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Alternatives Assessment for Toxics Use Reduction: A Survey of Methods and Tools

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Alternatives Assessment for Toxics Use Reduction:
A Survey of Methods and Tools

Prepared by:

Sally Edwards
Department of Work Environment
University of Massachusetts Lowell

Mark Rossi
Clean Water Action

and

Pamela Civie
Project Manager
Toxics Use Reduction Institute

Prepared for:

The Massachusetts Toxics Use Reduction Institute
University of Massachusetts Lowell

The authors would like to acknowledge the significant contributions of the following:
Gregory Morose, Maria Leet Socolof, and Joel Tickner

The Toxics Use Reduction Institute is a multi-disciplinary research, education, and policy center established by the Massachusetts Toxics Use Reduction Act of 1989. The Institute sponsors and conducts research, organizes education and training programs, and provides technical support to promote the reduction in the use of toxic chemicals or the generation of toxic chemical byproducts in industry and commerce. Further information can be obtained by going to our website: www.turi.org, or by writing to the Toxics Use Reduction Institute, University of Massachusetts Lowell, One University Avenue, Lowell, Massachusetts 01854-2866.

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Executive Summary

One of the key challenges in toxics use reduction planning is alternatives assessment. This is the process whereby a chemical, material or product that has been identified as toxic is compared with alternatives to find a substitute that is safer for workers, communities and ecosystems. This report reviews nine methods for alternatives assessment of chemicals that have been developed by government and private organizations in the United States and Europe and is designed to assist Massachusetts companies in the process of alternatives assessment for chemical hazards.

In its broadest sense, alternatives assessment is about evaluating a wide range of options, determining the risks and benefits of each choice, and comparing alternatives. The first step in conducting an assessment of alternatives is to look at the function provided by the chemical, material or product that you are looking to replace. Approaching alternatives assessment from the overall function of the system can sometimes lead to insights into ways of avoiding the need for the product altogether. However, in most cases, companies conduct alternatives assessments to compare different chemicals, materials or products that perform a necessary function to determine which are safest for humans and ecosystems.

A comprehensive alternatives assessment process can help businesses find a safer substitute to a current use of a toxic chemical and thereby protect worker, community and ecosystem health. The public has become much more sophisticated and knowledgeable about toxic chemicals. Alternatives assessment provides a tool to assist businesses as they work towards creating a healthier workplace, using safer materials in their processes and meeting increased public expectations for safe and healthy products. In addition, alternatives assessment can help businesses plan strategically and anticipate regulations to avoid future costs and liability.

The process of alternatives assessment of chemicals includes several steps. First, the chemical in use and possible alternatives are evaluated to identify known and suspected hazards. The tools reviewed in this document are particularly helpful in screening out chemicals that are associated with these hazards. Then, in order to find safer alternatives, ideally a list of positive attributes is identified for the needed chemical, such as biodegradability and minimal toxicity. Some companies have developed "positive" lists of chemicals possessing these attributes from which they choose for various uses. In some cases, industry may need to develop new chemicals that have these positive qualities using the principals of green chemistry.

The tools reviewed for this document can be divided into two categories: **hazard data display methods and screening/decision methods**. In hazard data display methods, data on a range of chemical hazards are arrayed and users are expected to develop their own rules for decision making among alternatives. In screening/decision methods, chemicals are evaluated for a range of hazards. Within each method, hazards are prioritized, and recommendations are made to eliminate use if chemicals are deemed to be high risk. In this way, decision rules are built into the screening tool for the user.

Hazard data array methods tend to require more effort as the user may need to research and input data and will also need to determine how to prioritize hazards, once they are identified for each chemical that is being evaluated. This may require an in depth consideration of toxic chemical use, management and potential for exposure. Although the effort may be

relatively high, a hazard data array method has advantages as it can provide a clear side-by-side comparison of alternatives. Screening/decision tools tend to require less effort because decision-rules are built into each approach and in some cases, a database of hazardous chemicals can be utilized. Screening methods provide a relatively simple means of flagging and prioritizing high hazard chemicals for elimination.

In addition to evaluating alternatives for environmental health and safety, the toxics use reduction planning process includes evaluations of technical feasibility and economic viability. Obviously, any alternative that is deemed as a "safer alternative" must also meet technical requirements and be economically feasible to implement. If payback is not immediate or obvious, it is important to determine when cost-savings will occur, and to consider indirect costs such as liability and hazardous waste management that may be eliminated by changing to a safer chemical.

The engineer, scientist and or industry manager engaged in alternatives assessment for chemical hazards will quickly learn that this process involves complex and often subjective decision-making. The approaches described in this report are decision-aids, but they do not make the decision for the user. It is important to use these methods for the purposes for which they are intended. Because of limited experimental or human data on the health and environmental effects of the vast majority of chemicals in commerce, it is difficult to know with certainty that an identified alternative is truly safe. The methods described here represent an important step to a more comprehensive alternatives assessment methodology that will screen out highly hazardous substances, define positive criteria and identify chemicals, processes, or other types of solutions that will provide long-term protection of workers, communities and ecosystems.

Introduction

The Toxics Use Reduction Institute has promoted the use of safer chemicals and improved manufacturing processes in industry and in communities since its inception in 1990. Our work has focused on providing education, training and research tools to assist individual companies and communities to evaluate available alternatives to minimize or eliminate their use of toxic chemicals. This report provides information on methods and tools available for industries to conduct alternatives assessments to support toxics use reduction (TUR) planning.

As described below, traditional toxics use reduction planning involves assessment of three major elements: technical or performance considerations, costs, and environmental and human health implications. Many of the methods described in this document consider environmental and human health implications, but do not encompass a technical or financial evaluation.

Toxics Use Reduction Planning and Alternatives Assessment

Toxics use reduction (TUR) is a fundamental form of pollution prevention that is designed to reduce the use of toxic chemicals and the generation of wastes in the manufacturing process prior to recycling, treatment or disposal. This approach does not include the management or treatment of wastes once they are produced. TUR means changing the way toxic chemicals are manufactured, processed or used and reducing the amount of byproduct generated. In an industrial setting, toxics use reduction is most effectively accomplished through a comprehensive planning process. In Massachusetts, companies that report their use of toxic chemicals under the Toxic Use Reduction Act (TURA) are required to undertake a detailed process to plan for toxics use reduction in their organization. This plan is signed by a senior company official and certified by a State toxics use reduction planner.

The Toxics Use Reduction Institute was created in 1990 to support the Commonwealth in its TUR efforts by providing training in TUR planning, and researching, testing and promoting alternatives to toxic chemicals used in Massachusetts. With the assistance of the Institute, the TUR planning process has been very successful in reducing toxic chemical use in Massachusetts, resulting in a 38% decrease in the use of toxic chemicals from 1990 to 2003.

The goal of TUR planning is to find alternative processes or safer chemicals and/or formulations that allow industries to reduce or eliminate their use of known toxic chemicals. The Institute has promoted TUR planning by providing: education (40-hour planner certification courses, continuing education courses and workshops), research into alternatives that can be used by industries; information; tools; and, technical support.

Options Assessment in Toxics Use Reduction Planning

The TUR Planner training course offered by the Institute provides a full day module dedicated to the task of assessing identified toxics use reduction options at a facility. This module (see Appendix A) summarizes the process of screening and evaluating alternatives for technical and economic performance. The module cannot address details specific to each unique site conducting TUR planning, but does provide useful tools for sites to conduct their own assessment.

One of the key challenges in TUR planning is assessing options or alternatives. This is the process whereby a chemical, material or product that has been identified as toxic is compared with alternatives to find a substitute that is safer for workers, communities and ecosystems. Typically the following steps form the framework for assessing alternatives in TUR planning:

1. The industrial process is described, the process flow is diagrammed and a materials balance is completed to track the finished product, air emissions and solid and hazardous wastes generated.
2. TUR opportunities are brainstormed. Options that may come out of this process include input substitution, product reformulation, process redesign, process modernization, improved operation and maintenance procedures, and integral recycling within the process. An initial screening is conducted to eliminate any ideas that do not fit the definition of toxics use reduction.
3. A detailed assessment of the remaining options is completed. This assessment consists of three parts: a technical assessment to determine the feasibility of implementing an option; a health, safety and environmental assessment to determine whether the option indeed reduces risks to workers and the environment; and a financial assessment to determine whether the option is economically viable.
4. The results of these individual assessments are considered as a whole and recommendations are made for implementing toxics use reduction activities.

As described, it is clear that alternatives assessment is integral to the TUR planning process. In Steps 1 and 2, production processes are analyzed and possible alternatives to currently used toxic chemicals are identified. Step 3 includes a detailed assessment of options.

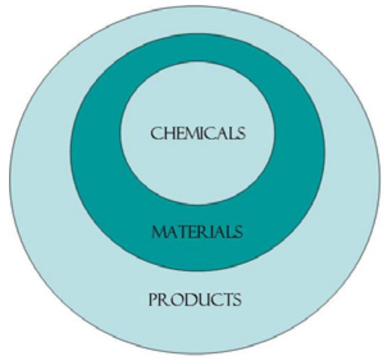
The tools described in this document may assist companies to prioritize chemicals for reduction, and may also highlight chemicals that are likely to pose little risk.

Assessing Chemicals, Materials or Products

In its broadest sense, alternatives assessment is about evaluating a wide range of options, determining the risks and benefits of each choice, and comparing alternatives. The first step in conducting an assessment of alternatives is to look at the function provided by the chemical, material or product that you are looking to replace. For example, a review of a product's function may lead to design options such as a service or product-service system in place of the product as currently produced (for example a leasing system where the producer maintains ownership of the product). Approaching alternatives assessment from the overall function of the system can sometimes lead to insights into ways of avoiding the need for the product altogether. However, in most cases companies conduct alternatives assessments to compare different chemicals, materials or products that perform a necessary function to determine which are safest for humans and ecosystems. For example, if a solvent in use has been found to contain hazardous chemicals, an alternatives assessment process may evaluate several other solvents and compare them with respect to worker health and safety, environmental concerns, economic costs and technical effectiveness for the intended use.

Chemicals, materials, and products can be viewed as having a nested relationship (see Figure 1; for definitions of these terms see Text Box 1).[1]

Figure 1 – Nested Relationship of Possible Alternatives



Chemicals are found in materials and chemicals and materials are found in products. For example, a computer (a product) is made from a variety of materials (such as plastic, glass, metals) and each of these materials is constituted from chemicals (such as silicon and lead). The product carpet tiles provide another example. They are made from a combination of backing and face materials. The face material is typically a type of nylon[2] and common backing materials include polypropylene, styrene butadiene rubber (SBR) and polyvinyl chloride (PVC). Nylon 6 is made from the chemical caprolactam; SBR is made from a mixture of chemicals styrene and butadiene and the material natural rubber; polypropylene is made from the chemical propylene; and PVC is made from the chemicals ethylene and chlorine.

Text Box 1 - Definitions

A **chemical** is "any element, chemical compound or mixture of elements and/or compounds."[i] Chemicals are the constituents of materials. A chemical "mixture," also known as a chemical "preparation," includes multiple chemicals.

A **material** is "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."[ii] Human-made materials like petroleum-based plastics are synthesized from chemicals.

A **product** is "something produced by physical labor or intellectual effort."[iii] Products made from physical matter (as opposed to intellectual products) are made of chemicals and/or materials. The terms "products" and "articles" are often used interchangeably.

The **"material economy"** is the physical matter upon which we base our lives.

[i] OSHA Hazard Communication Standard (HCS), Subpart Z, Toxic and Hazardous Substances, 29 CFR 1910.1200, Section "c", "Definitions."
[ii, iii] G&C Merriam Company, 1976, *Webster's Third New International Dictionary* (Springfield, MA: G&C Merriam Company).

[1] This section draws largely from Rossi, Mark, Joel Tickner and Sally Edwards, "Setting the Context for the Lowell Workshop on Designing and Selecting Safer Alternatives: Chemicals, Materials and Products", background paper for Lowell Center for Sustainable Production, December 2004.
[2] The two nylons are Nylon 6 and Nylon 6,6.

In some cases, individual chemicals comprise a product.[3]

This document focuses on the inner ring of Figure 1 (chemicals) and discusses methods for alternatives assessment of chemical substances. Other tools have been developed to compare alternative materials and products, but these methods are not reviewed in this document.

To be most effective in the long run, alternatives assessment of chemicals should be considered in a larger context. In Europe, alternatives assessment is encompassed in the principle of substitution. The German Ökopol Institute for Environmental Strategies and Kooperationsstelle Hamburg has defined substitution as:

> "the replacement or reduction of hazardous substances in products and processes by less hazardous or non-hazardous substances or by achieving an equivalent functionality via technological or organisational measures".[4]

As indicated in the definition above, the principle of substitution can be implemented at a variety of levels: chemical, material, product, system, organizational and cultural.

While some of the methods presented in the TUR planner's course are reiterated within this document, the alternatives assessment mechanisms described herein present decision making tools for any company interested in evaluating its use of toxic chemicals, not just those that are required to do annual federal and state reporting.

The **purpose of this document** is to provide to Massachusetts industry a compilation of tools for alternatives assessment of chemicals. Ideally, this analysis will be conducted by a company in the broader context of long term strategic business objectives for environmental improvement throughout its operations.

Why Do Alternatives Assessment of Chemicals?

There are many drivers for conducting alternatives assessment of chemicals. First, regulatory requirements motivate businesses to search for safer chemicals. As noted above, TURA requires Massachusetts companies to assess alternatives to toxic chemicals in use. Beyond these statewide regulations, international regulations are driving the need for alternatives assessment. For example, the Restriction of Certain Hazardous Substances (RoHS) Directive approved by the European Union specifies the elimination of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ethers in electrical and electronic equipment by July 2006. This legislation is spurring manufacturers of electronics and their suppliers to search for safe alternatives to these chemicals.

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[3] Examples of chemicals as product include: intermediates, process aids (e.g., chlorinated solvents in degreasing), disinfectants, and cleaning products. In such instances, chemicals are considered either singly or as a mixture of chemicals.

[4] Lohse, Joachim, Martin Wirts, Andreas Ahrens, Kerstin Heitmann, Sven Lundie, Lothar Libner and Annette Wagner, *Substitution of Hazardous Chemicals in Products and Processes*, Ökopol Institute of Environmental Strategies and Kooperationsstelle Hamburg, report compiled for the Directorate General Environment, Nuclear Safety and Civil Protection of the Commission of the European Communities, Final Report-Hamburg, March 2003.

