and consistent funding	Sufficient funds need to be committed to run the program for its lifetime, for credibility, maintaining industry relationships and removal of a perceived industry barrier.
Collaborative relationship with industry Single sector program focus	Provides credibility and trust with key 'players' at the implementation phase and allows focus on 'at risk' industry sectors. Allows appropriate initiatives and inclusion of specific sector information and resources providing added value to the industry involved.
Setting credible goals	Credible targets need to be established from current practices and agreed upon, to allow participants and authorities to evaluate progress.
Info-regulation and resources available	Shows commitment to industry, provides a conduit for information dissemination (Codes of practice and guidelines) allowing technological or competitive advantage to be maintained.
Threat of credible enforcement	Provides a backstop for the program, maintains credibility and motivates some participants to achieve. A transitional leniency component for some participants is required.
Regular and credible monitoring	Essential for tracking performance improvements, retaining credibility and level playing field for participants. Potential to invite a third party to maintain consistency.
Visible participant benefits	Provides an incentive to prospective sites and industry sectors to participate and a marketable feature for the instigating authority.
Transparent provision of program results	Provides validity for the program and all parties involved to interested or associated stakeholders.

Credible regulatory threats; and Penalties for non compliance, lack specificity and appear closely inter-related. While each is legitimate, they each require further subdivision into two sub-design features, namely 'threat of credible enforcement' and 'collaborative relationship with industry', and enhanced guidance to aid in their use.

We have added two further features to the design matrix. First, the provision for adequate and consistent funding from central or local government to protect the longevity of the program, is easily justified. This is relevant to program credibility and the collaborative relationship developed with industry. The United States research demonstrates the effects of limited or erratic funding affecting program credibility and industry respect, compared for program achievements in Australia, Canada and the United Kingdom with adequate and consistent levels of funding. The second addition was the inclusion of visible participant benefits, where a business participant has tangible (customized permit packages with extended terms and lower monitoring requirements) and even monetary benefit (reduced insurance costs, government subsidies, 'green' marketing potential) by being involved in a voluntary program. The Performance Track program progress report 2003 stated advertising membership to the local community ranked highly among its members (USEPA, 2005).

Table 3, based on the nine design features identified in this research, and the reconciliation against those listed by Borkey et al. (1999), presents an overall best practice matrix of features and their justification.

4. Conclusions

Voluntary environmental approaches/programs are collaborative arrangements between individual businesses, industry associations and regulatory agencies at local and/or national levels. There has been a worldwide increase in their use as 'command and control' style legislation encounters the law of diminishing returns. Environmental issues have moved beyond a local focus to a collective global one (Zarker and Kerr, 2008).

The targeted review of global literature from five case countries concerning voluntary approaches to pollution prevention programs found there have been varying levels of development and implementation in their design. The review's objective was to establish the design features of voluntary pollution prevention programs and develop a 'best practice' guideline from the reviewed literature.

The review shows that program success requires key design features and implementation structures. Programs dating back over 50 years in Japan, to more recent national programs in the United

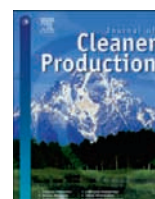
States, Canada, Australia and the United Kingdom provided the background and support for establishing a 'best practice' guideline (see Table 1). This research complements Borkey et al. (1999) who developed a recommended design for voluntary approaches/programs. A comparison of the two 'best practice' designs, Table 2, showed a high level of similarity in the features but provided also for the inclusion of two further design features. Table 3 thus provided a set of overall 'best practice' design features for voluntary pollution prevention programs.

Despite the findings of this review it is clear that the nine design features alone, while important, are insufficient. Hughey and Chittock (2011) found that government support in the way of environmental policy tools and/or a supportive national/regional policy and regulatory framework was also fundamental to having successful voluntary pollution prevention programs. Intra-organizational initiatives also require attention and when addressed appropriately can greatly enhance Pollution Prevention program performance (Calia et al., 2009).

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How the Toxics Use Reduction Act continues to promote clean production Internationally

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ABSTRACT

The Massachusetts' Toxics Use Reduction Act (TURA) of 1989 set an important milestone in the roadmap to Clean Production. The Act's focus on a clear definition, methodology, and mandatory planning requirements have proved successful in getting companies in Massachusetts to reduce their use of toxic chemicals in manufacturing processes. Such results are inspirational for government officials and advocacy groups attempting to reduce toxic emissions in their communities and set progressive chemicals use policies. This paper will summarize three initiatives where TURA was a catalyst and continues to impact international chemicals policy: the Sewer Use By-law in Toronto, Canada; the European Union's REACH chemicals legislation and the international campaign by Greenpeace in Asia and Latin America to achieve zero discharge of hazardous substances into rivers. The example of Toronto and REACH show how one or more essential aspects of TURA were incorporated into legislation. In the case of REACH TURA's requirement of mandatory planning became an important example and NGO demand during the formation of Europe's new chemicals regulation and resulted in the first substitution assessment planning requirement in EU wide legislation. Work is now ongoing to promote TURA type legislation in Latin America and Asia. However the ability to transfer the TURA framework to regions with inadequate government oversight and cheap disposal costs is seriously hampered. Although NGO campaigns in Asian and Latin America advocate zero discharge of hazardous emissions through toxics use reduction and elimination, much training and accountability will be needed within government and companies to understand the benefits of toxics use reduction and actually implement all or parts of the TURA framework. The Toxics Use Reduction Act came into force in 1989 with high environmental awareness, an engaged citizenry and a responsive government entity. Perhaps these are the same conditions that must exist for its successful transference to industrializing countries.

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1. Introduction

The Massachusetts Toxics Use Reduction Act (TURA) continues to be a catalyst for pollution prevention planning in regions far beyond its state's jurisdiction. This is due in large part to the success of the Act. When the Act was first passed in 1989 the intent was to reduce by half the use of toxic chemicals in the state of Massachusetts by 1997. Indeed results show that between 1990 and 2001 actions taken by the more than 600 companies who submitted plans resulted in a 45% reduction in chemical use; 69% reduction in toxic chemical byproducts and 92% reduction in releases of toxics. More recently, over the period of 2000–2007 Large Quantity Toxic Users continued to decrease their overall toxic chemical use in real terms (figures adjusted for the production drop) by 14% compared

to the 2000 base year, as well as generating 34% less byproducts or waste per unit of product and reducing by 44% the releases of TRI reported onsite chemicals. The quantities of chemicals shipped in product have also reduced by 14% since 2000. In other words significant decreases are still being achieved.¹

Why has TURA achieved these results? A clear definition and clear methodology allow clear performance measurement. The TURA statute² defines "Toxics use reduction," as in-plant changes in production processes or raw materials that reduce, avoid, or eliminate the use of toxic or hazardous substances or generation of hazardous byproducts per unit of product, so as to reduce risks to the health of workers, consumers, or the environment, without shifting

¹ TURA results: <http://turadata.turi.org/Success/ResultsToDate.html> accessed January 24, 2010.

² Toxics Use Reduction Act Statute (MGL c. 211) accessible at <http://www.mass.gov/dep/toxics/laws/laws.htm#tura>.

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risks between workers, consumers, or parts of the environment. This differentiates toxics use reduction from end of pipe controls to reduce emissions or the management or treatment of wastes once they are produced. Instead, it goes to the heart of the problem: that is the use of toxic chemicals in manufacturing processes.

Furthermore the Act clearly lists the six toxics use reduction techniques that are acceptable to achieve a measurable reduction of the use of toxic chemicals or generation of hazardous byproducts per unit of product:

- Input substitution: changing the raw materials of a product to use nontoxic or less toxic raw materials.
- Product reformulation: reformulating or redesigning end products to be nontoxic or less toxic upon use, release, or disposal.
- Production unit redesign or modification: using production units of a different design than those used previously.
- Production unit modernization: upgrading or replacing production unit equipment or methods.
- Improved operation and maintenance: modifying existing equipment or methods by such steps as improved house-keeping, system adjustments, or process/product inspections.
- Recycling, reuse, or extended use of toxics: by using equipment or methods that are integral to the production unit. External recycling of materials or waste is not considered toxics use reduction.

The Act further sets measurable performance goals within specified timelines, mandatory planning requirements and technical assistance provisions to help companies understand the techniques and produce well thought out and effective toxics use reduction plans. Fees generated from the companies' use of the Act's list of designated toxic chemicals funds the Toxics Use Reduction Institute and its staff as well as the staff of the state's Department of Environmental Protection tasked with TURA's management. The Office of Technology Assessment also plays an established role by providing onsite assistance to companies.

This clear workable and funded framework to implement the goals of TURA and the program's results over the last twenty years have proved inspirational for environmental advocates wishing to advance clean production practices within industrial sectors responsible for the use and generation of hazardous chemicals. However the ability to transfer key elements of TURA to other regions in Canada, Europe and even China and Latin America face challenges which increase with the scale of implementation, political reality and environmental awareness of the region.

2. The impact of TURA on the Toronto sewer use bylaw

The impact of TURA on pollution prevention policy in Canada's largest city allows some straight forward analysis of the effectiveness of the transfer of key elements of the Act. The practice of incineration has always been a contentious issue with local communities and the burning of sewage sludge in Toronto proved no different. In the 1990s community opposition mounted against the burning of biosolids at Ashbridge Bay, Toronto's largest treatment plant. In the mid 1990's World Wildlife Fund Canada began its campaign to reduce toxic discharges into the region's sewer network as part of their Great Lakes campaign.³ Their research revealed that approximately 37% of

toxic industrial effluents that reached surface waters in the Great Lakes ecosystem did so by passing through sewage treatment plants. Furthermore it was calculated that incineration of contaminated sludge generated a range of toxic air emissions into Ontario air including 1095 kg yr⁻¹ of heavy metals.

The campaign focus on indirect discharges through the sewer system was new. Regulatory attention had traditionally been focused on toxic direct discharges into Lake Ontario as part of the Canada/Ontario Agreement and the province's Municipal Industrial Strategy for Abatement (MISA) program was the main framework for Ontario to regulate industrial effluents. The MISA framework set acceptable discharge limits for specific contaminants within specific industrial sectors and required companies to publish an annual report.⁴ However there was no clear guidance on indirect discharges and WWF pushed for a stronger pollution prevention framework. This focus on sewage treatment plants resulted in the creation of a Sewage Sludge Sub-Committee within the Toronto Metro Works department in 1995 and consultations were held with Environment Canada, the Ontario Ministry of the Environment, Canadian Centre for Pollution Prevention and the World Wildlife Fund as well as extensive public consultation with industry associations and other stakeholders.⁵ The strategic focus on sewage sludge contaminants was timely. The city was looking for ways to cut costs and reduce chemical contaminants in the sludge to enable its application to land, forestry or other beneficial uses and this effort tied in well with the local communities' goals to shut down the Ashbridge Bay sludge incinerator.

By 1995, the Massachusetts Toxics Use Reduction Act had resulted in some concrete reductions in toxic chemicals use by Massachusetts companies and the legislation's goal of reducing toxics use by 50% by 1997 was gaining international attention.⁶ The timing was ripe for policies that reduced the use and generation of toxic chemicals: Greenpeace had been actively campaigning for reduction goals within the North Sea Convention in Europe and networking with other NGOs and policy leaders in North America to research best practice that advanced clean production in industry. The TURA and early results of the program were eagerly watched by Clean Production advocates and added to the growing body of expertise on clean production strategies within the international NGO community. WWF Canada tapped into this expertise to promote best practice in the province of Ontario.⁷ The emphasis on mandatory toxics use reduction planning and mass balance audits – all important elements of TURA – were important elements missing in the Ontario chemicals management policy and to this end, the TURA framework became the model for WWF Canada's lobby for regulatory reform. Meetings were held with citizens groups, policy experts, City Councillors and the Canadian Union of Public Employees and support grew for stronger pollution prevention requirements modeled on the TURA.