A comprehensive alternatives assessment process can help businesses find the safest substitute to a current use of a toxic chemical and thereby protect worker, community and ecosystem health. The public has become much more sophisticated and knowledgeable about toxic chemicals. Alternatives assessment provides a means for business to meet increased public expectations for safe and healthy products and work environments. In addition, alternatives assessment can help business to plan strategically and get ahead of regulations to avoid future costs and liability.

Issues in Alternatives Assessment

A variety of methods exist for conducting alternatives assessment of chemicals. In order to compile tools for this document, the Institute has reviewed methods developed by governments and private research organizations in Europe and the United States. These include methods developed by Sweden, Germany, Norway, the Netherlands, OSPAR (an organization representing 16 European countries), the US EPA, McDonough Braungart Design Chemistry (MBDC), the Zero Waste Alliance (ZWA), and the Institute. While these tools share common elements, there are differences as well.

> There is no one "right" way or method for alternatives assessment.

Alternatives assessment typically requires subjective judgments about the significance of various hazards as well as an evaluation of available data. Within each of the methods described herein, chemicals are evaluated to determine if experimental data has found any association with human health or environmental hazards such as carcinogenicity, reproductive toxicity, endocrine disruption and global warming potential. Ideally, an alternatives assessment would incontrovertibly identify hazards so that industry can eliminate the use of any chemical that poses a health or environmental risk. However, it is rare that hazard data is so clear cut, and it can be challenging to compare among alternatives when the alternatives are not risk free. In this situation, an industry will need to look at conditions of use, chemical management, performance, economics and exposure potential to help it in choosing the preferred alternative.

Experimental data often do not exist for the alternatives being evaluated. One of the greatest challenges for alternatives assessment is that the majority of chemicals are not well studied. To put it into context, consider that there are approximately 70,000 chemicals in commercial use today. Many of these chemicals are produced in low volumes and not all are classified as being hazardous. Of the approximately 2,800 high production volume chemicals (i.e., those produced in amounts exceeding one million pounds annually), less than 10% have basic toxicity data available and more than 40% have no toxicity information whatsoever.[5]

The goal of alternatives assessment is to find a safer option rather than choosing a little known chemical that may in the future be found to pose significant risks. In situations where experimental data do not exist, tools such as EPA's PBT Profiler may be used to assess hazard potential based on structure-activity relationships. The PBT Profiler is described in detail later in this document

Ideally, an alternatives assessment of chemicals should address the important question of product/process re-design. Functionality and need for the product should be considered first, prior to conducting an alternatives assessment of chemicals, as this up-front analysis could eliminate the need for the product as currently produced. As discussed earlier, this is part of considering a chemicals alternatives assessment in a broader context. Although the simplest application of

[5] *Integrated Chemicals Policy – Seeking New Direction in Chemicals Management*, Lowell Center for Sustainable Production, University of Massachusetts, Lowell.

alternatives assessment will result in a "drop in" substitute, in some cases, process or product redesign will be necessary to effectively implement toxics use reduction.

In addition, ideally a comprehensive alternatives assessment would be done in the context of the overall product life cycle. As well as considering toxic inputs to the production process, toxins that remain bound in the finished product when in use but may dissipate when disposed would be assessed for safer options. However, this document is written acknowledging that, for the most part, industries are not in a position to conduct such a resource-intensive evaluation of alternatives prior to making changes.

Methods for Alternatives Assessment of Chemicals

Appendix B provides a summary of over 100 various methods and tools that are available as of 2004. These range from full life cycle assessment to specific parameter assessment tools. It is not realistic for an industry to evaluate each of the many tools available. This report focuses on nine tools for alternatives assessment of chemicals that have been developed by government and private organizations in the United States and Europe.

In general, the process of assessing chemical alternatives using one of these methods includes several steps. First, the chemical in use and its potential alternatives are researched to identify known hazards. The tools reviewed in this document are particularly helpful in screening out chemicals that are associated with these hazards. Then, in order to identify safer alternatives, a list of positive attributes, such as biodegradability and minimal toxicity, is identified for the needed chemical. Some companies have developed "positive lists" of chemicals possessing these attributes from which they choose for various uses. In this way they can manage their chemical purchases to minimize the risk associated with using more hazardous substances. In some cases however, industry may need to conduct its own research and development to identify appropriate safer chemicals for its applications. In this case the principles of green chemistry can be used to help in the development of chemicals that have the required positive qualities. Text Box 2 provides a summary of the 10 principals generally associated with the practice of green chemistry.

Text Box 2 – Twelve Principles of Green Chemistry

1. Prevent waste (unconverted feedstock, spent reaction fluids)
2. Maximize the incorporation of all process materials into the finished product
3. Use and generate substances that possess little or no toxicity
4. Preserve efficacy of function while reducing toxicity
5. Minimize auxiliary substances (e.g., solvents, separating agents)
6. Minimize energy inputs (process at ambient temperatures and pressures)
7. Prefer renewable materials over nonrenewable materials
8. Avoid unnecessary derivations (e.g., protection/deprotection steps)
9. Prefer catalytic reagents over stoichiometric reagents
10. Design for natural post-use decomposition
11. Use in-process monitoring and control to prevent formation of hazardous substances
12. Minimize the potential for accidents

Adapted from: Paul T. Anastas and John C. Warner, *Green Chemistry: Theory and Practice*, New York, Oxford University Press, 1998.

The tools reviewed for this document can be divided into two categories:

1. Hazard data display methods: in these methods, data on a range of chemical hazards are arrayed and users are expected to develop their own rules for decision making among alternatives. Several methods within this category go further in that they aggregate data in order to create a risk index for comparing substances.
2. Screening methods: in these approaches, chemicals are evaluated for a range of hazards. Within each tool, hazards are prioritized, and recommendations made to eliminate use if chemicals are deemed to be high risk. In this way, decision rules are built into the screening tool for the user. These methods may or may not consider the potential for exposure.

Hazard Data Display Methods

Hazard data display methods that were reviewed for this document include:

- Pollution Prevention Options Analysis System developed by the Institute,
- The Column model,
- Five Step Evaluation Matrix created by the German Federal Environmental Agency, and
- Chemicals Assessment and Ranking System (CARS) designed by the Zero Waste Alliance, a private consulting organization based in Oregon.

A compendium of each of the Hazard Data Display Methods is provided in Appendix C as a quick reference source.

Pollution Prevention Options Analysis System (P_2OASys)

The Institute has developed a systematic tool that helps companies determine whether the toxics use reduction options they are considering may have unforeseen negative environmental, worker or public health impacts. P_2OASys allows companies to assess the potential environmental, worker, and public health impacts of alternative technologies aimed at reducing toxics use. The goal is to facilitate more comprehensive and systematic thinking about the potential hazards posed by current and alternative processes identified during the TUR planning process. The tool can be used in two ways:

1. To systematically examine the potential environmental and worker impacts of TUR options in a comprehensive manner, examining the total impacts of process changes, rather than simply those of chemical changes; and
2. To compare TUR options with the company's current process based on quantitative and qualitative factors.

Embedded formulae in P_2OASys provide a numerical hazard score for the company's current process and identified options, which can then be combined with other information sources and professional expertise to make decisions on TUR option implementation. Additional features of P_2OASys:

- It is available in both electronic spreadsheet and interactive web-enabled formats
- It is accompanied by a manual describing how to use and interpret results
- Actual examples from Massachusetts companies are provided in the manual.

Companies using P_2OASys input both quantitative and qualitative data on the chemical toxicity, ecological effects, physical properties, and changes in work organization as a result of the proposed option. Appendix D presents the P_2OASys tool.

P_2OASys can be used to analyze individual chemicals or a chemical mixture.[6] It arrays data on a range of hazards, including acute and chronic human health effects, environmental concerns, physical and chemical hazards such as flammability and reactivity. Exposure potential is estimated as low, medium or high. The chemical under evaluation receives a score for each type of hazard that indicates very low to very high risk. P_2OASys converts data for each hazard category into a numeric scale with the lowest score representing a lower hazard and the highest score representing a higher hazard. P_2OASys uses the "max-min" principle, meaning that the highest value within any hazard category dominates that category of analysis (e.g., chronic toxicity, acute toxicity, etc.).

Table 1, the final hazard score table in P_2OASys, illustrates how alternative chemicals can be compared in a side-by-side manner. The P_2OASys database contains 2,000 properties for over 700 chemicals.

Table 1 – P2OASys Summary Table

CATEGORY	Current Process	Alternative 1	Alternative 2	Alternative 3
Acute Human Effects				
Chronic Human Effects				
Physical Hazards				
Aquatic Hazard				
Persistence/Bioaccumulation				
Atmospheric Hazard				
Chemical Hazard				
Energy/Resource Use				
Product Hazard				
Exposure Potential				

Column Model

The Institute for Occupational Safety (BIA) of the German Federation of Institutions for Statutory Accident Insurance and Prevention developed the Column Model to provide industry with a practical tool for identification of alternative substances. This Model evaluates data on acute and chronic human health hazards, environmental hazards, fire and explosion hazards, and exposure potential. Table 2 illustrates how data are arrayed in the Column Model. The criteria for each cell in Table 2 are determined primarily by risk phrases (R-phrase). R-phrases are a European system that indicates different types of hazards using the letter R and a number. For example, in the "Fire and Explosion Hazards" column, the criteria for the very high risk cell are:

Because of data uncertainties, data quality and the mix of quantitative, semi-empirical and qualitative data used to complete the matrix, a risk index of **this type is very subjective and should be used with caution**.

[6] Discussion of P2OASys and other methods in this document is drawn largely from Rossi, Mark, Joel Tickner and Sally Edwards, "Chemical Hazard Assessment: Selecting and Designing for Safer Chemicals", background paper for Lowell Center for Sustainable Production, December 2004.

explosive substances/preparations, extremely flammable gases and liquids, and spontaneously flammable substances/preparations.[7]

The Column Model expects users to rely on information from Material Safety Data Sheets to fill in the columns. With either P2OAYSys or the Column Model, the user may need to go to additional data sources for information to complete the columns. The interpretation of these data is left to the user.

Table 2 – Column Model

Hazard Levels	**Hazard Endpoints**					
	Acute Health Hazards	Chronic Health Hazards	Environ-mental Hazards	Fire and Explosion Hazards	Exposure Potential	Hazards Caused by Procedures
Very high						
High						
Medium						
Low						
Negligible						

With the results of P2OAYSys or the Column Model, users can compare alternatives to arrive at a decision about substitution. The decision-making approaches of *dominance* analysis and *positional* analysis can be employed at this stage in the process. These approaches are defined in *The Use of Decision-aid Methods in the Assessment of Risk Reduction Measures in the Control of Chemicals* as follows: "In dominance analysis, an alternative is dominated if there is another alternative that excels it in one or more criteria and equals it in the remaining criteria. The first alternative is compared with the second and if one is dominated by the other, the dominated is discarded. A comparison with the next alternative follows. At the end the user obtains a set of non-dominated alternatives. In positional analysis the direction of the criteria is identified so that the desired direction is defined (minimization or maximization). The values for the criteria are contained in the reduced evaluation table, which is the source of information showing the possible combinations of the criteria supporting certain alternatives. Conclusions are drawn directly on the basis of this information. In this analysis the decision is made based on the criteria considered most important. This means omitting the values of other criteria".[8]

For example, with the Column Model dominance analysis could be used to assess whether Chemical A scores better or equal than Chemical B for all columns.[9] The Column Model is designed to compare alternatives only within a column and not across rows – in other words, substances can be compared for similar hazards only. Since the likelihood of dominance across all six columns is low, positional analysis is likely to be necessary. In positional analysis the decision maker narrows the assessment by prioritizing particular hazards and choosing one or more columns (e.g., only acute and chronic health hazards) for comparison. Users must determine which potential hazards are of greatest relevance in their production processes in order to prioritize hazards for positional analysis.

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[7] Directive 67/548/EEC- Classification, Packaging and Labeling of Dangerous Substances in the European Union, see Annex III for definitions of R-phrases.
[8] Hokkanen, Joonas and Jukka Pellinen, *The Use of Decision-aid Methods in the Assessment of Risk Reduction Measures in the Control of Chemicals,* report for Nordic Council of Ministers, Copenhagen 1997.
[9] See footnote 7, p.3.

Five Step Evaluation Matrix

The German Federal Environmental Agency has developed the Five Step Evaluation Matrix to assist businesses whose production processes may contribute to the contamination of water ecosystems because of the releases of persistence substances.[10] Users can array hazard information and compare alternatives. The tool is similar to the Column Model in that it also defines five risk levels for different hazards as well as use patterns (see Table 3). Users of the Five Step Evaluation Matrix can review the disaggregated data by column and compare alternatives. In addition, the data can be aggregated by weighting the hazards to create a risk index, as follows:

> A weighting can be assigned to various contributions to the risk (e.g. persistence = very important = 0.3 = 30% of the total risk). The extent of the risk can be scaled by number from 1-5. Summing up the weighted numbers results in the risk index of a certain substance in a specific application.[11]

A risk index can be developed for each alternative and these aggregated indices can be compared. It is important to note, however, that transparency is lost when these data are aggregated; therefore, assumptions and decisions made using these indices must be clearly articulated.

Table 3 - Five Step Evaluation Matrix (developed by Ökopol and Fraunhofer for the German Federal Environmental Agency)

Extent of Risk Contribution	Substance Properties					Use Pattern			Risk Index
	Persist-ance	Bioaccum-ulation	Aquatic Toxicity	Chronic Toxicity	Mobility	Amt.	Mobilizing Conditions	Indirect Releases	
Very High									
High									
Medium									
Low									
Very Low									
Weighting									

Chemical Assessment and Ranking System (CARS)

The Zero Waste Alliance (ZWA) based in Portland, Oregon developed CARS as a decision support tool for assessing chemicals and planning for elimination or substitution of hazardous materials and processes. The CARS database[12] contains chemicals on State and Federal regulatory lists and other substances known to exhibit characteristics such as carcinogenicity, aquatic toxicity, persistence, bioaccumulation and ecotoxicity. To use the tool, the chemical constituents and associated CAS numbers are identified for products being assessed. Material Safety Data Sheets are utilized to determine hazard properties. The resulting chemical inventory is screened in the CARS database. Chemicals that are associated with any well-documented hazard will be flagged. The user is then

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[10] Rossi et al, "Chemical Hazard Assessment: Selecting and Designing for Safer Chemicals", p.6.