After much discussion and at times, opposition from some industry sectors, the revised Sewer Use By-law was passed in July

³ World Wildlife Fund. 1995. Toxics In, Toxics Out: Toxics from Sewage Treatment Plants in the Great Lakes and St. Lawrence River. World Wildlife Fund Canada. Poster detailing the range of contaminants from sewage treatment plants in the Great Lakes ecosystem.

⁴ Ontario's Municipal Industrial strategy for abatement: <http://www.ene.gov.on.ca/envision/water/misa/index.htm> accessed January 24, 2010.

⁵ Thorpe, Beverley; Langer, J., et al. The Failure of Ontario's MISA Programme for sewer users: Pollution prevention recommendations for the way forward. Memo to Peter Victor and Phyllis Miller, Director of MISA Programme. October 10, 1995.

⁶ 1995 TURI company case studies available at <http://www.turi.org/content/view/full/4307/offset/48/year//month//day/> accessed January 24, 2010.

⁷ The author was the Clean Production Liaison for Greenpeace International from 1989 to 1999 and represented the organization as a co-founder of the UNEP Cleaner Production Programme in 1990. In 1995 the author was commissioned by WWF Canada to strategize a way forward to reduce toxic emissions from sewers and used the TURA as the framework for WWF's campaign to reduce toxins in Toronto's sewer discharges.

2000 making Toronto the first municipality in Canada to incorporate pollution prevention planning requirements into the Sewer Use By-law.⁸ Eleven metals and twenty-seven organic compounds/group of compounds are addressed in the By-law. Part 5 of the By-law requires the companies that discharge these chemicals to submit a detailed pollution prevention plan that identifies ways to avoid, reduce or eliminate pollutants at source and conduct a mass balance audit to ascertain total input and output of all designated chemicals use.⁹ Technical support is provided by the Canadian Centre for Pollution Prevention and plans are submitted every six years with summary updates every two years. Certain sectors such as the photofinishing and automotive sector must comply with industry specific Best Management Practices as set out by the City and are not required to submit pollution prevention plans. During the same year that the By-law revisions were passed, Toronto City Council approved a proposal to end incineration of sewage sludge at the Ashbridge Bay Treatment Plant with the goal of increasing the beneficial use of biosolids. The key objectives of Toronto's revised Sewers By-law are to:

- help facilities identify ways of reducing and/or eliminating pollutants, at the source
- continuously improve the quality of biosolids
- protect water quality. The new bylaw established more stringent limits on most of the 11 heavy metals found in the Ontario Guidelines for Utilisation of Biosolids and Other Wastes on Agricultural Land and included 27 toxic chemicals.

One of the key sectors identified was dental clinics. Research revealed that dental practices may contribute from 8 to 14% of the mercury to the sewer systems. Dental waste may have up to 500 mg L⁻¹ of mercury and on average, dental offices produce approximately 1.0 L per day per dentist.¹⁰

2.1. Some successes

Although the Sewer Use By-Law does not mandate the actual implementation of the plans, similar to the Massachusetts Toxics Use Reduction Act, early results showed the planning requirement was achieving success. The 2002 Toronto Water and Wastewater Services Annual Report¹¹ noted “that treated wastewater is starting to show a reduction in levels of heavy metals in the influent, biosolids and effluent. The most significant reduction is the mercury level in biosolids. Since establishing this law, the four sewage treatment plants have recorded between a 41% and 72% reduction in mercury levels.”

The 2004 report¹² noted that “agreements contributed \$9 million in revenue through enforcement of the By-law. A number of prosecutions primarily in the metal finishing sector have been conducted.” The same report graphed the substantial reduction in heavy metals in biosolids from the Ashbridge Bay treatment plant. Metal trend data for mercury, zinc, cadmium, lead and chrome over

the last 25 years spanning the years 1978 through to 2004 have declined continuously and the authors note that this is due to the implementation of the Sewer Use By-law.¹³

2.2. Weaknesses identified

However a review of the effectiveness of the Sewer use By-law conducted in June, 2008 by auditors revealed some structural weaknesses in the plan's ongoing implementation.¹⁴ Due to lack of staff resources, the submission of pollution prevention plans is not being monitored for many industries since the priority is given to high-risk business sectors such as metal finishing. Furthermore, many business owners were not always aware of the By-law and criteria and specific procedures and criteria for approval of pollution prevention plans have not been established. This is further compounded by the fact that only one full time staff person is responsible for reviewing the plans. The auditors furthermore noted that the City's lack of legal authority to enforce the implementation of the pollution prevention plans could be a major factor in the lack of compliance.

2.3. Discussion

It is worth comparing the actual management of the Toronto Sewer Use By-law to that of the Massachusetts TURA. Under TURA, a comprehensive training program ensures that a cadre of Toxics Use Reduction Planners (TURPs) is on the ground holding continuous ongoing dialogue with companies to ensure they are aware of their responsibilities and able to complete comprehensive plans. The lack of such a support service in Toronto and the designation of only one staff person to review the plans is an inherent weakness of the By-Law. The lack of staff resources for the Toronto By-law further demonstrates the value of the Massachusetts TURA approach where company fees fund the program and there are clearly established roles for the Toxics Use Reduction Institute, Department of Environmental Protection and the Office of Technical Assistance. It should also be noted that the Sewer Use By-law's scope of only 39 substances falls far short of the Massachusetts TURA list of all chemicals composed of over 600 chemicals listed under the US Toxic Release Inventory. As a minimum the Sewer Use By-law should consider expanding the scope to cover the 393 chemicals currently listed under Canada's National Pollutant and Release Inventory.

The city is now set to finalize its Biosolids and Residuals Master Plan to provide direction on the future management of biosolids to the year 2025.¹⁵ However these structural weaknesses need to be addressed if future use of biosolids is to be chemically clean enough for land utilization and other beneficial uses.

3. Substitution planning within the European chemicals REACH legislation

TURA's requirement of mandatory planning became an important example and NGO demand during the formation of Europe's new chemicals regulation and resulted in the first substitution assessment planning requirement in EU wide legislation. The new

⁸ Toronto Sewer By-law accessed at http://www.toronto.ca/water/protecting_quality/pollution_prevention/index.htm Accessed January 24, 2010.

⁹ Toronto Municipal Code Sewers http://www.toronto.ca/legdocs/municode/1184_681.pdf. See section 681–5. Pollution prevention planning. Accessed January 24, 2010.

¹⁰ Toronto Sewer Use By-law and Dental Offices brochure. http://www.toronto.ca/water/protecting_quality/pollution_prevention/pdf/brochures/brochure_dental.pdf Accessed January 24, 2010.

¹¹ Toronto Works and Emergency Services. Water and Wastewater Services Annual Report 2002. Page 46 http://www.toronto.ca/water/annual_report/pdf/annual_report_2002.pdf accessed January 24, 2010.

¹² Toronto Water. Annual Report 2004. Page 21 http://www.toronto.ca/water/annual_report/pdf/annual_report_2004.pdf accessed January 24, 2010.

¹³ Metal Trend Data in Toronto Water Annual Report 2004. Page 50 http://www.toronto.ca/water/annual_report/pdf/annual_report_2004.pdf accessed January 24, 2010.

¹⁴ Griffiths, J. 2008. Protecting Water Quality and Preventing Pollution – Assessing the Effectiveness of the City's Sewer Use By-Law, Toronto Water. Report accessed Jan 24, 2010 at http://www.toronto.ca/audit/2008/city_sewers_appendix_june2008.pdf.

¹⁵ Toronto Biosolids management: <http://www.toronto.ca/water/biosolids/index.htm> accessed January 24, 2010.

EU chemicals regulation, REACH (Registration, Evaluation, Authorization and Restriction of Chemicals), passed into force on June 1, 2007. The goals of REACH, as cited by the new European Chemicals Agency,¹⁶ are to:

- Improve the protection of human health and the environment from the risks that can be posed by chemicals
- Enhance the competitiveness of the EU chemicals industry
- Promote alternative methods for the assessment of hazards of substances

REACH was groundbreaking in its scope and intent. In short, industry and importers must now register all chemicals in use over 1 tonne per year per company and provide information on the chemicals they place on the market. Data gaps for chemicals already in use will be filled. Substances of high concern are now clearly defined and must go through an authorization process to justify ongoing use by the intended producer or user while being “progressively substituted by safer substances or technologies.”

The drafting process of REACH resulted in the most intensive dialogue ever experienced within the EU over any piece of legislation. Many interests were at work and the NGO and human/environmental health community were well coordinated. In 2000 a network of advocacy groups produced the Copenhagen Chemicals Charter¹⁷ which outlined 5 key demands from the new chemicals legislation:

1. A full right to know – including what chemicals are present in products
2. A deadline by which all chemicals on the market must have had their safety independently assessed. All uses of a chemical should be approved and should be demonstrated to be safe beyond reasonable doubt
3. A phase out of persistent or bioaccumulative chemicals
4. A requirement to substitute less safe chemicals with safer alternatives
5. A commitment to stop all releases to the environment of hazardous substances by 2020

In the last four years leading up to the final text, advocates focused their demands around the issue of substitution and the demand that all hazardous substances should be substituted if safer alternatives were available. The chemical industry was lobbying for the adequate control route for hazardous chemicals and campaigners could see that a fundamental issue was at stake: would substances of high concern be allowed in future through traditional risk assessment and exposure control arguments or would these hazardous substances be prioritized for substitution with inherently safer chemicals? To this end campaigners joined forces with retailers, companies, unions and other ‘downstream users of chemicals’ to promote the substitution principle. The issue then became how to operationalize this.

The Massachusetts’ Toxics Use Reduction Act had demonstrated the success of mandatory pollution prevention planning as a key element in the success of the TURA program. Clean Production Action (CPA) was tasked by the Greenpeace Environmental Trust to prepare a series of case studies to demonstrate how companies were already substituting safer chemicals for toxic chemicals in products and asked to recommend a policy framework to advance

the Substitution Principle within REACH. Policy experts in CPA took the experience of TURA mandatory planning requirement and evolved the practice of toxics use reduction plans into mandatory substitution assessment planning for chemicals of very high concern.¹⁸ Fig. 1 The framework proposed was that when an application for an authorization was made, the applicant should provide details of alternative substances, materials, processes or products currently in use (the substitution assessment). Other parties (e.g. manufacturers of potential substitutes) should be invited to respond to this substitution assessment. If the manufacturer, importer or user of a chemical of very high concern could demonstrate that no viable alternative is available; that there is need for the chemical (with a transparent socio/economic assessment); and that all steps are taken to minimize exposure, and therefore risks from continued use of the substance, then a time-limited authorization may be granted to allow the development of safer substitutes. Manufacturers and/or users would then be required to produce a substitution development plan to enable substitution to take place before the authorization expires.

The report’s framework recommendation generated much interest within the European Parliament and Guido Sacconi, the European Parliament’s rapporteur for REACH, along with a coalition of parties promoted the substitution principle and mandatory planning over the ensuing three years prior to the final text agreement in December 2006. This paper will not detail the political negotiations that ensued¹⁹ but suffice to say, the negotiations were contentious and much debate ensued around adequate control for hazardous chemicals versus the requirement that safer substitutes must be adopted if available.

The outcome was a compromise. In the final REACH regulation²⁰ any application to seek authorization for a chemical of high concern must include an analysis of alternatives considering their risks and the technical and economic feasibility of substitution, including, if appropriate information about any relevant R&D activities. Where analysis shows suitable alternatives are available then a substitution plan including a timetable for proposed actions will be required. Furthermore authorizations will be time limited and reviewed on a case by case basis. In this respect the final REACH regulation mirrors the recommendations of the NGOs and European Parliament.

However, an authorization shall be granted if the risk to human health or the environment can be adequately controlled. If this cannot be demonstrated then an authorization may still be granted if it is shown that socio-economic benefits outweigh the risk to human health or the environment arising from the use of the substance and if there are no suitable alternative substances or technologies. The adequate control route trumps the substitution planning process except for Very Persistent, Very Bioaccumulative and Toxic substance where the adequate control route cannot be a justification for ongoing use. In retrospect, however, it will be time and resource intensive for European companies to prove adequate control and socio-economic need for chemicals of very high concern determined as carcinogens, mutagens, reproductive toxins and persistent, bioaccumulative chemicals. The search for

¹⁶ About REACH. Accessed at http://guidance.echa.europa.eu/about_reach_en.htm accessed January 24, 2010.

¹⁷ Copenhagen Chemicals Charter 2000 accessed January 24, 2010 at http://www.eeb.org/publication/2000/CCC_from_BEUC_corrected_EL_clean.pdf.

¹⁸ Thorpe, B. 2005. Safer Chemicals within REACH. Using the Substitution Principle to Drive Green Chemistry. Report prepared by Clean Production Action for the Greenpeace Environmental Trust. October 2003 updated February 2005. Report accessed January 24, 2010 at http://cleanproduction.org/library/safer_chemicals_within_reach2005.pdf.

¹⁹ For a detailed account of the political fight and negotiations around the substitution principle within the draft REACH legislation visit: http://cleanproduction.org/library/The_fight_for_Substitution_in_REACH.doc.

²⁰ REACH final text available at http://guidance.echa.europa.eu/legislation_en.htm accessed January 24, 2010.

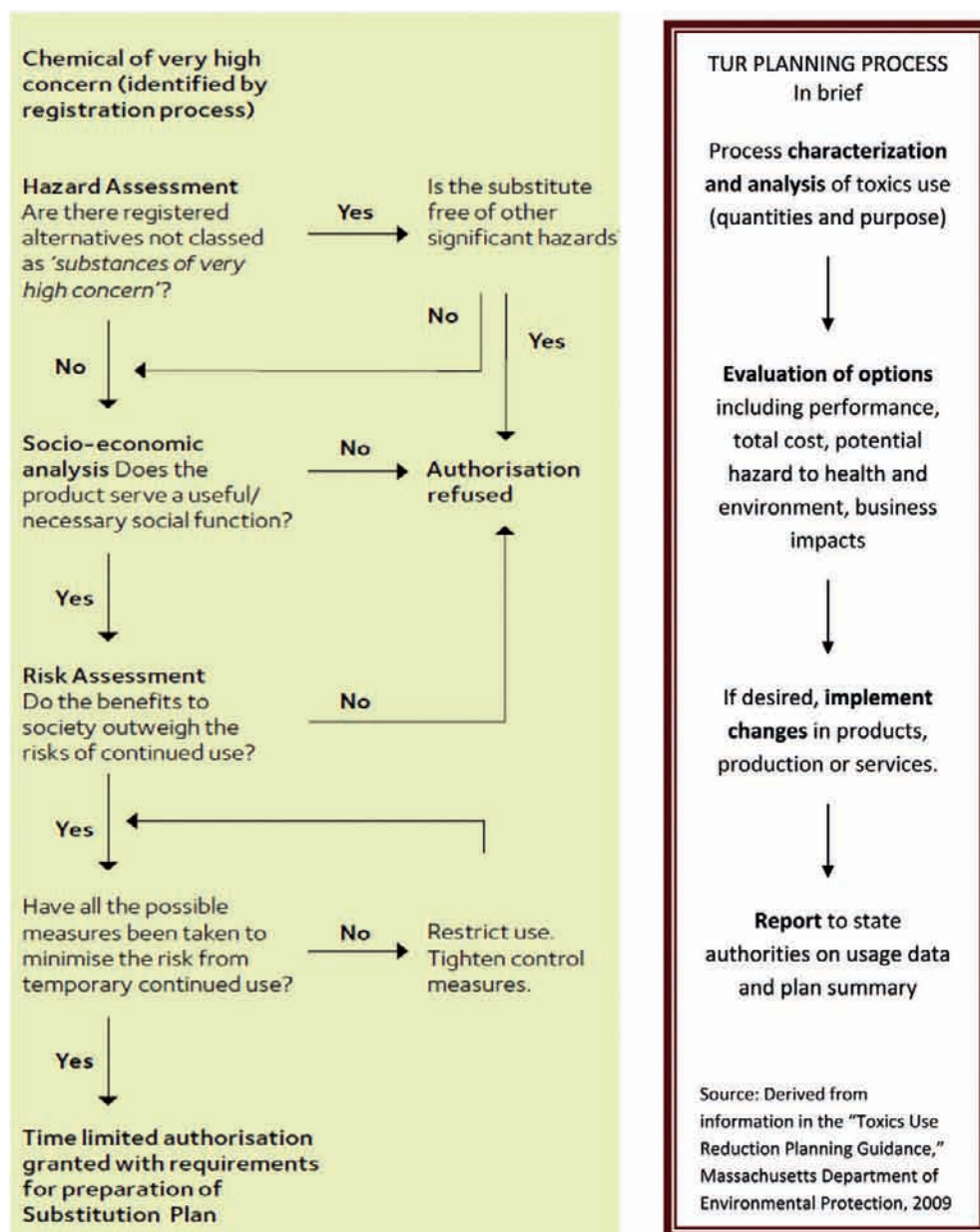


Fig. 1. Proposed decision making process to integrate substitution planning within REACH. Greenpeace, 2005.

safer substitutes that do not meet the criteria of a chemical of very high concern has increased. To date, the REACH Guidance on the Preparation for an Application for Authorization has not been completed and no information is available at the time of writing to comment on the nature of the substitution planning requirement.²¹

3.1. Discussion

The mandatory requirement to substitute chemicals of very high concern with safer alternatives was not directly achieved in the REACH regulation but has spurred company assessments of their chemicals use data to anticipate what possible action they may need to take. The launch of the Substitute It Now (SIN) List by the

²¹ REACH Implementation Guides are available at <http://ecb.jrc.ec.europa.eu/reach/rip/> accessed January 24, 2010.

International Chemical Secretariat in September 2008 was widely welcomed by many downstream users of chemicals.²² The SIN List was created based on the criteria of chemicals that would meet the need for authorization and in response to the slow pace of nominating chemicals as possible candidates for REACH authorization. Although the list is not currently recognized as an official REACH list it is inspiring companies to use the SIN List in their substitution work. REACH will take years to complete with final implementation of all registration, evaluation and candidate lists for authorization completed by June 2022. It will be interesting to see how the European Union addresses substitution planning requirements and how the search for safer substitutes will be assessed. Third party input will be encouraged via an open source web portal and this

²² Chemsec. A Big Day in Brussels: <http://chemsec.org/list/about-sin/the-sin-list-launch>.

could catalyze the creation and dissemination of safer chemical substitutes. However one of the strengths of the TURA was the need to do mandatory planning and have the plans certified. It is still unclear how REACH plans will be assessed for completeness and what guidance will be given to companies. The next few years will offer important opportunities to advance substitution planning and alternative assessment tools that go beyond chemical restriction lists and actually define safer substitutes such as the Green Screen for Safer Chemicals.²³ Experience gained in Massachusetts could be of great use to the European Chemicals Agency in their work to integrate good substitution planning within REACH.

4. The role of toxics use reduction in the international campaign by Greenpeace in Asia and Latin America to achieve zero discharge of hazardous substances into rivers

The burgeoning industrial model in Asia and Latin America has resulted in uncontrolled industrial effluents into many of the world's iconic rivers. Water, always a precious resource, is under increased stress from climate change and the decreasing flows in many of the world's rivers are exacerbating the severe water pollution crisis in many countries.

Greenpeace has responded with the launch of a zero discharge of hazardous substances campaign in Asia and Latin America with a focus in China, Russia, Philippines, Thailand, India, Argentina and Spain. The organization is no newcomer to campaigning against toxic industrial discharges having spearheaded many campaigns to eliminate hazardous discharges and dumping of toxic wastes into the European and North American rivers and oceans in the late 1980s and early 1990s.²⁴ The organization's new focus on eliminating discharges in Latin America and Asia is therefore a timely opportunity to advance the most successful clean production legislation that benefits workers, protects the environment and allows companies to thrive.

Since the creation of the UNEP/UNIDO Cleaner Production Programme in 1990 a wealth of cleaner production case studies and networks has been created and legislative initiatives such as Massachusetts' TURA have been tried and tested. It is this compilation of successful strategies and experience that Greenpeace seeks to proliferate within its international rivers campaign and lessons learned from TURA have now been incorporated into the information and training resources for campaigners in these key countries. In particular, TURA's focus on mandatory toxics use reduction planning, clear definition of pollution prevention and the provision of technical expertise and training for companies has been adopted as priority pushes within the campaign. To catalyze such clean production policies Clean Production Action produced a series of factsheets and training materials for campaigners in newly industrializing countries²⁵ focusing on how to lobby for zero discharge of hazardous substances and clean industrial production processes. The TURA is given prominent place in the training materials.

The world water toxic hotspots²⁶ that the campaign is addressing are the Pearl River Delta in southern China; The Rio Chuela in Argentina; the River Neva in Russia; the Chao Phraya River in Thailand, the Bay of Algeciras in Spain and Laguna Lake in the Philippines.

The Pearl River Delta in Southern China, is known as the world's factory floor and in 2007, 30% of China's exports were made here. The river provides water to 47 million people yet is heavily contaminated with hazardous industrial effluents as a recent investigation reveals.²⁷ The Greenpeace campaign goal in China is to achieve a clean production revolution in the Pearl River Delta and China as a whole. This is to be achieved by a defined set of action points²⁸ with three that particularly mirror TURA's goals and framework. These are the establishment of targets and timelines for progressively reducing and ultimately eliminating the use of hazardous substances; conducting a full chemical accounting and a clean production/solutions audit; and creating well-funded technical resources and providing ongoing help to enable companies (especially small and medium-scale enterprises) to implement plans to eliminate their use of hazardous chemicals. No one underestimates the challenge in advancing such policies but time is running out: currently 70% of the rivers, reservoirs and lakes in China are unfit for human consumption²⁹.

In Argentina, the Rio Chuela houses approximately 4100 factories which are causing the river to run black. Citizen action resulted in a law suit against the government for lack of a cleanup plan and the court has set the goal of 50% reduction of emissions of highly hazardous emissions within five years. In October 2009 a clean production conference and dialogue featured a speaker from the Toxics Use Reduction Institute to give an overview of the success of the TURA program. A series of factsheets prepared by Clean Production Action and translated into Spanish have been widely disseminated to policy makers in Argentina and make specific recommendations to use the TURA program as the framework for TURA type planning and goal setting into Argentina's industrial policy.³⁰ A second clean production conference is being planned for 2010 in China and this will offer more opportunities to spread the TURA framework.

4.1. Discussion

As the campaigners in all these countries become adept at arguing the benefits of mandatory toxics use reduction planning and other clean production strategies, it is hoped that the current unregulated industrial discharges will cease. However the challenge of working in regions which lack effective government run programs to issue permits, monitor compliance and enforce laws necessitates political change. Cheap disposal costs add to the disincentive to address the problem of toxic wastes. It is exactly for these reasons that NGO advocacy and a popular groundswell for clean production strategies are strategically prioritized within the campaigns. Greenpeace believes that change will ultimately occur through campaigns that highlight the crisis and force solutions. Toxics Use Reduction can in theory be applied to any company process but the political and economic realities of many industrializing countries will make the transfer of the key elements that made TURA successful a challenge. Also, it remains to be seen if the toxic emissions currently pouring into the Rio Chuela or Pearl River will be abated using toxics use reduction techniques or end of pipe controls and the transfer of hazardous emissions instead. Although the NGO campaigns in Argentina and China clearly state the need

²³ Clean Production Action. The Green Screen for Safer Chemicals. Available at <http://cleanproduction.org/Greenscreen.php>.