[11] Ahrens, Andreas, Eberhard Bohm, Kerstin Heitmann, and Thomas Hillenbrand, *Guidance for the use of environmentally sound substances*, Ökopol Institute for Environmental Strategies and Fraunhofer Institute for Systems and Innovation Research, project commissioned by the German Federal Environmental Agency, 2003.

[12] CARS can only be accessed through the consulting services of Zero Waste Alliance.

asked to assign "importance weights" to each hazard category, by considering the quantity and frequency of use. Chemical constituents or products are then ranked according to this weighting scheme. The resulting ranked list can be used to set priorities for elimination of hazardous chemicals.

This tool is a hybrid as it both arrays data for users and screens chemicals for known hazards. CARS can be used as a screening method to prioritize for elimination any chemical that is flagged as a human health or environmental hazard. The CARS approach incorporates the judgments of the user in deciding weights for each hazard category, which are determined by considering quantity and frequency of use, factors that may be considered proxies for exposure. This weighting is clearly a subjective process, which CARS states is a reflection of the organization's "values and priorities".[13]

Assessing Data in Hazard Array Methods

The advantages of data display models are that they allow users to see the range of hazards posed by chemicals, to understand how the hazard levels are defined for each endpoint (if the criteria behind the hazard level classifications are transparent), to consider potential risk trade-offs between chemicals, and to incorporate their values into deciding which types of hazard are most important to their decision making processes. Judgments are embedded in the methods according to how criteria are defined for each cell of the specific model. Users in turn overlay their values and priorities when prioritizing among columns. The interpretive flexibility of data display models can be a disadvantage because results are not always consistent between different users, and because these methods do not specify which hazards are of greatest concern to governments, industry, or environmental organizations.[14]

With the results of the various hazard array methods, users can compare alternatives to arrive at a decision about a preferred substitution. The decision-making approaches of dominance analysis and positional analysis can be employed at this stage in the process.

In dominance analysis, an alternative is dominated if there is another alternative that excels it in one or more criteria and equals it in the remaining criteria. All dominated alternatives are discarded.

In positional analysis the direction of the criteria is identified so that the desired direction is defined (e.g., minimization or maximization). The values for the criteria are contained in the simplified evaluation table, which is the source of information showing the possible combinations of the criteria supporting certain alternatives. Conclusions are drawn directly on the basis of this information. In this analysis the decision is made based on the criteria considered most important[15].

Many of the hazard data display methods described are designed to compare alternatives only within a column and not across rows or vice versa – in other words, substances can be compared for similar hazards only. Since the likelihood of dominance across all columns/rows is low, positional analysis is likely to be necessary. In positional analysis the decision maker narrows the assessment by prioritizing particular hazards and choosing one or more criteria (e.g., only acute and chronic

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[13] http://www.zerowaste.org/cars/

[14] Rossi et al, "Chemical Hazard Assessment: Selecting and Designing for Safer Chemicals", p.4.

[15] Hokkanen, Joonas and Jukka Pellinen, *The Use of Decision-aid Methods in the Assessment of Risk Reduction Measures in the Control of Chemicals,* report for Nordic Council of Ministers, Copenhagen 1997.

health hazards) for comparison.[16] Users must determine which potential hazards are of greatest relevance in their production processes in order to prioritize hazards for positional analysis.

Aggregated methods such as P2OASys and the Five Step Evaluation Matrix are convenient to decision-makers as they collapse data into risk indices that can be ordered and ranked. However, this process of data aggregation means that subjective human factors that were incorporated into decision-making become hidden. In general, users should work with models that do not aggregate data whenever possible in order to maintain a higher level of consistency and transparency between users. However the trade-offs associated with the amount of data that needs to be obtained and compared will often make the choice to use more complex tools that aggregate data the best choice. The user conducting an alternatives assessment will need to determine the preferred method on case by case basis.

Screening Methods

Screening methods have also been developed for alternatives assessment. Similar to the tools described above, these approaches evaluate chemicals for a range of hazards. These tools differ from previously described methods in that decision rules are built into each tool, hazards are prioritized, and recommendations made to eliminate use if chemicals are determined to pose high risk. TURI reviewed two screening tools developed by European governments for this document: Quick Scan developed by the government of the Netherlands and PRIO developed by the Swedish government. Also included are guidelines for substitution developed by the Norwegian government. In addition, TURI reviewed a protocol developed by McDonough Braungart Design Chemistry (MBDC), a private consulting organization in the US. Finally, the PBT Profiler, which was developed as part of the US EPA's P2 Framework to screen chemicals which lack experimental data is included here as a screening method.

A compendium of each Screening Method is provided in Appendix C as a quick reference source.

Quick Scan

The Dutch Ministry of Housing, Spatial Planning and the Environment developed the Quick Scan method, which forms an integral part of the Dutch Government's new chemicals policy for substitution of high hazard chemicals and chemical mixtures.[17] The responsibility for implementing Quick Scan resides with the industrial community. Quick Scan is implemented as follows:

Step 1: Develop hazard profile for each substance

Step 2: Use specified criteria to classify the substance into hazard categories

Step 3: Use decision-rules to combine and weight hazard categories and allocate substance to a category of concern (very high to low concern, no data is assumed to be very high concern)

Step 4: Determine exposure potential based on chemical use and adjust concern category accordingly

Step 5: Follow established policy for each category of concern.

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[16] Rossi et al, "Chemical Hazard Assessment: Selecting and Designing for Safer Chemicals", p.3.

[17] *Implementation Strategy on Management of Substances*, Dutch Ministry of Housing, Spatial Planning and the Environment, progress report December 2001 and second progress report October 2002.

In general the decision rules for converting human health hazard levels into concern categories using the Quick Scan method are straightforward.[18] For instance, a hazard such as carcinogenicity automatically translates into a "very high concern" category. The decision rules for persistent, bioaccumulative and toxic substances (PBTs) are more complex. In this case a chemical is assigned a concern category based upon the chemical's combined hazard level for persistence, bioaccumulative capacity and eco-toxicity. For example, a chemical that is highly persistent, bioaccumulative and toxic is considered of "very high concern," while a chemical that is persistent and somewhat bioaccumulative but only slightly toxic is considered of "concern". The concern categories are adjusted based upon exposure potential (considering chemical uses) and the availability of alternatives.

Table 4 displays the final matrix of the Quick Scan method, which places chemicals in cells according to hazard and exposure potential. The classification of a chemical as "very high concern" or "high concern" has specific policies associated with it as follows:

- "Substances giving rise to very high concern must, in principle, no longer be used;
- Substances of high concern are not to be permitted for consumer purposes and in open professional use, unless certain preconditions are satisfied; and
- Substances of concern are permitted, provided that certain limit conditions are satisfied

Table 4 – Quick Scan Model

Concern Level Based on Hazard	**Use of Substances as Indication of Exposure**			
	Low Exposure (Site Limited Intermediate Substances)	**Exposure** (Substances in Industrial Applications)	**High Exposure** (Open Professional Use of Substances)	**Very High Exposure** (Substances in Consumer Applications)
Very High Concern	High Concern	High Concern	Very High Concern	Very High Concern
High Concern	Concern	Concern	High Concern	High Concern
Concern	Concern	Concern	Concern	High Concern
Low Concern	Low Concern	Low Concern	Low Concern	Concern
No Data, Very High Concern	Very High Concern	Very High Concern	Very High Concern	Very High Concern

Source: *Implementation Strategy on Management of Substances*, 2002.

The Quick Scan Model is designed to eliminate the use of high hazard chemicals and can also be used to encourage use of chemicals identified as low concern. Subjective judgments enter into Quick Scan when defining criteria, decision making rules, and revising concern categories based upon use data.

[18] Rossi et al, "Chemical Hazard Assessment: Selecting and Designing for Safer Chemicals", pg. 4-6.

It is important to note that with the Quick Scan model, the user must input all the chemical data, and must rely almost exclusively on the R-Phrases[19] developed by the European Union. For this reason, this model may be too cumbersome for some users.

PRIO

The Swedish Chemicals Inspectorate (KemI) developed PRIO for Risk Reduction of Chemicals.[20] A non-toxic environment is one of the Swedish government's fifteen environmental quality objectives, and the PRIO tool is designed to assist chemical producers and users in making progress towards this goal. This web-based tool contains a database of chemicals that the Swedish government has identified as being of high concern to human health or the environment. Hazard characteristics have been prioritized in PRIO into two categories and substances are classified as appropriate for phase out or risk reduction. This differs from the hazard data array methods described above, as the PRIO prioritizes hazards for the user, with "phase out" chemicals (e.g., carcinogenic, toxic to the reproductive system, PBT, etc) identified as being of greatest concern and "risk reduction" chemicals (e.g., high acute or chronic toxicity, allergenic, etc) also being of concern.

> The Swedish government policy is that phase out substances should not be used because of their inherent hazard, whereas the continued use of risk reduction substances should be determined based on the conditions of use and potential for exposure.

Users of the PRIO tool can search the database for individual chemical substances. If the substance is in the database, the chemical will be identified as "phase out" or "risk reduction". If the chemical is not in the database the user will need to research the properties of the substance of concern and compare it to the PRIO criteria to determine whether it fits into the "phase out" or "risk reduction" category. Material Safety Data Sheets and other data sources may be needed to determine the constituents and hazard characteristics of chemical mixtures. If after review it is found that a substance is not associated with the hazards identified in the "phase out" or "risk reduction" categories, this may mean that the inherent hazards of this chemical are lower, relative to other substances. However, the PRIO tool does not assess flammability or explosiveness, which may pose a safety hazard.

Norwegian Pollution Control Authority

The Norwegian Pollution Control Authority has developed broad guidelines to encourage industry to evaluate their chemical use and find substitutes for hazardous chemicals[21]. Businesses in Norway are required to evaluate chemicals used in occupational settings and to look for substitutes for substances that pose human health or environmental hazards. The Norwegian government has developed a list of human health and environmental hazards and has criteria associated with each of these hazards. Using these criteria the government has created a list of approximately 3,000

[19] Chemicals are classified based on the physico-chemical, toxicological and ecotoxicological properties of the substance or preparation which may constitute a risk during normal handling or use. Having identified any hazardous properties, the substance or preparation is then labeled to indicate the hazard(s) in order to project the user, the general public and the environment. This information is typically available in EU-based data safety sheets.

[20] See KemI – Swedish Chemical Inspectorate for a non-toxic environment, http://www.kemi.se/default.aspx?id=550.

[21] Substitution of Hazardous Chemicals, Norwegian Pollution Control Authority: http://www.sft.no/publikasjoner/kjemikalier/2007/ta2007.html

Dangerous Substances. A subset of approximately 250 substances is called the Observation List. Elimination targets have been set for these particularly hazardous or widely used chemicals. A seven-step process guides users in evaluating their chemical use and the Observation List can be used to prioritize chemicals for substitution.

Cradle-To-Cradle Design Protocol

McDonough Braungart Design Chemistry is a product and process design firm founded by the architect William McDonough and the chemist Michael Braungart and based in Charlottesville, Virginia. MBDC has pioneered a concept called "cradle to cradle" design where materials used in making products are continually circulated in closed loops. The company has developed a materials assessment protocol called the "cradle to cradle" (C2C) design protocol[22]. Similar to other tools, the C2C protocol includes a list of human health and environmental hazards, with criteria associated with each endpoint. Chemicals are assessed using these criteria and are assigned a red, orange, yellow or green rating.

This tool prioritizes certain hazards: all known or suspected carcinogens, endocrine disrupters, mutagens, reproductive toxins, teratogens, and chemicals that "do not meet other human health or environmental relevance criteria" receive a red rating. Chemicals receive an orange rating if there is a lack of information to do a full assessment. A yellow rating indicates a low to moderate risk and a green rating indicates that the chemical presents little or no risk. This protocol is accessible only through the consulting services of MBDC.

PBT Profiler

The US EPA's Office of Pollution Prevention and Toxics (OPPT) created the P2 Framework as a compilation of many of its computer based method for predicting chemical risks. The P2 Framework is a risk screening approach that incorporates pollution prevention in the design and development of new chemicals. Included in this framework are a number of computer models that predict chemical risk based on structure activity relationships and default scenarios. The PBT profiler (www.pbtprofiler.net) is one of the tools offered within the P2 Framework. It is an online tool (made up of a subset of the P2 Framework models) that can be used to evaluate organic chemicals that lack experimental data for persistence, bioaccumulation and chronic fish toxicity.

The P2 Framework emphasizes that data from well designed experimental studies is always preferable to predictions based on structure activity relationships. The PBT Profiler software program retrieves information on chemical structure using CAS registry numbers and provides easy to read color-coded comparisons of predicted values to PBT criteria. If the chemical exceeds thresholds for persistence, bioaccumulation or chronic fish toxicity, the designators are shaded red or orange. If thresholds are not exceeded the designators are shaded green. Inorganic chemicals, reactive chemicals, organic salts, high molecular weight compounds, chemicals with unknown or variable composition, mixtures, surfactants, and highly fluorinated compounds cannot be evaluated by the PBT Profiler. This screening tool fills a gap as it provides a means of evaluating chemicals that are not well studied. It does not include data to screen chemicals for human health hazards.

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[22]Cradle to Cradle Design Protocol at www.MBDC.com.

Comparison of Screening Methods

Quick Scan, PRIO, the Norwegian Guidelines, the C2C protocol and the PBT profiler each contain built in decision rules to assist users in determining priorities for elimination based on inherent hazards. Exposure potential is addressed in several tools. The Quick Scan "category of concern" may be modified after considering exposure potential. The PRIO "phase out" chemicals are prioritized for elimination based on inherent hazard, while users are asked to consider the exposure potential of "risk reduction" chemicals. The Norwegian Observation List contains chemicals that are considered high hazards and are widely used, thereby increasing exposure potential.