²⁴ Huisingsh, D.; Baas, L et al., 1989. Clean Production in the North Sea. Greenpeace International.

²⁵ Thorpe, B. 2009. Clean Production Strategies factsheets accessed Jan 24, 2010 at <http://cleanproduction.org/Publications.php>.

²⁶ Greenpeace International. 2009. Map of world water toxic hot spots at <http://www.greenpeace.org/international/campaigns/toxics/water>.

²⁷ Poisoning the Pearl. Access at <http://www.greenpeace.org/raw/content/china/en/press/reports/pearl-river-delta-2009.pdf> accessed January 24, 2010.

²⁸ Ibid. see page 6.

²⁹ Greenpeace China website <http://www.greenpeace.org/china/en/campaigns/toxics>.

³⁰ Thorpe, B. 2009. Hacia la Produccion Limpia accessed Dec 20, 2009 at <http://www.greenpeace.org/argentina/contaminaci-n/producci-n-limpia/hacia-la-produccion-limpia>. For English version visit <http://cleanproduction.org/Publications.php>.

for zero discharge through toxics use reduction and substitution, much training and accountability will be needed within government and companies to understand the benefits of toxics use reduction and practice its implementation.

5. Conclusion

The TURA has been successful in reducing toxics use in the state of Massachusetts and the analysis of which elements can be credited with supporting these reductions is a topic of some study in this and other journals. O'Rourke and Lee (2004) identified measurable performance goals, mandatory planning and technical assistance as the most successful elements of TURA.³¹ Wilson (2006) reported that in considering model policies for the State of California, TURA's unique toxics use reporting requirements focused facility managers' attention on production processes rather than on end of pipe releases. Further, the planning process that requires firms to evaluate their processes – and to assist them with robust training, technical assistance and research – has been successful.³²

These key elements help to explain why the transfer of TURA type legislation to other regions may not generate the same kind of toxics use reduction results. For example, the lack of a comprehensive enforcement program for the Toronto Sewer Use By-law in Toronto coupled with a small list of targeted chemicals of concern will continue to prevent the elimination of all toxic chemicals flowing into Toronto's sewers. The establishment of mandatory pollution prevention planning as part of the By-law has engaged many sectors but the challenge now is to maintain the early momentum and ensure compliance and ongoing outreach to companies. Under TURA, a comprehensive training program ensures that a cadre of Toxics Use Reduction Planners (TURPs) is on the ground holding continuous ongoing dialogue with companies to ensure they are aware of their responsibilities and able to complete comprehensive plans. This builds long-term relationships and ongoing networking of businesses. The lack of such a support service in Toronto and the designation of only one staff person with little resources further demonstrate the value of the Massachusetts TURA approach where company fees fund the program and three government entities are clearly and effectively involved.

The mandatory planning requirements within TURA became a key policy instrument for NGOs lobbying for the mandatory substitution of chemicals of very high concern within the European REACH legislation. The ability to demonstrate TURA's successes

through the mandatory planning requirement coupled with dogged campaigning and lobbying by NGOs, environmental health advocates and leading companies in support of substitution, resulted in a substitution planning requirement in the final regulation. This signals the first time substitution planning has been required in EU legislation. The challenge now is to operationalize this and the forthcoming Guidance document will be an important tool to advance the burgeoning field of alternatives assessment. It will no longer be sufficient to simply avoid a chemical of high concern on a designated list; rather the focus will be on assessing if the alternative is truly safer through comparative hazard assessment tools such as the Green Screen for Safer Chemicals.³³ Tools such as this can be applied not only for process chemicals but also for chemical ingredients in products and will help shift more company and supply chain attention to input substitution and product reformulation as part of the suite of toxics use reduction techniques.

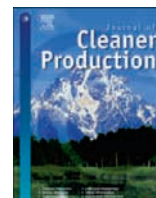
Transferring key elements of TURA to China and Argentina and other countries will in large part be dependent on the political and economic structures that prevail. The Greenpeace China campaign is advancing three key elements of TURA: establishing targets and timelines for progressively reducing and ultimately eliminating the use of hazardous substances; conducting a full chemical accounting and a clean production/solutions audit; and creating well-funded technical resources and providing ongoing help to enable companies (especially small and medium-scale enterprises) to implement plans to eliminate their use of hazardous chemicals. China already has a Cleaner Production Promotion Law but this recommends voluntary actions and reliance on local authority implementation.³⁴ In comparison the NGO campaign is focusing on clear pragmatic action with specified timelines. To achieve this, the campaign is exposing the crisis situation that exists with water pollution and increase public awareness within a country known for its censorship controls. For this reason a complementary focus on solutions and strategies that advance clean production and green chemistry is an important part of the water pollution campaign. However the ongoing reality of the cheap cost of hazardous waste disposal, the perception that environmental controls will make production too costly, and the lack of regulations and enforcement will stymie any attempt to advance clean production strategies in this or any other region of the world. The Toxics Use Reduction Act came into force in 1989 with high environmental awareness, an engaged citizenry and a responsive government entity. Perhaps these are the same conditions that must exist for its successful transference to industrializing countries.

³¹ O'Rourke, Dara and Eungkyoon Lee (2004), "Mandatory Planning for Environmental Innovation: Evaluating Regulatory Mechanisms for Toxics Use Reduction," *Journal of Environmental Planning and Management*, vol. 47, no. 2, March.

³² Michael P. Wilson, Chia, D and Ehlers, B. *Green Chemistry in California: A Framework for Leadership in Chemicals Policy and Innovation*. California Research Policy Centre. University of California. (2006). Page71.

³³ Clean Production Action. The Green Screen for Safer Chemicals. Available at <http://cleanproduction.org/Greenscreen.php>.

³⁴ China Cleaner Production Promotion Law. 2003. Accessible at <http://www.chinacp.com/EN/PolicyDetail.aspx?id=39>.



Government Initiatives

Business value of toxics reduction and pollution prevention planning

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ABSTRACT

As part of Ontario's Toxics Reduction Strategy, the Ontario Ministry of the Environment provided funding for two years to a partnership of the Ontario Centre for Environmental Technology Advancement (OCETA) and the Canadian Manufacturers & Exporters (CME) to deliver a Cleaner and Greener Manufacturing Program, which will include the development and delivery of training and technical assistance programs on toxics reduction and pollution prevention (P2). Over the next two years, OCETA and CME will be working with small-to-medium sized manufacturers to demonstrate the business value of toxics reduction and pollution prevention planning to help motivate businesses to move into a greener economy.

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1. Ontario's toxics reduction strategy

The Province of Ontario has developed a Toxics Reduction Strategy that included the introduction of the Toxics Reduction Act, 2009 to reduce pollution, and inform and help protect Ontarians from toxic chemicals in the air, water, land and consumer products. Other components of the Strategy include elements to build capacity and provide support to business facilities to reduce toxics, and to keep Ontarians informed about toxics in the environment and consumer products. The strategy is intended to refocus traditional 'end of pipe' management of chemicals to include a focus on chemical 'use'. It is designed to foster a greener economy and to encourage the adoption of safer alternatives and green technologies.

2. Cleaner and greener manufacturing program

In May 2010, as part of Ontario's Toxics Reduction Strategy, the Ontario Ministry of the Environment provided funding for two years to a partnership of the Ontario Centre for Environmental Technology Advancement (OCETA) and the Canadian Manufacturers & Exporters (CME) to deliver a *Cleaner and Greener Manufacturing Program*, which will include the development and delivery of training and technical assistance programs on toxics reduction and pollution prevention (P2).

Over the next two years, OCETA and CME will be working with small-to-medium sized manufacturers to demonstrate the business value of toxics reduction and pollution prevention planning to help motivate businesses to move into a greener economy.

Key elements of this new program include:

- Demonstrating the business value of toxics reduction and pollution prevention planning;
- Seminars for business leaders to increase their awareness and understanding of the benefits of toxics reduction planning for business;
- Training for small and medium enterprise (SME) manufacturing facility staff in the practices of toxics reduction accounting and planning, and pollution prevention planning;
- A "one window" information sharing web portal for businesses to search for and share best practices;
- Site-specific technical assistance for SME companies that will undertake toxic substance accounting, toxics reduction planning and pollution prevention assessments; and
- Preparation of public case studies on SME clients that have received pollution prevention/toxics reduction technical assistance.

2.1. OCETA's 2010 report: business value of toxics reduction and pollution prevention planning

OCETA's report includes an analysis of the business value of pollution prevention planning and toxics use reduction for 63

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Toronto Region Sustainability (TRSP) clients whose P2 assessments were completed as of June 2010, based on environmental performance improvements and the financial/economic metrics of cost avoidance, payback, business risk reduction and competitive advantage. OCETA conducted a confidential follow-up discussion with and obtained feedback from each program client and consultant, following completion of their P2 assessment. The report can be downloaded by hyper link from OCETA's website at www.trsp.ca/business-value-tr-p2-report.

Greater than 90% of participating companies have implemented all or most of the recommended actions identified through their pollution prevention assessment report. These businesses have not only improved their environmental performance, but also enhanced their business bottom line with significant cost savings, reduced business risks, and an average payback of less than one year. The environmental and economic benefits are publicly reported on the TRSP website: www.trsp.ca/results.htm.

OCETA's experience in providing pollution prevention technical assistance shows that companies need a mix of strategies to make a business case to implement pollution prevention and sustainability measures. Depending on the culture and history of the company the business case needs to be framed in terms of:

- Cost avoidance and profitability: cost savings, payback period, and operational efficiencies.
- Business risk reduction: Market risks (threat of regulation, customer backlash, reduced demand); Balance-sheet risks (remediation liabilities, insurance underwriting, property damage); Operating risks (hidden costs of cleanup, spills, accidents, risks to worker safety from materials handling, regulation-driven process change, rise in price of materials, energy); and Capital cost risks (product re-design to meet new industry standards, costly input material substitution, pollution control, and waste treatment).
- Competitive advantage: Green marketing, corporate image, access to global markets; and improved customer retention.

Integration of toxics reduction and pollution prevention planning with existing quality, health and safety and environmental management systems is fundamental to successful implementation.

Toxics reduction and pollution prevention planning provide clear business value for small-to-medium sized manufacturers to adopt and implement their process optimization solutions.

2.1.1. Senior executive seminars – demonstrating business value

CME and OCETA will be delivering four high value focused 2-h seminars for senior executives in four regions of Ontario in the fall of 2010. These seminars will emphasize the business case for adopting and implementing toxics reduction and pollution prevention planning. Presenters will include experts and successful practitioners in the areas of industrial process optimization, pollution prevention and toxics reduction.

2.1.2. Facility staff workshops – tools for greening the bottom line

CME and OCETA will be delivering a series of four two-day interactive workshops for manufacturing facility staff such as plant managers, environmental health and safety managers/coordinators, and others, in four regions of Ontario in the fall of 2010.

Each workshop will entail a comprehensive discussion and familiarization with the full toxics reduction and pollution prevention planning tool box, and will build capacity for the participants to understand the benefits of and conduct the following:

- ✓ toxic substance and waste characterization and quantification;
- ✓ process mapping and flow diagrams;
- ✓ prioritization of input and waste streams for detailed assessment;
- ✓ root cause analysis;
- ✓ development of source reduction solutions to eliminate the root causes of priority toxics, pollutants and wastes;
- ✓ development of the business case including reduction quantification, capital costs, annual savings and payback for each process optimization solution;
- ✓ ranking of toxics reduction and pollution prevention opportunities for implementation;
- ✓ integration of toxics reduction and pollution prevention planning with management systems such as ISO 14001 (environmental), ISO 9001 (quality) and Lean Manufacturing; and
- ✓ toxic substance accounting and toxics reduction planning as described under the Toxics Reduction Act 2009 and associated regulations.

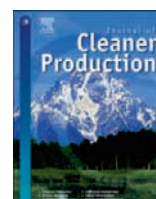
Each workshop will show how toxics reduction planning requirements can build on actions that companies have already taken or were planning with regard to reducing their environmental footprints in terms of toxics, sewer discharges/wastewater, criteria air contaminants/smog precursors, greenhouse gases, hazardous wastes, and energy and water consumption.

2.1.3. Technical and financial assistance – pollution prevention assessments

Site-specific technical assistance will be provided through OCETA's Toronto Region Sustainability Program to help SMEs in the Greater Toronto Regions to assess their toxic substance accounting and undertake a pollution prevention/toxics reduction assessment to identify process optimization and waste reduction opportunities. The resulting action plan will address priority environmental issues (toxics, sewer discharges/wastewater, criteria air contaminants/smog precursors, greenhouse gases, hazardous wastes, and energy and water consumption). Eligible companies are those SMEs with fewer than 500 staff at the facility, providing information to the National Pollutant Release Inventory (NPRI), or reporting for acetone under Ontario Regulation 127/01 and captured by the Toxics Reduction Act 2009. Funding is available until the end of fiscal year 2011–2012, for sixteen SMEs to receive fifty percent cost share (up to a maximum of \$7000) to help offset the costs of the multi-media pollution prevention/toxics reduction assessment.

2.1.4. Progress reporting

The web portal <http://www.cme-mec.ca/english/best-practices/programs/cleaner-greener.html?action=show&path=clean> will allow those interested to follow the progress and results of the *Cleaner and Greener Manufacturing Program*.



Sustainable principles: common values for achieving sustainability

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ABSTRACT

While there seems to be considerable consensus that a more sustainable society is in the best interest of everyone, opinions regarding what sustainability really means and how to achieve it are as diverse as the entities striving for it. With so many opinions and definitions circulating with respect to sustainability, the need exists for a set of core principles that can be applied evenly across all segments of society and disciplines. If we can establish universal principles associated with the development and implementation of a more sustainable society, it could help provide a consistent framework for human effectiveness in achieving sustainability. Three descriptions of such “sustainable principles” are described in this paper. These principles are rooted in the time-tested techniques associated with pollution prevention. They focus on developing and implementing better systems that reduce wastefulness through improved quality of products, processes and systems. By following these principles we can optimize resource utilization across all system components for the entire life cycle of the systems. In doing so, we will improve the sustainability of our ecosystems, production capabilities, community resources and human resources. Considerable educational resources already exist with respect to these principles. If we can apply them to sustainability issues, we can teach the skills and methods required for a more sustainable society.

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1. Introduction

When the U.S. EPA was created in the early 1970s, their initial focus was on controlling and cleaning up the most immediate environmental problems. While these practices initially yielded major reductions in pollution, the traditional “end-of-pipe” approaches were expensive and, in some cases, ineffective as they transferred pollution from one medium to another. Subsequently, more effective approaches to environmental protection required focusing efforts “upstream” to prevent pollution from occurring in the first place. In addition to achieving superior environmental protection, pollution prevention offered important economic benefits, as pollution never created eliminated the need for expensive investments in waste management or cleanup. Additionally, efficiencies gained through better utilization of materials and energy also provided economic benefits while protecting the environment. The pollution prevention movement led the paradigm shift away from reactive environmental protection strategies that dealt with problems after their creation

toward more proactive strategies that eliminated problems at their source through better designs, processes and systems. Consequently, today’s sustainability movement is rooted to a great extent in the pollution prevention pioneering efforts from previous decades.

The worldwide movement toward a more sustainable society has caught fire in recent years with diverse constituencies, including communities, businesses, government, universities, and individuals. It seems that everyone is attempting to develop and implement methods, practices, curricula, and technologies that meet today’s needs without jeopardizing the needs of future generations. Buzzwords such as “the triple bottom line” have now become commonplace in strategic planning sessions while organizations attempt to balance the needs of the environment, the economy and society. While there seems to be considerable consensus that a more sustainable society is in the best interest of everyone, opinions regarding what sustainability really means and how to achieve it are as diverse as the entities striving for it. Kirkby et al. (1995) noted that at least 70 different definitions of sustainable development appeared in the literature between 1974 and 1992. That number has certainly increased exponentially since then given that virtually all disciplines and organizations have a vested interest in the sustainability movement. The range in definitions is so varied that Lozano (2008) was able to separate them into 5 completely different categories. In their efforts to clarify ambiguity and classifying terms used in the sustainability field, Glavic and Lukman (2007) advocate that

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“sustainable development should be supported by a common, unambiguous terminology, applicable to real-world problems”. With so many opinions and definitions circulating with respect to sustainability, the need exists for a set of core principles that can be applied evenly across all segments of society and disciplines. Principles are fundamental concepts that serve as a basis for actions, and as an essential framework for the establishment of a more complex system (Glavic and Lukman, 2007). The notion of establishing principles as a guide to sustainable development is not new. The “Natural Step” framework (Robert, 2000) was compiled by ten pioneering sustainability scientists focused on principles for sustainable development that, if accomplished, would achieve sustainability. The Natural Step principles state that “In a sustainable society, nature is not subject to systematically increasing:

1. concentrations of substances extracted from the Earth’s crust;
2. concentrations of substances produced by society;
3. degradation by physical means, and, in that society, people are not subject to conditions that systematically undermine their capacity to meet their needs”.

The Natural Step principles do a nice job of describing a vision of what a sustainable society would look like (Korhonen, 2007). However, they do not address the “how-to” aspect associated with getting there. This paper describes a small set of *sustainable principles* that have been observed from over thirty years experience associated with making all types of organizations more sustainable through implementation of pollution prevention and energy efficiency strategies. It is the author’s hope that other change agents will be able to use these principles to stimulate sustainable development through merging the pollution prevention and sustainability strategies described below.

In his international best-selling book “The Seven Habits of Highly Effective People”, Stephen Covey (1989) argues that “there are principles that govern human effectiveness – natural laws in the human dimension that are just as real, just as unchanging and arguably *there* as laws such as gravity are in the physical dimension”. Covey focused on principles of personal growth and change, including fairness, integrity, honesty, dignity and service to name a few. It is difficult to argue against the value of these principles given their universal acceptance from moral and religious perspectives. Hence, these principles have stood the test of time and can be regarded as “sustainable” in their own right. One could argue that living sustainably is another example of a principle that should “govern human effectiveness” in and of itself. Likewise, if we can establish universal principles associated with the development and implementation of a more sustainable society, it could help provide a consistent framework for human effectiveness in achieving sustainability. Three descriptions of such “sustainable principles” are provided below. Considerable educational resources already exist with respect to these principles. If we can apply them to sustainability issues, we can teach the skills and methods required for a more sustainable society.

1.1. Principle #1: improved sustainability is achieved through reducing wastefulness

Over 30 years of experience with helping organizations of all types and sizes become more sustainable has produced one incontrovertible observation. That is “the less wasteful an individual, community, or country becomes, the more sustainable it becomes”. Wastefulness can occur in multiple forms that impact, products, processes, and systems. It can deplete the availability of materials and energy and reduce the value and capabilities of agricultural, industrial, community, and natural resources. Finally, wastefulness

can reduce the ability of current and future generations to reach their full potential. The focus of this paper is on wastefulness associated with “natural capital”. The term ‘natural capital’ was coined by Schumacher (1973) to describe all of the ecosystem services that the earth provides to people.

Natural capital is wasted through two primary mechanisms, 1) consumption and 2) degradation. Consumption usually involves the use of raw materials such as water, metals, chemicals, paint, plastic, wood, etc. that go into products and leave the value chain when they end up as unusable waste. Consumption also includes using energy from non-renewable sources – after fossil fuels are consumed for their energy content, we have lost them forever. Degradation includes the resources that are tied up to store wastes (e.g., landfills) and the pollution that occurs as wastes are introduced into the environment. As pollutants build up in water, air, land, and living organisms, they reduce their quality and waste their full potential as important sources of natural capital. Society also wastes natural capital through degradation associated with neglect and overuse of the following:

- *Ecosystems* – Overuse of national parks and wilderness areas has resulted in considerable degradation of some of our most beloved resources – wasting their potential use by current and future generations.
- *Production capabilities* (factories, farms, etc.) – When the American industrial complex closes down a factory, the natural capital invested in those facilities is wasted. Unsustainable farming practices deplete topsoil and pollute bodies of water – wasting their potential for current and future generations.
- *Community resources* – Urban decay reduces the value of existing infrastructure and also wastes the natural capital that was invested in it.
- *Human resources* – Deteriorating ecosystems, production capabilities, and community resources, translate to reduced quality of life for current and future generations, thus wasting some of their potential for achievement. Extreme wastefulness can result in shortages of basic staples that ultimately causes social unrest and in some cases war. As Lozano (2008) noted: “When any individuals and societies have not filled their basic needs the long-term safeguarding of the environment becomes relatively unimportant, at least in the short-term”.

This principle creates an important link between sustainability for the ecological system on the one hand, and sustainability for the social system on the other and is consistent with strategies advocated by Missimer et al. (2010). Reducing wastefulness through more efficient utilization of natural capital has to be at the core of any sustainability initiative. Consequently, it stands to reason that pollution prevention strategies that improve efficiency by eliminating waste at its source should also be a guiding strategy for sustainable development.

1.2. Principle #2: improving quality improves sustainability

Reducing wastefulness is a common mantra for virtually every type of quality improvement program currently used in the business world. Waste is fundamentally the result of a defective product, process, or system. Consequently, eliminating defects and waste through quality improvement is a reasonable way to eliminate wasted natural capital as well and, therefore, improve sustainability.

From the time of the first industrial revolution until World War II, conventional business philosophy believed that quality and productivity were at odds with one another. That philosophy was proven specious when innovators such as Deming (1982) showed

that quality and productivity could be improved simultaneously through the prevention of defects and wastes. Today's sustainability movement merely extends this train of thought incrementally. If we can simultaneously improve productivity and quality through the prevention of defects and wastes, we can also improve sustainability and quality of life through waste and pollution prevention.

Seven deadly wastes that can greatly reduce an organization's efficiency are frequently identified in quality assurance programs such as "LEAN" or "Six Sigma" (Womack and Jones, 2003). These include:

- Over-production
- Waiting
- Transport
- Processing
- Inventory
- Motion, and
- Repair/Rejects

Organizations such as Toyota have been able to improve their production, quality, and market share through reduction of these wastes. However, an excellent case can be made for adding natural capital to this list as an eighth waste in need of elimination. This would facilitate improving sustainability through existing quality assurance programs in thousands of organizations globally. Incorporating sustainability into existing quality management systems has been advocated by Azapagic (2003) who suggests that it can be utilized to make corporate sustainability an integral part of business instead of an "add on" approach.

As organizations continuously look for ways to reduce waste and improve competitiveness, they can also identify ways to reduce natural capital consumption and degradation and, in turn, improve sustainability. Kronenberg (2007) noted that "changing the properties of a product (e.g., increasing its durability)... will lead to more sustainable consumption". Likewise, Hawken et al. (1999) predicted, "The first industrial revolution maximized the productivity of people. The next industrial revolution will maximize the productivity of resources".

One complicating factor associated with achieving sustainability through reducing wastefulness is the way markets value natural capital. Azapagic (2003) notes that "it is not always easy or possible to quantify direct financial benefits of corporate sustainability; and often, even if they are obvious, they may have longer-than-usual pay-back times". Some forms of natural capital such as energy, metals, wood, etc. are very well valued by the market. Consequently, efforts to reduce wastefulness associated with these items are often well justified in economic terms. However, other forms of natural capital such as water and air are not well valued in the market in spite of their irreplaceable contributions to life functions (if you think that the air you breathe isn't valuable because you pay nothing for it, try going 5 min without it).