These tools are most useful in screening out undesirable chemicals, but they do not necessarily identify safer alternatives. However, any identified alternative can be analyzed with these screening methods to see if it is associated with known hazards. If no hazard association is found this may either mean that the chemical is not well studied or it that it is indeed a safer alternative. Both the Quick Scan method and the C2C protocol highlight chemicals for which there are insufficient data to conduct a complete assessment as high risk. A green rating from the C2C protocol indicates a chemical that has been fully assessed and presents little or no risk. The "low concern" category of Quick Scan indicates a chemical that presents a low level of risk. In this way, a safer alternative is identified by an absence of negative attributes.

What Method Should You Use?

As a first step you should consider whether a hazard data array or a screening method would be more useful in meeting your planning and decision-making objectives. Each organization's objectives may differ depending on whether the chemical being assessed is used as an intermediary in a process or as a final product. Table 5 provides a detailed description of the attributes of each of the methods described above, and in more detail in Appendix C, including what is assessed and what are the associated limitations. Table 6 is provided as a quick reference of the methods and tools described herein, with an indication of their possible uses and the level of effort associated with using the tools. Refer to Appendix C for a summary of the methods listed in these tables.

Hazard data array methods tend to require more effort associated with researching and inputting data. The user of this type of method must determine how to prioritize hazards once they are identified for each chemical that is being evaluated. This may require an in depth consideration of toxic chemical use, management and potential for exposure. Although the level of effort may be relatively high, a hazard data array method such as P2OASys has advantages as it can provide a clear side-by-side comparison of alternatives.

The screening tools listed in Table 5 tend to require less effort than the hazards array tools because decision-making rules are built into each approach and, in some cases (e.g., PRIO and CARS), a database of hazardous chemicals can be utilized. These screening methods provide a relatively simple means of flagging and prioritizing high hazard chemicals for reduction or elimination.

An alternatives assessment will ideally determine the chemical hazards associated with each option and identify which alternative is inherently safer. However, in some cases a clearly preferable choice may not be identified through the alternatives assessment process. In this situation there are several options. The analyst can evaluate conditions of use, available chemical management systems, and exposure potential in order to determine if the hazard posed by a particular option can be adequately controlled, thereby posing a reduced overall risk. In some cases none of the options may emerge as preferable.

In addition to evaluating alternatives for environmental health and safety, the toxics use reduction planning process includes evaluations of technical feasibility and economic viability. Obviously, any alternative that is deemed as "safer" must also meet technical requirements and be economically feasible in order to be adopted. If payback is not immediate or obvious, it is important to determine when cost-savings will occur, and to consider indirect costs such as liability and hazardous waste management that may be eliminated by changing to a safer chemical.

Table 5. Comparison of Methods for Evaluating Chemical Hazards and Safer Alternatives

Alternatives Assessment Method / Model	Human Health Hazards Evaluated	Environmental Hazards Evaluated	Exposure Considered	How Hazards Are Ranked/Data Aggregated or Not	Criteria Weighting	Limitations Addressing Data Gaps
P_2OASYS (Mass. Toxics Use Reduction Institute)	Acute toxicity; Chronic tox.; Carcinogenicity Reproductive tox; Respiratory sensitivity; Physical/ ergonomic; Chemical – VP, flashpoint, VOC; Consumer haz.	Persistence Bioaccumulation Aquatic/Eco toxicity Ozone depletion Greenhouse gas Hazardous air pollutant Disposal Energy, water, resource use Recycling	Potential exposure is evaluated as low, medium, high (1,2,3)	Qualitative data are scored as 1, 2 or 3 with 3 indicating greater hazard. All quantitative data are converted to numerical scores in which the lower number represents the safer alternative. Data are not aggregated. Color coding scheme makes it easy to compare alternatives in specific hazard categories	Weighting of criteria is done by user	Data availability
Column Model (Germany)	Acute toxicity; Chronic toxicity; Carcinogenicity Reproductive toxicity; Mutagenicity; Ocular hazards; Irritants; Reactivity; Corrosivity	Water polluting substances as characterized by: Aquatic toxicity, Biodegradability (hydrolysis, photolysis, oxidation, etc.), Soil mobility, Bioaccumulation	Substances receive a risk ranking according to vapor pressure and procedures for use are considered.	Within each column, substances are assessed as very high risk, high risk, medium risk, low risk, negligible risk. Columns representing different hazards are not aggregated.	Criteria are not weighted. User determines which hazards are most relevant to their operations.	Column model relies on data from German MSDS to complete table. If test data unavailable, substances scored as high risk.
PRIO (Sweden)	Acute toxicity; Chronic toxicity; Carcinogenicity Reproductive toxicity; Mutagenicity; Hazardous metals (Hg, Cd, Pb and compounds); Endocrine disruption; Allergen	Persistence Bioaccumulation Aquatic toxicity Ozone depletion Very persistent Very bioaccumulative	No, but PRIO recommends that exposure be assessed for "risk reduction" substances	Substances are divided into 2 classes ("phase-out" and "risk reduction") according to the properties they exhibit: "Phase out" substances should be replaced; PRIO recommends that exposure be evaluated for "risk reduction" substances. Data are not aggregated	Criteria that identify "phase out" substances are weighted as more significant than "risk reduction" criteria	Incomplete database; hazards such as flammability are not evaluated

Alternatives Assessment Method / Model	Human Health Hazards Evaluated	Environmental Hazards Evaluated	Exposure Considered	How Hazards Are Ranked/Data Aggregated or Not	Criteria Weighting	Limitations Addressing Data Gaps
Five Step Evaluation Matrix (Germany)	None	Persistence Bioaccumulation Aquatic toxicity Chronic vertebrate toxicity Intrinsic mobility (determined by VP, water solubility, dustiness, matrix binding)	Conditions of use examined: Amount used, application in industrial and consumer settings, degree of containment, mobility under use conditions	Qualitative matrix – one column describes extent of risk contribution as: Very high, High, Medium, Low, Very Low. (Extent of risk can be scaled from 1-5) Substances are assigned hazard levels according to the properties they exhibit – e.g., a PBT is very high, but a P and/or B and/or T is high or medium risk. Other columns of matrix describe hazard and exposure properties. Data can be aggregated into a "risk index" by summing the weighted numbers for each hazard category	Weights can be assigned to each hazard category	Framework for comparison of hazards and exposure potential; data availability may be an issue
CARS (Zero Waste Alliance)	Carcinogenicity Teratogenicity; Endocrine disruption	Persistence Bioaccumulation Aquatic toxicity Ozone depletion Greenhouse gas Hazardous air pollutant	Screening done without consideration of exposure, further analysis may include qualitative exposure evaluation	Qualitative tool which flags chemicals that exhibit hazard properties listed above. Final prioritization of substances integrates hazard information, exposure proxy information (amount and frequency of use) and "importance weights" as determined by user	User determines "importance weights" for each hazard category	Database includes chemicals for which hazards are well documented; relies on info in MSDS. Fee to use
Quick Scan (Netherlands)	Chronic toxicity; Carcinogenicity Reproductive toxicity; Mutagenicity; Hormone disruption	Persistence Bioaccumulation Ecotoxicity	Exposure potential is based on use category; Industrial use, site-limited intermediate use, open applications /professional use, consumer applications	Qualitative matrix – one column categorizes hazard as: Very high concern, High concern, Concern, Low concern, No data-very high concern. Other columns of matrix categorize exposure potential from: low exposure, exposure, high exposure, very high exposure. Some hazard data are aggregated – P, B, and T criteria are combined in a matrix to assign substance to a hazard category. Human health data are not combined – if substance is assigned to highest hazard class for any one property, then it is placed in high concern category. Overall category of concern reflects highest category for either human health or environmental effects	Criteria are not weighted	Chemicals for which no data exists are placed in very high concern category. Use is proxy for exposure

Alternatives Assessment Method / Model	Human Health Hazards Evaluated	Environmental Hazards Evaluated	Exposure Considered	How Hazards Are Ranked/Data Aggregated or Not	Criteria Weighting	Limitations Addressing Data Gaps
Norwegian Guidelines	Acute toxicity; Chronic toxicity; Carcinogenicity Reproductive toxicity; Mutagenicity; Sensitization; Endocrine disruption; Immuno-toxicity; Effects during lactation	Bioaccumulative/ low biodegradability; Bioaccumulative/ High acute toxicity; Low biodegradability/ High acute toxicity; Very high acute aquatic toxicity; Bioaccumulative/ very high chronic toxicity; Ozone depletion potential Greenhouse gas	Yes, substances placed on Observation List if are used in amounts and ways that create exposure potential	Criteria are not aggregated. Substances are placed on "Observation List" if meet one or more of criteria and are used widely or in large amounts. "Observation List" is subset of "Dangerous Substances" list. Users of these chemicals are required to evaluate whether less hazardous substitutes are available.	Criteria are not weighted	7-Step process provides guidelines for substitution. Because no data exists for many chemicals, it remains difficult to assess relative safety of alternatives.
C2C Design Protocol	Acute toxicity; Chronic toxicity; Carcinogenicity Reproductive toxicity; Mutagenicity; Teratogenicity; Endocrine disruption; Sensitization; Physical hazards such as flammability	Persistence/ biodegradation Bioaccumulation Fish toxicity Daphnia toxicity Algae toxicity Toxicity to soil organisms Ozone depletion potential Content of halogenated compounds Heavy metal content	No	Qualitative rating: Green – little or no risk Yellow – low to moderate risk Orange – lack of data prevents complete assessment Red – high risk Criteria are not aggregated	Criteria in red category are weighted as being of highest concern. Criteria and weights for yellow or green rating are not transparent.	Chemicals without data cannot be evaluated. Protocol flags chemicals orange if data are missing. Fee to use
PBT Profiler (US EPA)	None	Persistence Bioaccumulation Chronic fish toxicity	No	If the chemical exceeds thresholds for P, B or T designators are shaded red or orange. Data are not aggregated; however, for chemical to be considered a PBT it must exceed criteria in all 3 areas	Criteria are not weighted.	Screening level tool for evaluating organic chemicals without experimental data

Table 6: Summary of Methods and Tools for Alternatives Assessment of Chemical Hazards[23]

	Method Type[24]	Best used to:	User effort[25]	Accessibility Issues	Limitations
P2OASys	Hazard data display	Compare alternatives	High	On-line tool/ Fee to use?	Database incomplete
Column Model	Hazard data display	Compare alternatives within columns	High	None	Relies on MSDS
5 Step Evaluation Matrix	Hazard data display	Compare aquatic hazards -PBT	High	None	Data availability Evaluates PBT only
CARS	Hybrid	Flag hazardous chemicals in use	Med/low	Access through consultant only/fee to use	Database incomplete/relies on MSDS
Quick Scan	Screening/ Decision	Hazard/exposure matrix can be used to compare alternatives	Med/high	None	Data availability
PRIO	Screening/ Decision	Prioritize hazardous chemicals for elimination/reduction	Med/low	On-line tool	Database incomplete/flammability and explosiveness not evaluated
Norway Guidelines	Screening/ Decision	Prioritize hazardous chemicals for elimination	Med/low	None	Data availability
MBDC	Screening/ Decision	Screen out hazards/identify safe alternatives	Med/low	Access through consultant only/fee to use	Data availability
PBT Profiler	PBT Screening	Predict PBT based on structure/activity relationships	Low	On-line tool	Evaluates organic chemicals only

[23] This is not an exhaustive list of alternatives assessment methods, but represents a summary of methods reviewed for this document.
[24] Hazard data display methods array data on chemical hazards and users develop their own decision rules; screening/decision methods have decision rules built in. CARS is a "hybrid" type as it arrays data, flags hazards and asks users to develop "importance weights".
[25] High effort – user makes decision rules and may need to research and input data; medium effort – decision rules built in but user may need to research and input data; low effort – decision rules built in and user inputs chemical name and/or structure into database.

Limitations and Considerations in Conducting Alternatives Assessments

Subjective judgments are embedded in the various methods for assessing alternatives according to how criteria are defined for each model. Users of the chosen method in turn overlay their values and priorities when establishing criteria. Therefore it is essential that the organization conducting an alternatives assessment be very transparent in describing criteria and assumptions associated with the decision-making process.

> Because of data uncertainties, data quality and the mix of quantitative, semi-empirical and qualitative data used to complete the matrix, an overall aggregated risk index is very subjective and **should be used with caution**. A significant limitation associated with the use of the generalized alternatives assessment methodologies described in this document is the relative lack of data about various health and environmental criteria, and the inconsistency that is often apparent between varying sources of this information.

Use of data estimation models such as the PBT Profiler provide valuable approximations of environmental impacts based on structure-activity relationships of certain chemicals. However these models cannot replace the value of actual experimental data. When using data from any chosen source, the user must determine the level of data accuracy and validation desired.

In addition, there are often situations where data is not available either experimentally or by estimation models. In this case, the user must determine how to handle lack of information. In some cases (for example, the Dutch Quick Scan method) the user assumes that no information translates into a very high concern for that chemical. In other models the user can assume that information does not translate into a concern relative to the chemical being substituted. Both of these approaches have their limitations and it is up to the user to determine how best to address data gaps.

An alternatives assessment of chemicals is most effective when it involves the identification of positive attributes for alternatives as well as screening to avoid negative attributes.[26] This allows the user to develop a proactive and sustainable approach to its chemical and materials choices. Examples of positive attribute guidelines include the "Twelve Principles of Green Chemistry" described in Text Box 2, which define positive principles for developing chemicals that prevent waste and accidents, have little to no toxicity, are energy efficient, and use renewable resources.

In his book "Materials Matter", Ken Geiser provides another set of positive design criteria for the development of environmentally friendly substances and processes: use of inherently safer, non-bioavailable, physically benign and biodegradable materials, on-demand generation, and manufacturing in contained systems under ambient conditions.[27]

The OSPAR Commission has created a list of positive criteria that includes substances and preparations used and discharged offshore that "pose little or no risk" (PLONOR). The PLONOR list criteria include positive attributes as well as the absence of negative attributes, as follows:

[26] Rossi et al, "Chemical Hazard Assessment: Selecting and Designing for Safer Chemicals", pg. 8-9.
[27] Geiser, Kenneth. Materials Matter: Toward a Sustainable Materials Policy, Cambridge: MIT Press, 2001.