Introducing mechanisms into the market place that ensure that natural capital is more accurately and equitably valued poses the greatest challenge to the sustainability movement. Waage (2008) suggests that "there is enormous potential for a government agency to address these issues through the creation of public databases with building block Life Cycle Analysis information and maintenance of these databases over time". However, as Bartelmus (1999) points out, "the value of the environment cannot be expressed in monetary terms. Equally, the value of societies and their individuals cannot be put in monetary terms. It is not possible to price the life of a human being, even if governments and corporations try to through compensation systems".

1.3. Principle #3: sustainability is best achieved through implementing better systems

It has long been understood that Mother Nature provides living, breathing and examples of the most efficient systems on the planet in the form of ecosystems. As shown below, energy is input directly from the cleanest of all sources, the sun, and is transformed and stored by producers (plants) for use by other organisms. Energy and materials continuously move from producers to consumers to decomposers with elegant efficiency that transforms products and by-products from each organism into usable forms for other organisms such that nothing is wasted. Regardless of the ecosystem in question (forest, desert, ocean, etc.) these systems function with perfect efficiency in terms of sustainability (Fig. 1).

Man-made systems are not perfect. As described by Deming (1982) and portrayed in the chart below, man-made systems are comprised of a combination of materials, energy, people, machines, methods, surroundings (environment, market conditions, political climate, etc.) and the way we manage them. Individual components of man-made systems tend to be optimized in isolation without regard to how they will affect other components of the system. System managers tend to only be concerned about wastefulness within their own organizations even though their decisions regularly affect both their supplier's and their customer's consumption of natural capital as well.

Waage (2008) notes that designers of products and systems have been "unclear about what sustainability principles, strategies approaches and tools to use at what points in time. At present, few companies publicly proclaim that their product design processes integrate either environmental or social aspects of sustainability thinking or take into account a systems-based view of sustainability". Additionally, life cycle impacts regarding natural capital consumption are often not considered properly. Decisions to go with the lowest bidder frequently offer short term benefits coupled with long-term commitments to waste natural capital excessively (e.g., an inexpensive appliance with low energy efficiency). Consequently, man-made systems tend to be un-balanced and generate considerable waste.

It would be ludicrous for an automaker to design and optimize individual components of an automobile (engine, transmission, steering, wheels, chassis, etc.) without consideration of the other components. To do so, would inevitably produce a vehicle that would not function well as a system. In fact, the notion is ridiculous

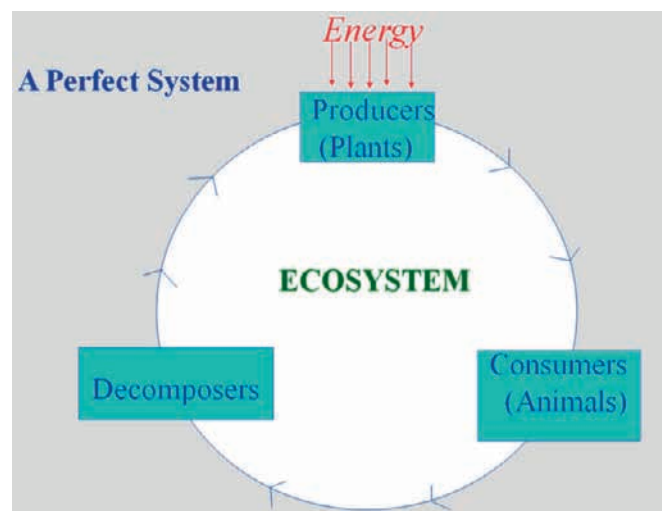


Fig. 1

because, in this example, an automotive company would be in control of all components of the system and would ensure that the components are designed and fabricated to mesh together and form an efficiently functioning system (Fig. 2).

Unfortunately, in most man-made systems, the design and management of the individual components is not controlled by a single entity. In these cases, the individual components tend to be optimized in isolation without regard to other components and do not function well together. For instance, an ethanol production facility is optimized to efficiently produce ethanol from corn without regard to how it will impact food supply (apologies to next generation biofuels developers who are well on their way to developing better systems).

Nowhere is the lack of balance in a man-made system more evident than in today's electronics industry. Electronic devices tend to be designed and manufactured without regard to how they can be collected, sorted, disassembled, refurbished, remanufactured or redistributed. Consequently, about two-thirds of the electronic devices removed from service are still in working order. However, only about 15% of this material is recycled while the vast majority is disposed in landfills (United States Environmental Protection Agency, 2008). The manufacturers of the devices do not own the waste – instead they count on their customers to become electronic waste management experts and deal with the waste appropriately. Consequently, the waste frequently ends up in developing countries where unregulated enterprises utilize primitive methods (e.g., burning) to recover metals without regard to impacts to human health and the environment. A better electronics management system would design and manufacture devices such that they could be easily refurbished and remanufactured. Business models would be reconfigured such that customers pay for performance of the devices and manufacturers would recover the equipment from customers and manage the remanufacturing of the used components. Such a system would not only be better for the environment, the economy and society; it would also be more conducive to a localized business model of service and flow that could bring substantial portions of this industry back to the United States.

Another key component to the design and implementation of more sustainable systems is to consider the natural capital consumption of all the groups influenced by an organization. Initial focus tends to be on internal products, processes and systems for

good reason. In-house opportunities for improving sustainability are easier to identify and change. However, opportunities associated with suppliers and customers should also be considered. When specifications are made regarding materials selection, processing methods, packaging, shipping, etc. we invariably impact the natural capital consumption of suppliers and customers.

Kronenberg (2007) noted the need to move from selling matter to selling function. He explains that “reducing material consumption does not lead to a decrease in well-being, as long as matter is replaced by non-material consumption”. He further explains that “products only provide certain services and what is consumed is their function (or utility) and not their physical properties”. Business models focused on selling performance instead of selling goods have become increasingly popular in recent years. Such models can greatly reduce inefficiency and waste because they align the interests of both supplier and customer. If a supplier is simply selling goods, the supplier is able to increase profits when the customer is more wasteful. However, if the supplier sells only the performance of their goods, then both entities benefit from reduced wastefulness. Several examples of performance based models that have become popular in recent years include:

- *Chemical Management* – Automotive, aerospace and other sectors no longer purchase chemicals (paints, lubricants, degreasers, etc.) from their suppliers. They pay only for the successful performance of the chemicals (i.e., cost per car) and the supplier makes more money by supplying less chemicals.
- *Waste Management* – Many organizations no longer pay for waste management services on a per container basis. They pay only for the service of managing wastes and by-products which encourage the waste manager to find recycling and alternative use opportunities.
- *Air Conditioning* – Some air conditioning suppliers now offer packages whereby their customers pay for comfort (an acceptable temperature range) instead of buying air conditioners. This encourages the supplier to optimize the entire building (caulk windows, etc.) instead of simply selling the largest unit they can justify.
- *Carpeting* – Some carpeting suppliers now offer programs whereby their customers do not purchase carpet. They simply pay to have their floors covered. The supplier comes in at night and replaces the worn carpet (typically 10%–20% of the total) thus reducing customer disruptions and overall material exchange.

The performance based programs described above share a common theme. The customer pays only for the performance they need – not the materials. These programs are inherently less wasteful, are more conducive to localized markets, and can improve domestic competitiveness.

1.4. Combining sustainable principles

Developing and implementing *better systems* that *reduce wastefulness* through *improved quality* of products, processes and systems is the key to a more sustainable society. Considerable educational resources already exist with respect to these principles. We need only to apply them to sustainability issues to teach the skills and methods required for a more sustainable society. By following these principles we can optimize natural capital utilization across all system components for the entire life cycle of the systems. In doing so, we will improve the sustainability of our ecosystems, production capabilities, community resources and human resources. But then again, we already knew that – mother nature has been showing us how to do it for thousands of years.

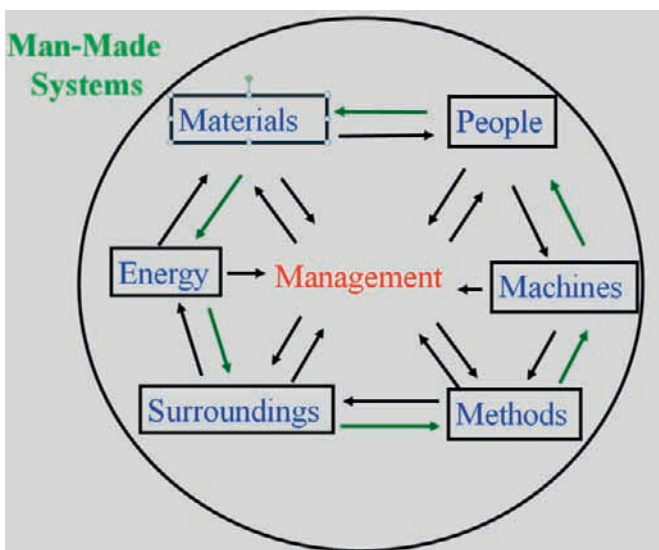


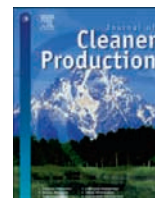
Fig. 2

Acknowledgements

I would like to express my gratitude to my wife, Professor Brenda Lindsey. Thirty years of marital bliss with a Social Work Professional has expanded my views of sustainability to more fully consider the disadvantaged and how to use sustainable principles to improve their situation. Happy Anniversary!!

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Book reviews

Book reviews for special issue

1. Introduction

As noted by Dr. Geiser and Dr. Ellenbecker in their introductory article in this Special Issue, context, motivation and leadership are essential in fostering social innovations such as toxics use reduction. The articles in this issue were compiled with the goal of providing insights into those factors and the complexities of reducing the use of toxic chemicals – the technical, political, financial, scientific and social forces that are integral to achieving change.

Similarly, the five books that are reviewed below explore many of the themes that recur in any discussion of toxics use reduction. They include the role of science in policy formulation; the challenge of understanding and regulating emerging technologies; the globalization of supply chains; impacts of toxic chemicals on workers' health; the concepts of risk and precaution; and the importance of considering the effects of chemical exposures on the health of children and families.

The first two works (*Shoes, glues and homework: dangerous work in the global footwear industry* by Pia Markkanen, and *Beyond child's play: sustainable product design in the global doll-making industry* by Sally Edwards) are in-depth studies of specific industries – the manufacture of shoes and of dolls – that are representative of the challenges faced by workers in a global economy. The third book (*Poisoned profits: the toxic assault on our children* by Philip Shabecoff and Alice Shabecoff), through a focus on the evidence that environmental contamination can damage the health of children, presents a compelling rationale for implementing toxics use reduction policies. The final two books (*Green intelligence: creating environments that protect human health* by John Wargo, and *Governing uncertainty: environmental regulation in the age of nanotechnology* edited by Christopher J. Bosso) discuss policy, its relation to science, and government's role in regulating technology.

1. Shoes, glues and homework: dangerous work in the global footwear industry by Pia Markkanen (2009) Baywood Publishing Company, Amityville, NY. ISBN 978-0-89503-328-4. 120 pages.

Dr. Markkanen delves deeply into the workings of the home-based footwear industry in the Philippines and Indonesia. The book describes working conditions through the examination of both the health, safety and environmental hazards that affect this globalized industry as well as the issues around gender and age in the sector. Of particular concern are the organic solvents used in the shoemaking process, and how the complicated supply chain gets in the way of the introduction of safer adhesives, which are being used effectively in other parts of the world. Workplace policies in these countries are discussed, and while they often exist,

they are typically weak and/or not enforced – the industry is decentralized and there is little if any worker organizing. Material Safety Data Sheets (MSDS) are non-existent or incomplete, preventing workers from knowing the hazards they were exposed to. The author maintains that the health, safety and environmental consequences of these practices will have serious global impacts. This argument also carries over to other home-based industries in other parts of the developing world. Anyone interested in the impact of home-based industries on worker health and safety, global workplace policy, or economic justice should read this book.

Much of the information in the book is based on personal visits to the various shoe workshops in 2002, and includes information from many in-depth interviews, helping the reader to more clearly understand the working conditions. Brief profiles are presented in table-form, making it easy to see the broad variety of experiences among workers and shop owners.

The poverty in the regions Dr. Markkanen writes about is a driving force behind the acceptance of extremely poor working conditions. Business owners and employees have no choice but to do this type of work, despite exposure to hazards known and unknown. Due to the contractual nature of the business, people work long hours and sometimes have no work at all. The work is by contract, with a very steep hierarchy, and those who are exposed to the dangers are at the bottom of the structure. Work is done in or just outside the home, resulting in exposures to families and neighbors. When businesses are small, the women often do the majority of the domestic and business work in the home, and adolescents leave school to work with the assumption that it will boost their earning potential more than studies. As the businesses grow, the men tend to leave the home to do the marketing, while the women and children remain doing the homework, and thus their exposure levels are higher.

This highly unbalanced social and political structure in these regions makes it extremely difficult for industrial hygienists, engineers, and medical professionals to help improve the situation. The development of trade unions and the improvement of government intervention are unlikely in this situation. Shareholders in some of the international companies have protested the use of toxics in consumer products, but have not addressed the unsafe working conditions in which these products are made. Dr. Markkanen suggests that rather than regulating the existing informal economy, the only solution would be to create a more formal economy. This seems an accurate solution, but one whose implementation is a long stretch from the current situation.

Though the book is fairly short, the subject matter is often dense and the relationships among the different parties confusing, often making it necessary to take the time to reread and digest the subject matter and its importance. The book has some editorial problems, including errant pagination (in TOC) beginning in Chapter 3, incongruent reference to figures (see Fig. 3, Chapter 2), and scattered grammatical and spelling errors.

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2. Beyond child's play: sustainable product design in the global doll-making industry by Sally Edwards. (2010) Baywood Publishing Company, Amityville, NY. ISBN 978-0-89503-386-4. 180 pages.

Using three doll-making ventures as case studies, author Sally Edwards examines the impacts of product design and production on the environment, the workers and the surrounding communities, consumers, and the businesses economics in her book, "Beyond Child's Play." The author creates a conceptual framework for sustainable product design with five key elements, and then using a combination of interviews, site tours, literature research, interpretation and analysis, the author presents each case study in detail and concludes by comparing the case studies to one another and to the framework. The author finishes the book by addressing in broad terms the necessary links between product design, production and consumption in the quest for a sustainable society.

Based in Middleton, Wisconsin, the American Girl Doll Company markets their high-quality dolls, made of hard vinyl and cloth with synthetic hair, and numerous accessories and services, including a doll hospital, to the "thinking" girl. Now owned by Mattel, the American Girl Dolls are mass-produced in Southern China in Mattel-owned factories and in Chinese-owned outsourcing companies, all with varying controls on health, safety, working hours and ensuring fair pay. The American Girl Doll Company chapter concludes: "The company's marketing strategies imply that this product can "save girlhood"; meanwhile young Asian women face daily health hazards as they produce these dolls."

Located in Donauwörth, Germany the Kathe Kruse Doll Company's five types of dolls are craft produced in Germany and Latvia using high-quality, natural materials, such as wool and reindeer hair in some models, and some synthetic materials, such as vinyl, polypropylene pellets and polyurethane foam, in other models. The dolls are marketed primarily to adult collectors, the German and American Waldorf communities and very young children. Workers are trained semi-annually about the safe use of chemicals and machinery due to the presence of some hazardous chemicals and sharp-bladed machinery. Much attention is paid to worker satisfaction resulting in a flexible workplace where employees are cross-trained and not "tied to an assembly line doing one repetitive task after another."

In Andahuaylillas, Peru the Q'ewar Project's intent is to "build a shared cultural and social community that benefits everyone" and produces dolls. According to the founder, Julio Herrera Burgos, "human dignity is the most important consideration, above and beyond the product itself." Mostly "through handwork done in community," the Q'ewar Project produces four types of dolls, all soft and made of natural (e.g., cotton fabric, alpaca fiber and thread, sheep's wool) and, to a very large extent, local materials. Childcare, education and healthcare are provided for workers; job rotation helps to prevent repetitive motion stress. Workers also enjoy a garden and banking services.

The American Girl Doll Company and the Kathe Kruse Company case studies present the major benefits and drawbacks of globalization in a concrete and easily accessible fashion. The lessons of these two companies are especially dramatic when compared side-by-side to the Q'ewar Project, which began with very different intention. The book also offers a glimpse into the difficult material choices facing all three ventures, needing to consider function, hazardousness, availability and price among other things.

Scholarly yet readable, if occasionally repetitive, the book offered many lessons for me as a cleaner production professional and as a parent/concerned citizen of the world. For a cleaner production professional the book provides a qualitative assessment

of the risks and benefits along these three doll-making supply chains as well as a sustainable product design framework against which endless products can be evaluated. For the parent/concerned citizen of the world, the book offers a thought-provoking look at globalization. Due to the calculated choice of subject matters, the reader cannot help but view the globalization risks and benefits through the eyes of the child and its doll, which serves to simplify the exceedingly complex issues. (Unfortunately the book is not intended or able to make simple the parent's choice of a doll for their child!)

Ms. Edwards chose an in-depth product study in order to help the reader understand the "complex constellation of factors that impact product design and the globalization of production and consumption." The author chose dolls as the product in order to "engage a new audience – that of women and girls – in a vital conversation about sustainable production and consumption." While I would have welcomed additional information on the consumption choices and final disposal issues of dolls, the end result is a valuable and effective addition to the body of work on sustainable production.

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3. Poisoned profits: the toxic assault on our children by Philip Shabecoff and Alice Shabecoff (2008) Random House, New York, NY. ISBN 978-1400064304. 368 pages.

This book presents evidence that "a vast and largely uncontrolled array of hazardous, human-created substances" have contributed to chronic, disabling, and sometimes life-threatening diseases in children. The authors assert that this constitutes a "toxic assault" and much of the book describes the elements of the "crime", including victims, evidence, forensics, perpetrators, co-conspirators, and witnesses for the defense. It is an indictment of a system that at its base does not see the protection of children's health as one of our society's highest priorities.

Philip Shabecoff a former environmental reporter for the New York Times and his wife Alice Shabecoff, journalist and former executive director of the National Consumers League, wrote this book to chronicle the tragic stories of too many children and families and to call for a social movement that can restore a sense of community and protect the health of American children.

It was not widely recognized until quite recently children's immature bodies react differently to chemicals than adults, especially their increased susceptibility at specific developmental stages. Not until the 1990s did a major scientific study examine the special vulnerabilities of children. It was only in 1995 that the EPA started to require that assessment of environmental risks take the special vulnerabilities of children into account.

In addition, emerging research is showing associations between children's chemical exposures and various behavioral and learning disorders such as lowered IQ, autism, or ADHD. Research is also showing that contrary to what had been thought for many years, low doses of a chemical may have a more harmful effect than higher doses. All of this means that some chemicals may have far more powerful effects on children than adults.

The damage from children's exposure over the last 50 years may be devastating: increased rates of diseases such as childhood cancer, asthma, learning disabilities, autism, and genital abnormalities in boys are among the concerns.

The authors identify the "perpetrators" as industries that produced, used, and disposed of chemicals in ways that expose communities and consumers. Toxic exposures are a side effect of the need to operate at the lowest cost and make the most profit. For example, the DuPont Corporation did not disclose for decades

that PFOA, a highly persistent chemical in Teflon, was being released into the water, air, and soil from its plants. Even after its own scientists came to realize the potential harms of the chemical, the company continued to produce and distribute it.

Story after story is presented of unwitting parents or communities being exposed to toxic chemical pollution, radiation, or even hazardous chemicals in consumer products. Families suffering from cancer or birth defects in places such as Pittsfield, Massachusetts or Toms River, New Jersey or Dickson, Tennessee are angered that such things can happen and no one held responsible. They are also frustrated that institutions that are supposed to protect their health turn a deaf ear or even deny that there is a problem.

The “co-conspirators” are the “legislators and government officials and institutions that impose lax laws and rules to regulate pollution and then laxly enforce those rules and seldom even bother to keep track of illness patterns of children.” The uncertainties inherent in linking illness and toxic exposures are exploited to deny blame, to prevent regulation, and to deny justice for the victims.

It is not only regulators and other government officials who are called to task. The authors describe how “much of the nation’s scientific community remains reluctant to demand action to stem the flow of these hazards in the absence of definitive proof of harm.” Noted researchers Dr. Philip Landrigan and Dr. Herbert Needleman have said: “We are by default conducting a massive clinical toxicological trial. And our children and their children are the experimental animals.” As described in the book, Landrigan, Needleman, and other researchers who have raised these concerns have themselves been harassed and threatened.

The underlying problem is the inherent difficulty or even impossibility of conclusively demonstrating the causal relationship between a specific exposure and a specific disease occurrence. In the absence of such definitive proof, our current health, legal, political, and scientific systems often do not mandate the need for action, even when there is strong evidence of a problem. This enables the “perpetrators” to deny any harm or continue producing a hazard.

While most of the book focuses on what the authors see as enablers of a crime, a central tenet of the book is that the toxic exposures that cause such harms can be prevented. They highlight the “posse comitatus”: physicians, scientists, community organizers, academics, journalists, lawyers, and others who are committed to finding ways “to heal our children and to protect them from the consequences of a degrading environment.” This includes people such as Hilton Kelley of Port Arthur, Texas, who organizes to reduce the pollution of numerous refineries and petrochemical plants, without the support of either local churches or the NAACP. Or Ed Masry, whose firm hired Erin Brockovich, and who started “bucket brigades” that collect air samples near factories. Or Betty Mekdeci and her family who started the National Birth Defect Registry. There are others all around the world.

In addition to the people who can help change the system, there are emerging tools and disciplines that can help prevent more toxic exposures. Applying the precautionary principle would demand that when potential harm cannot be proved, hazardous substances can be regulated or banned. The growing green chemistry field can lead to more effective chemicals that are less harmful.

The last part of the book is a powerful plea for citizens to become active in making significant changes to our system. They call for a “responsive, nonideological politics that puts partisanship in a backseat in order to deal with the real, pressing needs of the American people, including and especially taking care of its children. We urgently need decent, intelligent people to run this country.”

It has been the authors’ hope that the book will lead to a national movement for protecting children’s health. With an information-rich

but readable narrative backed up by 259 footnotes, this book provides ammunition, if not the spark, for such a movement.

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4. Green intelligence: creating environments that protect human health by John Wargo. (2009) Yale University Press, New Haven, CT. ISBN 978-0300110371. 400 pages.

This careful presentation of fifty years of our nation’s experience with the presumed-safe-but-toxic materials in our lives makes very compelling reading. John Wargo is deeply expert as professor and advisor to several Environmental Protection Agency (EPA) administrations, the National Academy of Sciences, the U.S. Congress, the U.N. World Health Organization and Vice President Al Gore. In this book, he builds on previous work concerning the toxic legacy this nation has left its children, who he demonstrates are particularly vulnerable.

The stories of ideation, experiment, discovery, policy formation, use in products and processes, and appalling realization of impacts and hazard are told with commanding detail. The lessons from strontium-90 releases from weapons testing reveal much about persistence, atmospheric distribution by weather systems and uptake by our food systems. Equally dire to read about are the inaccurate assumptions, covert sampling of human tissue and the cavalier policy decisions related to risks involved in nuclear weapons testing from Bikini Atoll to Nevada and also Vieques. Wargo uses these stories to identify lessons which he carries across the broader topic of toxic substances in the environment as fugitives from our technologies, slipping under our policies and through our science. From heavy metals and diesel fuel to pesticides, plastics and formaldehyde, the patterns of persistence, distribution, exposures, and cumulative effects are grounded with stories of children and farmers and others with heartbreaking exposures.