- Inorganic salts that are naturally occurring/constituents of seawater (excluding salts of heavy metals).
- Minerals that are not soluble in seawater.
- Organic substances that meet the following criteria:
    - no carcinogen, mutagen, or reproductive toxicity properties and
    - LC50 or EC50 > 100 mg/L and
    - Log P_{ow} <3 or BCR <100 or MW>1,000 and
    - Substance is readily biodegradable
- Other organic substances that are non-water soluble (e.g., nutshells and fibers).[28]

Users of alternatives assessment methods must evaluate each of these limitations and considerations when establishing a protocol for conducting the assessment. As mentioned in the beginning of this document, the methods described in this document for evaluating chemical alternatives may not be appropriate for considering materials or products.

Conclusions

Industries and organizations interested in conducting an assessment of alternative chemicals are faced with the challenge of determining the most appropriate method for their purposes. While this document outlines some of the benefits and limitations associated with ten methods, there are in fact a multitude of methods and combinations of methods that may yield the best results (refer to Appendix B for a summary of this larger list). Often the biggest factor in determining which method to employ is the resources (both time and money) required.

The engineer, scientist or industry manager engaged in alternatives assessment for chemical hazards will quickly learn that this process involves complex and often subjective decision making. This document has reviewed and summarized a number of methods currently available for evaluating chemical hazards and choosing safer alternatives. The approaches described in this report are decision aids, but they do not make the decision for the user. It is important to use these methods for the purposes for which they were intended. Because of limited experimental or human data on the health and environmental effects for the vast majority of chemicals in commerce, it is difficult to know with certainty that an identified alternative is truly safe. The methods described herein represent an important step to a more comprehensive alternatives assessment methodology that will screen out highly hazardous substances, define positive criteria and identify chemicals, processes or other types of solutions that will provide long-term protection of workers, communities and ecosystems.

The Institute has determined that piloting some of the methods described in this report would be of value. The goal of this pilot study would be to evaluate the time required to conduct an assessment and the quality and usefulness of the results. Guidance on how to interpret the results of any alternatives assessment is also necessary in order to make the process more accessible and effective for industry and other organizations.

Ultimately, the goal of conducting an alternatives assessment is to assist organizations in determining preferred chemicals, materials and/or products that meet technical and economic criteria and are also protective of human and environmental health.

[28] OSPAR List of Substances/Preparations Used and Discharged Offshore which are considered to Pose Little or No Risk to the Environment (PLONOR), Reference number: 2004-10E.

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Rossi, Mark, Joel Tickner and Sally Edwards, "Chemical Hazard Assessment: Selecting and Designing for Safer Chemicals", background paper for Lowell Center for Sustainable Production, December 2004.

Rossi, Mark, Joel Tickner and Sally Edwards. "Setting the Context for the Lowell Workshop on Designing and Selecting Safer Alternatives: Chemicals, Materials and Products", background paper for Lowell Center for Sustainable Production, December 2004.

United States Environmental Protection Agency. *Chemical Hazard Data Availability Study: What Do We Really Know About the Safety of High Production Volume Chemicals?* Washington DC, 1998.

Web Sites for Alternatives Assessment Methods/Tools

1. P2OASys – Pollution Prevention Options Analysis System
TURI version (free, Excel spreadsheet): www.turi.org/content/content/view/full/1125/
Web-enabled version (fee-based):
http://sbso2.mrcnh.com/DesktopDefault.aspx?tabindex=0&tabid=1, Click on Advisors tab, then click on P2OASys

2. The Column Model
http://www.hvbg.de/e/bia/pra/spalte/index.html

3. Five Step Evaluation Matrix
www.umweltdaten.de/umweltvertraegliche-stoffe-e/part1.pdf and
www.umweltdaten.de/umweltvertraegliche-stoffe-e/part2.pdf

4. CARS – Chemical Assessment and Ranking System
http://www.zerowaste.org/cars/

5. Quick Scan
http://www2.vrom.nl/pagina.html?id=7386

6. PRIO
http://www.kemi.se/default.aspx?id=550

7. Norwegian Pollution Control Authority – Guidelines for Substitution of Hazardous Chemicals

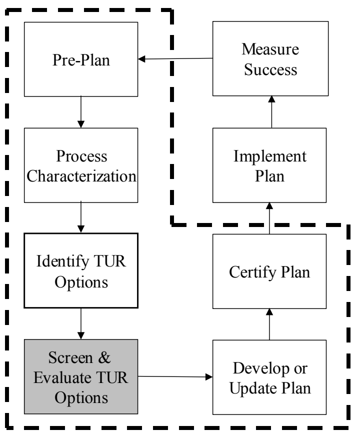
http://www.sft.no/publikasjoner/kjemikalier/2007/ta2007.html

8. MBDC Cradle to Cradle Design Protocol
www.mbdc.com

9. PBT Profiler
www.pbtprofiler.net

Appendix A: Toxics Use Reduction Planner's Course, Module 7 – TUR Options Evaluation

TUR Options Evaluation



Objectives: At the end of this chapter participants will be able to:

- Develop criteria to assess TUR options
- Use skills and techniques from earlier sections to assess options based on technical and economic criteria
- Develop a methodology for comparing options

Introduction to Evaluating TUR Options

After a comprehensive list of TUR options has been developed, the next step is to evaluate the technical and economic feasibility of each option. This module summarizes the TURA requirements for evaluating TUR options, and then presents a framework for evaluating TUR options, including screening and assessment steps. Finally, this module will present an overview of some of the resources – such as websites, case studies and publications – available to facilitate research of TUR opportunities and successes by other companies.

Options can be evaluated either formally or informally depending on the size of the company, the capacity of the TUR planning team, the options being examined, and available resources. In a small firm, most options could be evaluated by a couple of knowledgeable employees sitting down and discussing the positive and negative aspects of different products and systems. Sometimes a more detailed, objective assessment is necessary or desirable. Either way, some discussion of the assessment process must be included in the certified TUR plan.

Evaluation of TUR options can be a time-consuming phase of the planning process because it usually involves research and repeated evaluation. But it is important not to eliminate TUR options too hastily. Options that may seem impractical at first glance may, in fact, be successful solutions in the long run.

Screening TUR Options

In many cases, it is not necessary to thoroughly investigate every TUR option the planning team suggests during brainstorming. The Toxics Use Reduction Act allows companies to screen and immediately eliminate from further consideration any options that clearly are not technically or economically feasible, or that would not actually reduce toxics or byproduct.

TURA Requirements for TUR Options Analysis (310 CMR 50.46)

- **Screen the universe** - Companies may immediately eliminate from further consideration TUR options that meet any of the following:
    - It is clearly technically infeasible
    - It is clearly economically infeasible
    - It is not TUR (will not result in a decrease in toxics use or byproduct per unit of product)

NOTE: Companies must still include in the plan a description of each TUR option that was rejected, and the reason it was rejected.

- **Conduct technical and economic evaluations** – Companies must make a good faith business decision about whether or not to implement a given TUR option, based on a comprehensive technical and economic analysis on all options that were not eliminated during screening. For options chosen for implementation, the company's plan must include the following:
    - A description of the TUR option to be implemented.
    - Anticipated costs and savings associated with the option.
    - TUR byproduct reductions, and the byproduct reduction index (BRI) 2 and 5 years into the future. These projections are made on the assumption that the selected options are implemented as planned. NOTE: Companies must set these projections, but they are NOT required by TURA to achieve them.
    - An implementation schedule.

You might find that some options are so straightforward, inexpensive, effective and easy to implement that no further assessment is needed to approve them.

Technical Screening

Examples of factors that might immediately make a TUR option technically infeasible could include:

- Equipment is not available or cannot be developed
- Worker skills are inadequate
- The impact on product quality would be unacceptable
- There is insufficient space to install the necessary equipment

Economic Screening

The point of this screening is to eliminate options that are clearly far beyond the means of the company. This step does not require a detailed analysis; "back-of-the-envelope" calculations are perfectly acceptable. However, be careful not to eliminate options too quickly just because they have a high up-front cost. Some projects with large initial investments pay for themselves quickly in savings and productivity improvements.

Examples of factors that might immediately make a TUR option economically infeasible could include:

- The technique does not meet the company's investment criteria

- The project costs exceed available financing

Screening Strategy

Choose a strategy to pursue throughout the screening process that is based on the team's knowledge of the firm. If a facility's equipment is old and fully depreciated, management may be open to TUR options that require capital expenditures on replacement equipment. A small operation's financial constraints may limit the range of possible options. If a firm's business strategy involves innovation and cutting edge technologies, then it may be a likely candidate for trying new technologies and new materials.

Construct a list of questions that reflect the conditions of the firm to help guide you, such as:

- What are the main benefits of this option?
- What is the TUR potential of this option in this facility?
- How old and in what condition are buildings and equipment, and how does this relate to proposed changes?
- Does this option fit well with other company goals?
- Does this option have a good chance of succeeding?

The plan must include a description of the options that were rejected and the reason they were rejected. But the analyses conducted during the screening stage do not necessarily need to be highly refined or neatly formatted. For purposes of the screening requirements, it is perfectly acceptable to include hand-written calculations in the plan. It is during the evaluation stage that more detail should be provided.

Technical and Economic Evaluation

All options that remain after screening must be evaluated to determine:

- Costs and savings associated with the option.
- Expected changes in the total use, byproduct generation, and BRI that would result from implementation of the option for a full year of operation at planning year production levels.
- Relationship between the option and other applicable laws and regulations, including whether implementation will violate any other law or regulation.
- Whether or not the facility plans to implement the option and, if so, an implementation schedule and the projected TUR.

Some or all of these bulleted items may already have been answered during the screening phase. On the other hand, additional work done during this evaluation stage may reveal that a technique is actually inappropriate. Also, new options may be generated during this phase (see Example 7A). Companies may use whatever method for evaluation they deem appropriate. Evaluation of an option is complete when that option is determined inappropriate, or the bulleted items above are known.

Technical Evaluation

The technical assessment determines whether equipment and materials will work in a specific application. Depending on the option, a number of technical feasibility studies—from a paper study to a pilot project—may be needed. However, an exhaustive technical analysis may not always be necessary or useful.
Technical criteria to consider include the availability, applicability, effects on product quality, and sustainability of each TUR option:

Is this option available?

- Is this option "off-the-shelf" technology with demonstrated successful use?
- What is the likelihood of widespread commercialization?
- How reliable is the new technology?
- What is the vendor's track record?
- Is this option applicable to my firm?

Is the option compatible with existing process technology?

- Are equipment, materials, or processes used in the option compatible with current procedures, work flows, and production rates?
- Will the system installation require downtime that will interfere with the production schedule?
- How complex are the operations and maintenance requirements?
- Is floor space available?
- Are utilities available, or will they have to be installed?
- Does this option require personnel training?

Will product quality be affected?

- Will the defect rate increase?
- Will the finished product still comply with customer specifications?
- Will the option affect the product cosmetically?

Will this option be sustainable?

- What is the toxics use reduction potential of this option?
- Will this option remain viable despite market and regulatory changes?
- Is it flexible/durable enough for the firm's anticipated needs?

Suppliers and industry trade associations may be able to help with information about new materials and systems. Often suppliers will allow companies to test new equipment on a trial basis or will provide bench scale or pilot scale demonstrations. If you are considering changes in equipment or processes, try to visit facilities using the new equipment or process. Check the track record of the technology with operators on the floor to see how vendors' claims work out in practice.

In considering substitutes for current toxic chemicals, the TUR planner must assess the toxic and hazardous properties of the chemicals or process being proposed as substitutes. A brief analysis of the risks of the proposed substitutes may be useful. If you are considering a substitution of input chemicals, make sure that the substitute chemical is not equally toxic or does not generate other workplace or environmental risks. For example, some aqueous-based substitutes for solvents, while perhaps safer for workers, may cause wastewater disposal problems.

In conducting a substitutes assessment, consider the entire life cycle of a material or process. Some rather benign substitutes may pose significant environmental costs at points in their life cycle that are well beyond your plant. For example, the substitute may have significant environmental impacts during its production or end-of-life phases. In evaluating options, it is essential to include in the assessment all personnel affected by any change in processes, equipment, or materials. The technical assessment will determine whether options will require staffing changes, whether additional operations and maintenance personnel will be needed, and whether they will need training or special skills. If fewer employees are required to run a process, retraining or other provisions may be necessary.

Economic Evaluation of TUR Options

"Toxics users shall evaluate the economic feasibility of each technology, procedure, or training program identified as technically feasible" [310 CMR 50.46A].

How expensive will the option be to implement? There are, of course, the obvious economic aspects of implementing a TUR option to consider, such as operating costs, material costs and labor costs. But there are also less-obvious costs such as potential future liability, lost productivity due to worker illness, product quality, and corporate image. These less tangible costs will affect an option's economic feasibility.

The different methods for assessing the economic criteria are discussed in detail in Module 8, Financial Analysis. The methods of financial analysis can be used at this stage in the planning process to gauge the costs and savings attached to each option. When conducting an economic analysis, it is important to be mindful of the overall objectives. If a given option costs less to implement, but will increase worker exposure to a toxic, is it really more cost-effective?

Issues to consider during an economic assessment include:

What are the direct costs or savings of this option?

- What capital expenditures will be needed to implement this option?
- What will it cost to operate and maintain the new system?
- What are the treatment, storage, and disposal costs?

What are the hidden costs or savings associated with this option?

- Will this option affect costs of compliance-related activities?
- Will this option decrease taxes and fees?
- Will capital and operating expenses for emergency preparedness decrease?
- Will there be less lost time due to accidents or exposures?
- Will Workers' Compensation premiums decrease?

Will this option affect future liability?

- Will there be less potential future liability for hazardous releases?
- Will liability insurance premiums decrease?
- Will potential penalties and fines be avoided?

Are there fewer tangible or non-monetized costs or benefits?

- Will the firm's public image be enhanced?
- Will community and employee relations be improved?

What new revenue sources are associated with this option?

- Will this option provide new markets for modified products?
- Does this option allow sale or use of byproducts?
- Does this option allow sale or use of recovered products?
- Will market share lost to competing non-toxic products be regained?

Look at capital and operating costs first. If an option can be justified by looking at standard costs, building a case around less tangible factors such as potential liability is not necessary. However, if a project does entail significant capital costs, a more thorough economic analysis should be done that includes intangibles as well as standard costs and benefits.

One of the more difficult cost factors to quantify in assessing the feasibility of toxics use reduction is potential liability for continued usage of toxics. Consideration of liability can tip the balance in favor of TUR options being economically viable when they might be deemed less feasible if only short-term, direct costs are examined. This includes the potential for reduced liability insurance premiums.

When making investment decisions, a company will determine the appropriate return on investment for a given level of risk. If it can be shown that investing in a TUR option represents a reduced level of risk, the firm may opt to reduce its return on investment requirements. This can be done by extending the acceptable payback period by a year or reducing the required rate of return by some percentage points.

Evaluation Matrix Tool

One method for formally comparing options is to construct a matrix ranking the options in terms of how well they meet criteria important to the firm. This method has five steps:

1. **Establish a set of criteria** that are important to the firm and need to be considered. The list can reflect the issues examined by the technical and economic assessments. For example:

Product quality	Low capital costs
Ease of implementation	Low operating costs
Future liability	Personnel requirements
TUR potential	Level of change required
Health and safety	Worker acceptance
Extent used in industry	Flexibility of process

   Criteria can be fairly broad or more specific. Note that choosing a disproportionate number of criteria that relate to a particular issue, such as product quality or costs, will build a strong bias into your ranking system.

2. **Weight each criterion** according to its importance to the firm. Use a scale of 1–10, with 10 being the most important consideration and 1 the least important.

   For example, the team agrees that product quality is extremely important and it is weighted 9. Ease of implementation is not considered as important and is weighted 3.

3. **Score by criterion** for each TUR option. Assign a score from 1–10, with 10 the highest and 1 the lowest. Define specifically what high and low scores mean for each criterion.

   Product quality: options that maintain a high level of quality will receive a high score.

   - Option #1 turns out parts as high in quality as the current system, so it gets a score of 10.
   - Option #2 also turns out excellent parts, but it has not yet been approved by government specifications, so it gets a score of 8.

   Ease of implementation: options that involve minimal R&D, readily available equipment and materials, minimal down-time for installation, minor changes in operating procedures, and little additional employee training will receive a high score.

   For example, Option #1 involves major equipment installation; Option #2 will be relatively easy to implement. Option #1 receives a score of 6; Option #2 receives an 8.

4. **Multiply** the score for each criterion by its weight, for each option.

5. **Add the total weighted scores** for each option. Assuming that the highest total score means that option does the best in important areas, rank the options. If two options have close scores, then both should be subjected to further technical evaluations.

This method is illustrated in Figure 7A.

Figure 7A. Example of Scoring Method

		Option 1		Option 2	
Criteria	**Weight (1-10)**	**Score (1-10)**	**Weight x Score**	**Score (1-10)**	**Weight x Score**
Product quality	9	10	90	8	72
Ease of implementation	3	6	18	8	24
Future liability					
TUR potential					
Health and safety					
Extent used in industry					
Low capital costs					
Low operating costs					
Personnel required					
Level of change					
Worker acceptance					
Flexibility of process					
TOTALS:		**16**	**108**	**16**	**96**

Using this kind of tool to rank options can be helpful in creating a proposal that upper-level management will find convincing. However, a range of factors will still influence decision making in companies with different needs and procedures. In evaluating different options, consideration of such factors as corporate goals for market share and profit growth, acceptable payback periods, and tolerable degrees of change are important. If just-in-time manufacturing or quality improvement systems are being implemented, they may provide opportunities for the TUR program. Site-specific considerations, such as the need for replacement or upgrading of equipment and existing commitments to other capital projects, will also have an effect. Returning to the firm-specific criteria used to initially screen options may help in selecting options at this stage.

Aggressive reduction options are often more feasible in firms with previous TUR or pollution prevention experience, a commitment from top management to reducing toxics, a corporate culture that encourages innovative programs, or a workforce that contributes important information about product quality needs.

If the firm in question has not previously done toxics use reduction, it may be worthwhile to implement the smaller/easier options first and continue investigating the long-term options. Continuing the investigation of long-term options is critical, as it allows for continual improvement in the processes at hand.

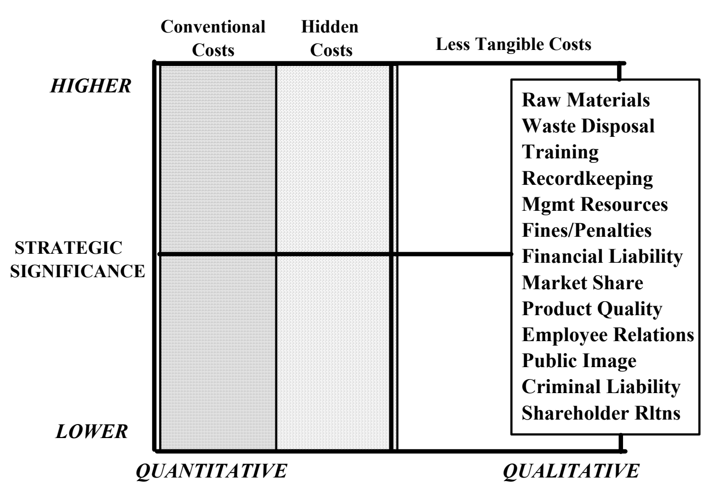
Qualitative Assessment

The technical and economic evaluation of a TUR project should be augmented by the evaluation of other factors that are difficult to quantify but that may have strategic significance. A project's impact on market share, pubic image, financial liability or stakeholder relations can even dwarf strict economic criteria in the decision-making process. Although such factors are often referred to as ‘qualitative’ or ‘intangible’, such a strict either/or classification (quantitative/ qualitative or tangible/intangible) is often misleading. Many issues fall between these end points and may be subject to some form of quantification or projection, especially given the ease of using a computer spreadsheet to perform sensitivity analysis. Moreover, a pitfall of defining issues too simplistically as ‘qualitative’ or ‘intangible’ is the tendency to pay less attention to those items that are not expressed in numerical terms. Because of the current emphasis on ‘measurement’ (“You are what you measure”; “You can’t change what you can’t measure”), issues that are outside the quantitative domain may not receive sufficient emphasis, even though their significance to the long-term success of an enterprise may be high. This section presents approaches and suggestions for ways to evaluate and highlight less tangible issues in a TUR project proposal.

A Framework for Analyzing Issues

Figure 7B provides a mapping framework for charting the strategic and quantifiable dimensions of issues that a business should consider in assessing a TUR project. The framework is intended to be a flexible, conceptual tool that practitioners can use in a variety of ways to help guide project assessment and inform the development of a justification package. Initially a project team might use the map to identify those issues that are likely to be of the greatest significance in order to focus attention and limited resources on their analysis. Alternatively, the team might use it to think through which factors should be included in the financial analysis and which should be dealt with qualitatively. Use of the framework may also prove valuable in a written proposal or oral presentation to illustrate the fact the many less tangible issues are often of high strategic significance. The map can thus help to highlight some of the benefits of TUR projects that may tend to be ignored or undervalued.

Figure 7B. Assessment Map

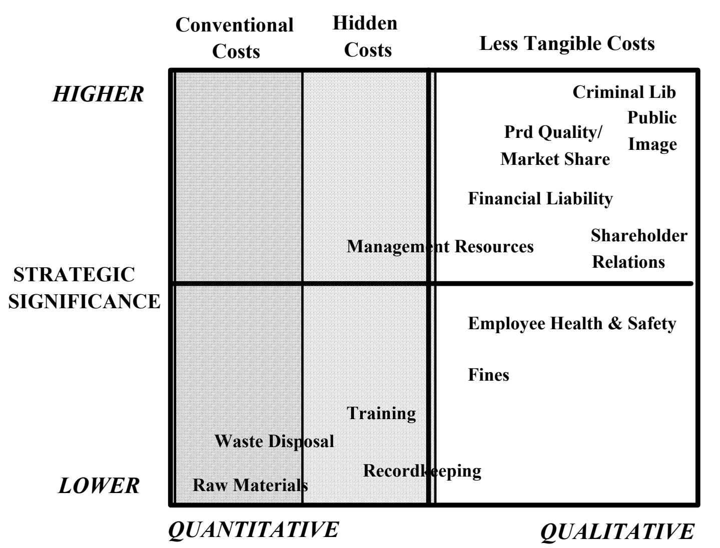


It is recommended that a team make a ‘first pass’ effort to fill in the map prior to performing any detailed analysis and then revisit the process later in their work. The list on the right-hand side provides examples of issues on which a TUR project is likely to have an impact. Although these examples are common to many projects, the list is not intended to be comprehensive; conditions peculiar to specific projects will create a variety of other issues. The items can be plotted on the Y axis according to their relative strategic significance and on the X axis based on the feasibility of quantifying them.

The map groups items into three cost categories. The first vertical section indicates the realm of "conventional costs" that are usually included in a typical capital budgeting analysis, and the second section shows the expansion of the capital budgeting model to include the indirect "hidden costs" that are usually buried in overhead accounts. The right vertical half of the map includes impacts whose costs are more difficult to project but may have quantifiable ramifications.

Figure 7C offers one example of how issues might be mapped for a particular project. The placement of these factors is not an absolute ranking of the importance of these issues for an organization; rather it is relative and project specific and thus will vary considerably even within the same company for different projects. This is a subjective process and the following example is presented to illustrate how the mapping framework can be used, NOT to establish a pattern of interpretation to be copied.

Figure 7C. Assessment Map Example



Once a team has identified the project impacts that are less tangible but strategically significant, it needs to assess those impacts and incorporate them into a justification package. The following section provides guidance on some of the more common issues that businesses need to address.

Assessing Less Tangible Factors

The Assessment Map provides a general framework for thinking about the relative importance of the various impacts of a TUR project. These include effects on: product quality, productivity, public image, market share, stakeholder relations and employee health and safety. This section explains why these issues may be important and suggests ways that a project team can focus attention on them to emphasize their significance. Some of these issues, such as "public image", tend to be straightforward: the impact of a TUR project is presumed to be positive, and the question is 'to what extent and how quickly'. Other issues, such as product quality, arise as (possibly) unintended consequences of the effort to reduce toxics. In these cases, toxics use reduction changes may have either a positive or a negative impact. After determining the nature of the impact, the project team must figure out how best to communicate fully the positive benefits, or it must consider ways to restructure the project to minimize unwanted consequences.

Product quality: Customers are increasingly demanding environmentally-friendly products yet are rarely willing to surrender price or quality to achieve their demands. A TUR project that is detrimental to product quality (e.g., through inferior material substitution or process changes that fail to meet design specifications) will rapidly translate into lost sales or into increased costs of rework and downtime. Alternatively, a TUR initiative may improve quality and/or enable a product to be marketed as 'green', a benefit that may engender greater market acceptance and boost sales.

Impact on Productivity/Capacity: Process changes resulting from the implementation of a TUR project could potentially increase or decrease the productivity and/or effective capacity of a plant. For example, an aqueous degreaser may reduce solvent use but may require a longer cycle time to remove contaminants effectively, thereby increasing throughput time and lowering productivity. On the other hand, installing new equipment to add a parallel process line might both reduce solvent use required for product changeovers and increase production capacity.

Public image: The importance of an environmentally-correct image has greatly increased in the past decade, and many companies now tout their 'green' credentials. While a good public image is important for its own intangible reasons, its value is increasing as the link between a company's public image and market acceptance of its products becomes stronger. Image can be especially important to a company that has suffered a poor environmental reputation. Although almost any pollution prevention project can bolster the environmental record of a business, one that directly addresses a publicly-recognized problem can be especially valuable. If a proposed TUR project eliminates a source of bad publicity, such as the discharge of effluent that discolors a waterway, the pubic relations benefits of the project should be strongly emphasized in the justification package.

Market share (i.e., consumer acceptance): Numerous surveys have documented the trend of "green" consumerism, and companies have responded by emphasizing environmental attributes in new product development. The growing inclination of consumers to buy "green" refers to purchases of products or services that are environmentally-benign or that are offered by companies with good environmental records. A TUR project that 'creates' a green process or product may have a significant impact on sales, depending upon customer demand. A project justification proposal could promote the value of this factor by including survey data related to the particular industry or product type.

Stakeholder relations: The term "stakeholders" can broadly include almost any person, group or organization with which a business has contact: employees, stockholders, lending institutions, customers, suppliers, surrounding communities and others. The benefits of a TUR project may affect relationships with these groups in different ways, such as pubic image, employee health and safety, and market share. Generally, most firms place increased importance on the value of being recognized as a "good neighbor". If this is an important issue to the company, it should be mentioned as part of the justification argument in a project proposal.

Employee health and safety: Improving working conditions can have both substantial short and long-term benefits, including lower worker compensation rates due to safer conditions, lower health care payments, increased productivity, reduced absenteeism and reduced OSHA regulatory oversight. Combining equipment/process specifications with occupational health and safety data can provide documentation of expected improvements in working conditions.

Pro-active environmental strategy: Environmental regulation shows a clear trend toward increasingly stringent limitations for contaminants in air emissions, wastewater, and hazardous waste. TUR projects have the ability, inherent in their prevention philosophy, to position a company to meet or surpass projected future toxic use and discharge limits. A strong argument for a TUR project is its capacity to alleviate such unknown factors as purchase price, disposal costs, or new health issues that accompany the use of substances known to be environmentally damaging. A project team can mention these issues in a project justification packet and point to proposed new regulations or regulatory trends to support their arguments.

Potential Liability

Financial liability: The financial liability from using and disposing of hazardous substances is potentially unlimited. One of the greatest benefits of a pollution prevention strategy is its capacity to reduce exposure to potential liability: Financial liability may be associated with:

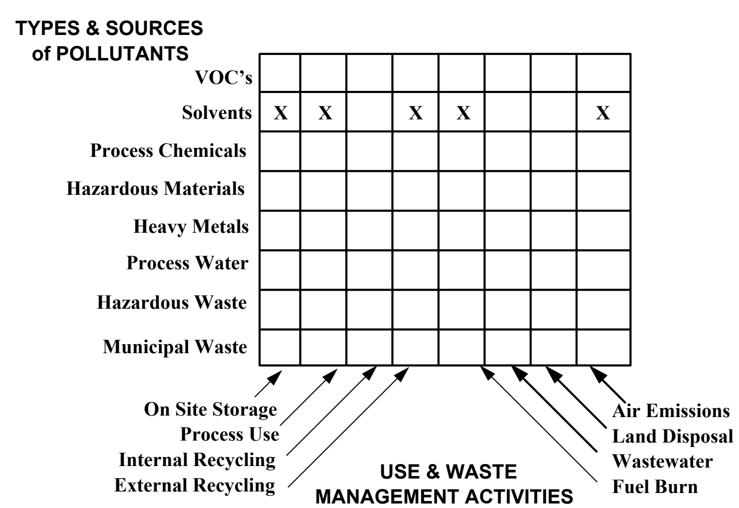
- Disposal
- Storage
- Transportation
- Real property damage
- Civil actions
- Toxic tort suits
- Fines/penalties

Liability Risk Assessment

The following steps offer an approach to thinking about liability risk that balances the need for accurate information with the cost of conducting an analysis. As with the Assessment Map above, the process described here is more of a conceptual framework than it is a rigid procedure that will be applicable to all projects and conditions.