The author’s unique perspective offers rare insights. Why was the Atomic Energy Commission (AEC) able to understand risks from certain atomic testing activities, and adjust its policies within 10 years while the EPA stumbled on achieving effective pesticide policies for much of its first 35 years? Wargo suggests that in part this is because the AEC began as a highly centralized science program whereas “the EPA effort depended on highly decentralized and incrementally produced corporate science.” Other interesting questions are posed: Why tolerate pesticide accumulations in humans after choosing not to tolerate the presence of radionuclides? How have changes in threshold limits and safety factors weakened corporate arguments to limit but not ban marketplace hazards? What has been the health cost of focusing regulation on outdoor pollution rather than indoor hazards?

Wargo’s conclusions that “environmental risks are usually poorly understood by society at large and neglected by states, corporations and individuals” does not – remarkably – leave the reader in despair. He has presented such a dynamic story of our civic debate and few hard won advancements in science and effective policies that there is hope as well as a call to develop a “second wave of environmental law” and “environmentally intelligent society”. At this point he offers principles for intelligence gathering and then for managing hazards. These fifteen wise suggestions include improving transparency, especially of knowledge of hazardous condition for those exposed; use of precaution when data are uncertain and the correlative burden of proof on those who control the technology; and the development of healthier alternatives. Wargo finishes his book with guidance for taking personal control, a reminder that we must teach our children how to live here and now.

Green Intelligence might have been organized differently to good effect. Chronologic elements might be easier for the reader to track if the groupings and conclusions more obviously tied to the principles of green intelligence identified in the last chapters. It is not that the case is not well made. This is a terrific book that connects the reader's mind with more visceral urgency, and brings a sense of order and control of our next steps toward a healthier environment.

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5. Governing uncertainty: environmental regulation in the age of nanotechnology edited by Christopher J. Bosso (2010) RFF Press, Washington, DC. ISBN 978-1933115801. 160 pages.

This book frames the complex and confusing question of how to regulate nanotechnology in an extremely useful way. Each contributor brings clarity to key aspects of the issue within an overall structure that artfully brings the reader to understand crucially important points about what should be done. It should be used as a guide to future policy development.

Sean O'Donnell of Harvard and Jacqueline Isaacs of Northeastern University note that nanotechnology's potential includes more efficient solar energy capture, higher performing fuel cells, better batteries, highly sensitive sensors, new catalysts, new structural materials, and advances in computing and medicine. However, more than 1000 products using nanomaterials are already on the market and we know very little about what is in them, or what impacts they might already be having.

Editor Christopher Bosso of Northeastern describes the "wow to yuck trajectory" (a term coined by Rice University's Kristen Kulinski) of new technologies that first spawn predictions of revolutionary impacts, but then raise such concerns that "some applications are constrained or rejected outright because of public anxiety about potential risk. Government and scientific elites are first reflexively boosterish...and then concerned when some uses or mishaps spark public debate and resistance". Nuclear physics, synthetic chemical pesticides and genetic modification of organisms have followed this path. "Technology boosters and free-market advocates have always been slow to admit a need for some anticipatory government attention to these potential effects – even when they are strongly suspected – with subsequent impacts on available resources and room to maneuver..." Might we "handle the potential side effects of nanotechnology even before they are made manifest"?

Wesleyan's Marc Eisner observes that "New regulatory capacity largely is created after the damage is done, and often in haphazard, incremental, and incomplete spasms of governmental response." He states that "it would be unfortunate if the eventual regulation of nanotechnology were grafted on to existing regulatory capacity", because our current risk assessment process "presumes a causal relationship between material volume and exposure, on the one hand, and toxicity, on the other. But given the novel properties of nanotechnology, we cannot simply infer toxicity of a nanomaterial from what is known about its macro-scale counterpart." He and others envision a system of "regulatory pluralism, combining mandatory controls and elements of firm- or association-based self-regulation," and notes that agency officials have had little discretion in the past to create such flexible regimes.

Cary Coglianese of the University of Pennsylvania discusses engaging businesses in the act of regulation as a way of addressing the "comparative informational disadvantage" in which regulators find themselves. This approach has the potential to achieve results

but requires assurances that businesses don't take advantage of regulators "and, by extension, the public". Reviewing experience with voluntary programs, planning requirements that provide flexibility to regulated entities, and requirements for information disclosure, he concludes that "Engaging business in regulatory governance can be successful when firms use their flexibility within an overarching system of oversight by their industry peers, third parties, or the government."

How government could provide that overarching system is described by Terry Davies, (one of the original organizers of the U.S. Environmental Protection Agency), who notes that "many of the changes needed to deal with nanotechnology are the same as those needed to remake the currently dysfunctional regulatory system." He advocates creating a new Department of Environmental and Consumer Protection to foster an integrated approach that bases strong oversight on science and monitoring. "The future context for dealing with risk will be unlike anything we have known," he writes, and "the policies of the past will not provide the protection we need".

Marc Landy of Boston College argues for a "hypothesis testing/weight of the evidence" approach to change the deliberation from our current adversarial contest toward "what is most observable and testable", and notes that adopting such a change in approach is not impossible but is impeded by the inertial forces of our political history. However, the possibility for a positive evolution in policy is enhanced by the fact that "Nanotechnology puts both environmentalists and industry off their accustomed game", and a great bargain is possible in which environmentalists can accept such validation of safety "in exchange for industry willingness to take on a far greater amount of preproduction environmental testing and data-sharing."

Barry Rabe of the University of Michigan introduces the idea that regulation of nanotechnology can also grow from the bottom up, as states have in recent years expanded their authority in environmental areas, with some states acting on the idea that aggressive environmental protection is not contrary to economic self-interest. While at least twenty states have made some commitment to invest in nanotechnology infrastructure, California, Massachusetts, Wisconsin, and Minnesota have articulated the concept that strong environmental health and safety protection must be a part of any program for fostering nanotechnology. Rabe envisions a "network" approach to governance that "defies conventional hierarchical patterns", breaks through agency rivalries, and secures collaboration.

Bosso and W.D. Kay of Northeastern note that the city of Cambridge, MA created capacity for assessing the complex informational problem that intelligent nanotechnology policy demands by establishing a citizens' advisory committee. They point out that if "the asymmetries in information possessed by business compel government to afford greater discretion to the regulated," (as noted by Eisner and Coglianese), "it should also compel greater formal representation of non-business interests in decision making." Their version of Landy's "grand bargain" would combine informed self-regulation by business with "more expansive and formal inclusion of advocacy groups, science advisory panels, and expert citizens in oversight and regulatory deliberations... expanding the narrowly configured relationship between regulators and the regulated into a broader discursive network of interests." If we are to learn from our experience with nuclear energy and other modern industries, more, not less, participation in deliberations about risk could avoid citizen resistance to the development of new technology. To these analysts, the root question is whether government can act as a fair arbiter of conflicts.

They apply the term "capacity," so often referring to technical and informational resources, to the quality of the interaction of the agencies with their public. Their stressing of the importance of democratic capacity is extremely valuable. It provides the strongest foundation for a legitimate system of oversight, that "can lead

us away from the limited discourse of technocratic elites about public fear (and fear of the public)", rationally prevent harm, and stimulate the development of desirable products at the same time. Let us hope that this book will be widely read.

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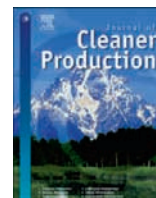
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journal homepage: www.elsevier.com/locate/jclepro

Book review

Cleanersolutions database at <http://www.cleanersolutions.org/>

The CleanerSolutions Database is a powerful and unique capability. In the past decade there have been many database and selection tools that have been developed and promulgated. Some of these tools had good functionality, but they all failed to develop a sustainable model and did not stand the test of time. TURI has assembled years of practical knowledge into an intuitive tool that guides designers, users and engineers through the maze of solvent substitution alternatives. The database links performance and environmental considerations and provides options based on process information provided by the investigator. The CleanerSolutions Database is a great tool that is built on the critical understanding that to effectively implement alternatives there must be an understanding of both process and performance requirements. There are many challenges to identifying, qualifying and implementing alternative cleaning products and/or processes. The CleanerSolutions Database addresses these challenges by guided questions and a feedback cycle that provide the best available solution or suggestions for products to consider.

One consistent theme in discussions concerning alternative implementation is the need for solid information to support decision making. The lack of systems to aggregate and disseminate information on performance and ESOH issues inhibits the development of preferred, sustainable processes to influence the design process, address current issues, and anticipate emerging issues. The focus of "greening" our industrial operations is based on a realization that environmental regulations impacting the industrial base are system engineering challenges and not environmental engineering problems. The CleanerSolutions Database not only provides guidance on solutions it enables the investigator to build a business case based on the experience of other operators.

Second review

In my role as a process engineer, I have found TURI's CleanerSolutions Database to be useful both in setting up new cleaning processes and also in improving existing cleaning processes. The database contains a large amount of information on cleaners, vendors, and tests performed, and the user interface is intuitive. For example to

find a suitable cleaner, the user selects contaminant, substrate, and equipment, and the database returns a list of cleaners that have been tested for those conditions. Depending on the search criteria, usually you can quickly arrive at multiple cleaner options that have been found effective in similar applications. The list of cleaners can then be sorted by manufacturer, classification, efficacy (Y/N), and other criteria. To further help you select a cleaner, the database also allows you to compare up to three cleaners side-by-side, so you can quickly review the descriptions of the candidate cleaners.

TURI assigns safety scores to cleaners, which considers volatile organic compounds (VOCs), global warming & ozone depletion potential, toxicity, and pH. A rolled-up single-value safety score is reported in the initial search of cleaners, which is a reasonable first-pass way to rate and compare cleaner safety. As you drill down to final cleaner selections, the safety score is broken out into its components, so that you can identify the aspects most important to your situation. For example, depending on what waste stream capabilities your company already has, you may have different concerns for VOC and pH values.

Links to MSDSs and technical data sheets are provided. Cost is not addressed in the database, but links to the manufacturers' websites will get you to the answer. Part geometry is also not addressed in the database, other than by reviewing specific case studies.

In summary, there are undoubtedly many cleaners, contaminants, and substrates not included in the database, but 20 years of testing by TURI has provided plenty of breadth. For many applications the user should find it quite helpful.

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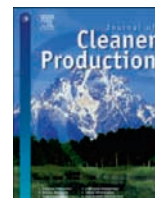
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Book review

Greenlist bulletin at http://www.turi.org/library/greenlist_tm_bulletin

The Greenlist Bulletin published weekly by the Toxic Use Reduction Institute is one of the most interesting and useful information pieces that I receive as an environmental professional. We all are deluged with information, often to the point where less is more. This is nearly always the case with Greenlist. Since 2001, Greenlist has consistently proved to be just the right length, handle the correct spread of topics and have the right links to make it quick to scan and easy to share with colleagues. I can scan the abstracts in a minute or two, read the ones that interest me (there are nearly always at least one or two), click on the link to read more about the ones I find most interesting, copy the abstract and email it to several colleagues here at EPA or in the states and tribes – all in the time it takes to drink a cup of coffee.

My assignments at EPA have changed several times in the past twelve years, and frequently, when that happens, you wind up unsubscribing from the news lists you followed in that particular job. But Greenlist always managed to catch my interest with

abstracts related to health, pollution prevention or environmental economics. Here are some recent examples of articles that I found interesting: Pet flea treatments can be dangerous, more safety steps in the works, EPA says; How mercury becomes toxic in the environment, or Corrosion in homes and connections to Chinese drywall.

In these times when programs face staff and funding cuts, one of the first things I would be concerned about was Greenlist. Fortunately, the TURI leadership seems to appreciate the value of this great vehicle and manage to keep it running. TURI has my appreciation for keeping this terrific news source coming to the environmental community.

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