1. **Draft process flow diagram (PFD) for current process, marking potential liability sources.**
2. **Arrange liability sources into risk groups**. Assemble information about sources of risk and define risk groups using a table such as the one in Figure 7D.

Figure 7D. Defining Risk Groups



Steps 3 through 5 are then applied to each risk group. Figure 7E illustrates this using the example of a risk group defined by the intersection of solvent (ethyl acetate) and process use.

Figure 7E – Ethyl Acetate Process Use

Event	Probability (1-5)*	Severity (1-5)*
Minor spill or leak	3	1
Major spill or leak	1	3
Explosion	1	5
Employee exposure	2	3

3. **List various exposure events for each risk group**: Each risk group would have an associated group of events that could be potential sources of liability. The TUR project team can assemble this list from discussions with plant personnel, hazardous materials information sheets, vendors and internal "brainstorming."
4. **Assign probabilities for each event**: Any alphanumeric (1–3, 1–5, A–E) or qualitative (low, medium, high) system can be used as long as there is consistency in the plant over time to ensure equal comparisons between projects.
5. **Estimate severity of event**: As with the assignment of probabilities, any consistently-used system is acceptable.
6. **Use best professional judgment to assign high, medium, low degree of risk to overall liability**: The assignment of probability and severity is subjective and based on best professional judgment. The process of thinking through the possible consequences of each of the risk groups can help a team to develop and convey a general sense of the overall liability risk associated with the use of certain substances. As an additional benefit, even if a TUR project does not completely eliminate the use of those substances, this process may assist management in devising ways to reduce risk by addressing those areas with the highest probability or severity of occurrence.

A project team could further characterize the possible consequences of specific liability risk groups by tracking recent judgments, fines, penalties and suits stemming from events similar to those that might occur at its facility. Including specific details in a proposal about the liability costs other firms have incurred can be a persuasive tool to sell a TUR project that has the ability to reduce the risks of those costs.

<u>**Criminal liability**</u>: Although most businesses operate within the law, managers should be aware of the increased exposure to criminal liability that these ruling have created when they manage facilities that use and dispose of toxic and hazardous substances. A project proposal could identify the reduction of this risk as one additional reason for implementing a project.

Psychological Burden

The successful implementation of a TUR strategy has the ability to reduce the psychological burden that usually accompanies the management of environmentally-regulated processes. When a business reduces or eliminates its pollutant-causing activities to the point where it is no longer under the jurisdiction of a regulatory body, the benefit to owners and employees is immeasurable. Anyone who has received a certified letter from the EPA "Superfund" division, been cited by a state environmental agency for non-compliance, or simply spent innumerable hours completing emissions reports knows how enervating such events or activities can be. A TUR project that starts or drives a company along the road to "zero regulatory oversight" has a large reward as its final destination.

In some cases, the initiation of a TUR project can appear to add to managerial headaches, at least in the short-term. For a company that is currently in compliance with existing regulations and has developed and instituted a sound environmental program that manages wastes in an acceptable manner, the effort, time and cost of starting a P2 project that is not mandated by regulation may seem burdensome and excessive. Proponents of a P2 project may encounter the argument: "Why rock the boat? We're in compliance now." Issues described in this section — market share, public image, employee health and safety — can offer sound arguments to promote a particular P2 project in these cases.

Responding to advances in environmental and health knowledge and technical expertise, environmental officials continue to promulgate ever-more-stringent regulations. With increased knowledge about the dangers of pollutants and refinements to the sensitivity of analytical tools to measure them, regulatory agencies correspondingly "ratchet-down" the allowable limits on their discharge. While regulatory compliance pushes companies to meet tougher environmental targets, market forces are starting to pull them along that path with even greater speed. Green consumerism, manufacturers' demands on suppliers, and socially responsible investing all encourage more pro-active management of environmental issues. Thus, simply being satisfied with meeting today's compliance requirements and environmental standards will leave companies stranded in both the regulatory and competitive backwaters, while organizations with forward-looking strategies pass them by. A TUR strategy can be a necessary basic ingredient both for meeting future regulatory limits and for improving the company's competitive position.

SOURCES:

Practical Guide to TUR, Massachusetts Office of Technical Assistance, 1992.

Improving Your Competitive Position: Strategic and Financial Assessment of Pollution Prevention Projects, Northeast Waste Management Officials Association, 1994

Appendix B: Comprehensive Matrix of Alternatives Assessment Methods and Tools

(with special thanks to Maria Socolof)

Alternatives Assessments Methods and Tools		Methods and tools currently being developed or used that relate to the analysis of alternative materials, products and/or processes from an environmental, human health, technological and/or economic standpoint (March 2005)											
Name of Tool/ Method	**Author/ Organiza-tion**	**Description/ Application**	**Format**	**Analysis Type (a)**	**Compara-tive Focus**	**Parameters (risks/impacts) Analyzed**	**Users**	**Accepta-bility/Use by others**	**Applica-tion PROS**	**Applica-tion CONS**	**Relative Useful-ness**	**References/ Sources**	**Contact(s)**
Cleaner Technologies Substitutes Assessment (CTSA)	University of Tennessee (UT) Center for Clean Production and Clean Technology (CCPCT)/US Environmental Protection Agency Design for the Environment (DfE) Program	Screening risk assessment for comparing chemical substitutes in manufacturing processes	Guidance document	env, hh, tech, econ	chemicals in mfg/industrial processes	Addresses human health and ecological risks (tends to focus on occupational risks, but also includes public health risks; aquatic toxicity risks represent the ecological risks); includes conservation issues (energy impacts and resource conservation); and also incorporates cost and performance comparisons along with environmental (risk-based) impacts.	manufacturers, government, academia	Developed under the auspice of EPA and used for EPA DfE projects	detailed screening risk assessment that also evaluates cost and performance	lengthy process; specific to chemicals and processes evaluated	lengthy, data intensive process, but useful for detailed analysis of chemical substitutes in a manufacturing process	Kincaid et al., 1996; http://www.epa.gov/dfe/pubs/tools/ctsa/index.htm	Jack Geibig (jgeibig@utk.edu) or Kathy Hart (hart.kathy@epa.gov)
Pollution Prevention Option Analysis System (P2OASys)	Toxics Use Reduction Institute	Evaluates toxic use reduction options (i.e., alternate technologies in industrial processes) for environmental and health impacts	Computer spreadsheet and worksheet formats, with accompany-ing manual	env, hh (worker and public)	chemicals in mfg/industrial processes	occupational health and safety, public health, ecological toxicity, combined into one overall score	designed for companies/ industry; however, available and useful for anyone	Used mostly by TURI since its development in 1996; Mission Research is currently turning it into a web based small business occupational health program.	Easy to use; incorporates occupational safety and health as well as public health, unlike many others	May be time-consuming to collect all data for each chemical if there are many chemicals	useful for screening chemicals in toxic use reduction options	Was previously available on the Internet (checked in February, 2004); cannot currently locate. (www.turi.org, click on Index of Topics then Cleaner Production)	Mike Ellenbecker (ellenbec@turi.org)
Chemical Hazard Evaluation for Management Strategies (CHEMS)-modified	UT CCPCT	CHEMS is a chemical ranking and scoring (CRS) system used to compare toxicities of chemicals used in any industrial or chemical process (uses inherent toxicity and some fate and transport factors).	Spreadsheet; not currently distributed beyond UT CCPCT; available through references cited in later column	hh, env	chemicals in mfg/industrial processes	chemical toxicity/screening for risk - sometimes fate and transport included	anyone (industry, government)	Original CHEMS used and modified by Monsanto and the Indiana Pollution Prevention and Safe Materials Institute as well as by UT CCPCT for use in EPA LCA projects	Allows for comparison of many chemicals for toxicity; simple method allows for screening level comparisons of chemical toxicity	Requires searching for toxicity data for chemicals not currently in the database	Useful for screening a large number of chemicals for their toxicity as used in industrial processes	Modified from original: Davis et al., 1994. The modified methodology as applied in a life-cycle assessment is provided in Socolof et al. 2001.	Mary Swanson (mbswanson@charter.net)
TRACI - The Tool for the Reduction and Assessment of Chemical and other Environmental Impacts	Jane Bare, EPA Office of Research and Development (ORD)	A tool that facilitates the characterization of environmental stressors as used in life-cycle assessment (LCA). Used to characterize several types of environmental and health impacts.	Stand-alone computer program for a PC	hh, env	chemicals in products or processes	Ozone depletion, global warming, acidification, eutrophication, tropospheric ozone (smog) formation, ecotoxicity, human health criteria-related effects, human health cancer effects, human health noncancer effects, fossil fuel depletion, and land-use effects. Includes human toxicity potentials developed (HTPs) using CalTox to assist in fate modeling for toxicity impacts	unknown at this time	Not sure how widely used. Method relatively recently published. Developed for use in LCA to characterize several types of environmental and health impacts and it is expected to find wider application in the future (Bare et al., 2003).	Includes regional US data not found in competing tools developed in Europe; provides a greater level of complexity in LCIA than has generally been available, particularly for US interests.	Does not include any Monte Carlo analysis for propagation of errors; may provide a level of sophistication and complexity that is difficult to match given inventory data and type of analyses done in LCA.	Expected to be relatively useful for its application (particularly more regional specificity).	Bare, J. C. et al, 2003 Journal of Industrial Ecology, Vol. 6 No. 3-4; http://mitpress.mit.edu/jie	Jane Bare (bare.jane@epa.gov), phone: 513-569-7513

Alternatives Assessments Methods and Tools	Methods and tools currently being developed or used that relate to the analysis of alternative materials, products and/or processes from an environmental, human health, technological and/or economic standpoint (March 2005)												
Name of Tool/ Method	**Author/ Organiza-tion**	**Description/ Application**	**Format**	**Analysis Type (a)**	**Compara-tive Focus**	**Parameters (risks/impacts) Analyzed**	**Users**	**Accepta-bility/Use by others**	**Applica-tion PROS**	**Applica-tion CONS**	**Relative Useful-ness**	**References/ Sources**	**Contact(s)**
Human Toxicity Potentials (HTPs) (US-developed)	University of California, Berkley (Edgar Herwich, Tom McKone); Environmental Defense Fund (Sarah Mateles, William Pease)	A calculated index that reflects the potential harm of a unit of chemical released into the environment, based on inherent toxicity and potential dose. Used for comparing toxicities of chemicals; can be applied to life-cycle assessment (LCA) toxicity impact categories or used to screen risks of other chemical releases (e.g., Toxics Release Inventory).	spreadsheet or lists of HTP values in reference documents	hh, env	chemicals in the environment	human and ecological toxicity: human toxicity potentials (HTPs) Multimedia fate model coupled with human exposure correlations for 23 pathways which estimates exposure doses.	LCA practitioners, risk assessors,		Provides an index for comparing human and ecological toxicity of chemicals for LCA. Incorporates fate and transport and inherent toxicity. Includes 330 chemical compounds. Distinguishes between cancer and non-cancer effects.	Although a large number of chemicals have HTPs, still limited by lack of data for many chemicals.	Useful for toxicity impacts in LCA, however, level of details and complexity with fate parameters and exposure routes may be unnecessary for levels of uncertainty associated with LCA. However, easy to use for chemicals with HTPs (assuming exposure pathways are known)	Hertwich et al., 2001.	University of California, Berkley (Edgar Hertwich or Tom McKone) - not contacted for this matrix.
Human and Ecological Toxicity Potentials (European-developed)	Guinee, Heijungs, Huijbregts	Used in life-cycle assessment (LCA) toxicity impact categories	spreadsheet or lists of HTP values in reference documents; also available in some LCA software	hh, env	chemicals in products or processes	human and ecological toxicity: human toxicity potentials (HTPs)	LCA practitioners	Used widely in European LCAs by LCA practitioners and companies.	Provides an index for comparing human and ecological toxicity of chemicals for LCA. Incorporates fate and transport and inherent toxicity. Huijbregts HTPs includes a more geographically differentiated model	European-based, not necessarily globally relevant; incorporates some fate and transport factors that are only valid for Europe. Limited number of chemicals have available toxicity potentials (e.g., an initial 94 HTPs are widely used in LCA, Guinee, Heijungs et al., 1996; Huijbregts et al calculate toxicity potentials for 181 substances)	Useful for toxicity impacts in LCA, particularly in Europe. As with US-based HTPs, level of details with fate parameters and exposure routes may be unnecessary for levels of uncertainty associated with LCA. However, easy to use for chemicals with HTPs (assuming exposure pathways are known).	Guinee and Heijungs, 1993; Guinee, Heijungs et al., 1996; Huijbregts et al., 2000.	
Okopol and Fraunhofer Institute Guidance for the Use of Environmentally Sound Substances (Part 1 and Part 2)	Ahrens et al., 2003 (Okopol--Institute for Environmental Strategies and Fraunhofer Institute for Systems and Innovation) (Germany)	This guidance outlines a systematic procedure for the environmental evaluation (related to aquatic impacts) of chemical substances and the identification of appropriate risk reduction strategies. Its focus is on the priority substances under the European Water Policy.	Guidance document	env (aquatic only)	PBTs (persistent, bioaccumulative, toxic) in products and processes	Aquatic environment; contributions to risk: persistence, bioaccumulation, aquatic toxicity, vertebrate chronic toxicity, intrinsic mobility, mobilizing conditions of use, amount (release), indirect release.	Producers and professional users of chemical products relevant to the aquatic environment					http://www.umweltdaten.de/umweltvertraeglich e-stoffe-e/part1.pdf; http://www.umweltdaten.de/umweltvertraeglich e-stoffe-e/part2.pdf	

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MBDC C2C Materials Assessment Protocol	McDonough Braungart (with White House Office of Science and Technology and US EPA)	A tool used for choosing chemicals for industrial processes to minimize environmental and health impacts over the life-cycle using a cradle-to-cradle approach (e.g., recycling/reusing process outputs). It involves applying the principles of green engineering to cradle-to-cradle design.	An internal MBDC tool (described in a journal article)	hh and env	chemicals in products or processes	Human health: carcinogenicity, teratogenicity, reproductive toxicity, mutageneicty, endocrine disruption, acute toxicity, chronic toxicity, irritation of skin/mucous membranes, sensitization, other relevant data (e.g., skin penetration potential, flammability, etc). Ecological: algae toxicity, bioaccumulation, climatic relevance, content of halogenated organic compounds, daphnia toxicity, fish toxicity, heavy metal content, persistence/biodegradation, other (water danger list, toxicity to soil organisms, etc).	Applied by MBDC for companies purchasing MBDC's services	Used by companies such as Herman Miller, Shaw Carpets who have employed MBDC to conduct assessments.	Provides companies with easily understandable information (e.g., green, yellow, red, orange ratings)	Methodology not completely transparent	Appears to be useful for companies using the method. Lacks transparency.	Environmental Science and Technology, December 1, 2003, p. 434A-441A (© 2003 American Chemical Society)	
Nordic Council of Ministers review of decision-aid methods in assessing risk reduction measures.	Nordic Council of Ministers	"The use of decision-aid methods in the assessment of risk reduction measures in the control of chemicals" (Nordic Council of Ministers, 1997) is an overview of different decision-aid methods which might be applicable to the assessment of advantages and drawbacks of risk reduction measures in the control of chemicals.	Guidance document/re port	hh and env	chemicals in risk reduction measures (processes--industrial/mfg applications); life-cycle focus	Risks to the environment or to human health, consideration of costs, technical concerns, employment, etc. The impact areas as well as the duration of the impacts may vary significantly for different risk reduction measures. All this results in a complex decision making situation with conflicting impacts and interests.						http://www.norden.org/pub/miljo/miljo/sk/TN97_622.asp?lang=6; note this website is only an abstract and order location	
DfE Formulator Initiative	EPA DfE Program	Companies work with DfE to design or reformulate products with a more positive environmental and human health profile. The DfE Formulator Initiative encourages and assists formulators in designing products with more positive environmental and health profiles than conventional products. This process considers alternatives and tries to minimize health and risk in new chemical formulations, but it is not necessarily used as an alternatives assessment tool, but does consider chemical alternatives.	No formal structure or tool; formulators submit formulations to DfE who develops hazard profiles based on each formulation ingredient. Guidance documents and background information available to formulators.	hh and env	chemicals in products	Hazard identification and toxicity; through the program, DfE recognizes products with improved environmental and health characteristics; DfE can provide formulators with information on chemical characteristics and toxicities of raw materials and additives; look at toxicity, biodegradation products, how ingredients might combine (e.g., oxidization)	Companies working with EPA DfE.		Works individually with companies on specific formulations	Not a specific tool for a third party to use.		http://www.epa.gov/dfe/projects/formulat/; David DiFiore, EPA DfE	David DiFiore, EPA OPPT
P2 Framework	EPA Office of Pollution Prevention and Treatment (OPPT)	The P2 Framework is an approach to risk screening that incorporates pollution prevention principles in the design and development of chemicals. This approach is implemented by means of a subset of estimation methods included in OPPT's P2 Framework.	The Framework includes direction toward the use of various computer-based models	env, hh	chemicals in products or processes	This approach is implemented by means of a set of computer models that predict risk-related properties of chemicals using structure activity relationships (SARs) and standard (default) scenarios. Focuses on ecotoxicity impacts.						www.epa.gov/oppt/p2framework/ provides information on the models and how to use them.	Bill Waugh, EPA OPPT (202-564-7657). Have not spoken with yet, waiting for response.

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PBT Profiler	EPA OPPT	The PBT Profiler was developed as a voluntary screening tool to identify Pollution Prevention (P2) opportunities for non-reactive organic chemicals lacking experimental data. PBT Profiler is a subset of methods included in the P2 Framework. It is a screening assessment that can be used early in the decision making process to help users better focus resources and identify P2 opportunities.	Web-based program gives immediate results (with CAS# or SMILES notation)	env & fish toxicity: persistence, bioaccumulation and fish toxicity	chemicals in processes (industrial/mfg applications)	The PBT Profiler is a screening-level tool that provides estimates of the persistence, bioaccumulation, and chronic fish toxicity potential of chemical compounds.						http://www.pbtprofiler.net/	Bill Waugh, EPA OPPT (202-564-7657) or Maggie Wilson, EPA OPPT (202-564-8924). Have not spoken with yet, waiting for response.
Waste Minimization Prioritization Tool (WMPT)	EPA OSWER and OPPT	In 1998, EPA released the draft WMPT which was used to compose the RCRA Draft PBT Chemical List. It is a chemical hazard screening tool that generates rankings of chemicals based on their potential to cause chronic human health and ecological problems.	Windows-based beta version of WMPT released for public commit in June 1997; revised spreadsheet version released in November 1998.	hh, env	chemicals in source reduction and recycling activities	The rankings are based on persistent, bioaccumulative, or toxic characteristics that may have impacts on human or ecological systems	Used to determine EPA's PBT chemical list					EPA530-R-97-019, June 1997, Draft. Or call the RCRA Docket at (703) 603-9230, or rcradocket@epa.gov (reference document number: F1998MMLPS0002). Also see EPA, 2000.	Bill Waugh, EPA OPPT (202-564-7657). Have not spoken with yet, waiting for response.
Alternatives assessment	O'Brien	Alternative to risk assessment: look at available alternatives and evaluate least damaging versus trying to identify risks associated with certain chemicals and applications	concept	hh	chemicals in processes	human health risk						O'Brien, M. Making Better Environmental Decisions--An Alternative to Risk Assessment, MIT Press, ISBN 0-262-65053-3	
Environmental Impact Analysis (EIA) (e.g., EIS, EA)	National Environmental Policy Act, United Nations Environmental Programme (UNEP)	Compares major proposed federal actions (e.g., manufacturing, construction, etc.) for environmental, health, socioeconomic impacts. The actions are not necessarily specific to industrial processes, but may include them.	Federal and other guidance documents	env, hh, social, etc.	multiple processes/ activities (generally industrial- or construction-type activities)	Generally site-specific, impacts to air, water, human health, socioeconomics, etc.; can incorporate risk assessment	U.S. government; international users (e.g., UNEP)	Commonly used; well established methodology	can evaluate complex actions	time-consuming analysis, including qualitative and quantitative analyses	useful for assisting in deciding on what action to take	http://www.uneptie.org/pc/pc/tools/eia.htm	
Life-cycle assessment (LCA)	multiple	LCA tools focus on quantifying the environmental burdens of a product, process, or activity, looking at the whole cycle from extraction of resources, product design and manufacturing, use and distribution, through to recycling or disposal. An LCA attempts to make systematic, holistic sense of information on energy and other resource requirements as well as other environmental impacts associated with every stage in the life cycle of a product. Life-cycle analysis of product, process, or activity; compares alternatives or benchmarks a baseline considering multiple impact categories.	Concept/method; various software tools available	env, hh	products, processes, services	Various impact categories (e.g., energy use, global warming, acidification, toxicity); varies by study.	Companies, government	Becoming a very common tool, particularly in Europe, with growing acceptance in the US. Approaches to streamlining LCA are of growing interest.	Provides an important overview of many types of impacts across the life-cycle(s) of products, processes or services	Lengthy, time-consuming process	Useful for understanding the environmental impacts across a life-cycle.	EPA ORD has a very useful website listing LCA resources, including a list of software tools and databases: http://www.epa.gov/ORD/NRMRL/lcaccess/resources.htm. See also ISO 14040 series (also listed in above ORD website). Other websites that provide good information include: http://cleantechinitiative.com/cti/prod-dgn.htm; http://www.indigodev.com/Tools.html	
Market-oriented LCA	European Union	Simplified LCA addressing product systems on a macro-economic level (i.e., integrating consumption patterns in the European Union); conducted under development of EU Integrated Product Policy (IPP)	concept/method	econ	products, processes, services over the whole life cycle	costs						http://europa.eu.int/comm/environment/ipp/ext_effects_finalreport.pdf	

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LCA tool for electronics	European Commission (Phil White)	Simplified LCA tool to help design green products and increase awareness (legislation, green purchasing, etc.). Provides green design, an LCA tool, green purchasing and assessment for: electronics, wood products kitchens, medical, textiles, office equipment, urban furniture, and hotels	web-based; currently being developed (per 5/04 email)	env	products over the whole life cycle							information via Viccy Salazar, EPA Region 10	Viccy Salazar, EPA Region 10
Building for Environmental and Economic Sustainability (BEES) 3.0	National Institute of Standards and Technology (NIST) with support from EPA OPPT	LCA approach for building products: BEES measures the environmental performance of building products by using the life-cycle assessment approach specified in ISO 14000 standards. All stages in the life of a product are analyzed. Economic performance is measured using the ASTM standard life-cycle cost method. Environmental and economic performances are combined into an overall performance measure. For the entire BEES analysis, building products are defined and classified according to the ASTM standard classification for building elements known as UNIFORMAT II.	Windows-based decision support software	env, econ, performance (tech)	Building products	Environmental performance from all life-cycle stages: raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management; economic performance measures include: ASTM standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. The overall performance measure uses the ASTM standard for Multi-Attribute Decision Analysis	the tool is aimed at designers, builders, and [product manufactures					http://www.bfrl.nist.gov/oae/publications/nistirs/6916.pdf	
Industrial Ecology	Tom Graedel and Braden Allenby		concept									Journal of Industrial Ecology; Graedel and Allenby, 1995; Allenby and Richards, 1994.	
Design for Environment (DfE)	not applicable	DfE considers environmental objectives and constraints in process and product design. DfE is an approach to support designers in making design decisions, by considering all potential environmental implications of a product or process being designed. It may also consider cost and performance aspects in design and may or may not incorporate the full analysis of the process or product life cycle. . (Braden Allenby 1994)	concept/method	env, hh, tech, econ	products, processes	Systemic approach to decision support for designers, developed within the industrial ecology framework. DfE teams apply this approach to all potential environmental implications of a product or process being designed--energy and materials used, manufacture and packaging; transportation; consumer use, reuse or recycling; and disposal. DfE tools enable consideration of these implications at every step of the production process from chemical design, process engineering, procurement practices, and end-product specification to post-use recycling or disposal.	Product/process designers	Many - govt, industry				http://www.indigodev.com/Tools.html; Allenby and Richards, 1994.	
Life-cycle engineering (LCE)	not applicable	LCE is a framework for product and process development teams to develop specifications for product, system, and process or facility life cycle. It embodies material and energy use and waste generation throughout, material production, manufacturing and construction, use, support and maintenance and decommissioning, material recovery and disposal.	concept/method	env/hh, tech, econ	products, processes	Both LCA and LCE focus on the full breadth of activities from acquisition to raw materials through ultimate disposal of waste products and both attempt to relate wastes to causative process or activities. The difference between the two is that LCA does not account for performance or cost criteria and it does not, necessarily, feedback results into the design decision process. DfE is also similar, but it may not necessarily be life-cycle based, although it can an improvement assessment portion of an LCA.						http://cleantechinitiative.com/cti/prod-dgn.htm	

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Industrial Metabolism (IM)		IM traces materials and energy flows from initial extraction of resources through industrial and consumer systems to the final disposal of wastes. IM can be usefully applied at many different levels: globally, nationally, regionally, by industry, by company and by site.	concept/method	material flows, energy	products, processes, services	IM studies have tended to focus on flows of materials. The method is also useful in analysis of energy and water flows.						http://www.indigodev.com/Tools.html	
Urban footprint (ecological footprint)	discussed by Indigo Development	Mathias Wackernagel and William Rees have created an urban planning and industrial metabolism method used to convey the demand upon resources that any geographic unit makes	concept/method	resource use	products, processes, services	not yet completed						Wackernagel and Rees 1996. Also discussed at: http://www.indigodev.com/Tools.htm.	
Pollution Prevention (P2)	discussed by Indigo Development	P2 is a well-developed field of environmental management that focuses particularly on the design of industrial processes within plants. This approach has led to development of many strategies, assessment methods and a wide range of "clean technologies" that often improve both environmental and economic performance.	concept	env, economic, hh?	industrial processes							http://www.indigodev.com/Tools.html	
Product life extension	Walter Stahel	Product life extension is based on the concept that by designing durable and upgradeable products with a long-life span there will be a lower demand for energy and materials. The idea is that manufacturing companies should refocus their mission to delivering customer service (selling results, performance, and satisfaction rather than products) and owning the equipment themselves as the means of providing this service.		energy, resources (materials)	services							Stahel, W., 1994. Also discussed at: http://www.indigodev.com/Tools.html	
Integrated Product Policy (IPP)	European Commission (others??)	IPP seeks to minimize the environmental degradation caused by a product by looking at all phases of a product's life-cycle and taking action where it is most effective, thus incorporating LCA and policy. This method includes stakeholders (e.g., designers, industry, marketing personnel, retailers, consumers). IPP attempts to stimulate each part of these individual phases to improve their environmental performance.		env/life-cycle	products							http://europa.eu.int/comm/environment/ipp/integratedpp.htm	
Dynamic Input-Output Models	Faye Duchin, Director of New York University's Institute of Economic Analysis	Dynamic input-output models enable business and policy decision-makers to perceive the broad business, economic, and environmental implications of systemic technical change. Dynamic input-output models are used to develop a set of possible solutions rather than a single optimal one, making it possible to experiment with changes in input structures that might reduce water usage in production, for instance, or recover products of economic value. A more complex set of results, involving economic and environmental trade-offs, can be evaluated.		econ, env	products, processes, services	I-O models add environmental resource accounts to economic information about the 100+ industrial sectors found in standard national input-output tables. By incorporating a time dimension Duchin has created a means of analyzing the total impacts of alternative scenarios of industrial change. How would the changes affect the environment, businesses in the target industry, and their major suppliers and customers?						Duchin, F., 1992. Also discussed at: http://www.indigodev.com/Tools.html	

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Economic Input-Output-Based Life-Cycle Assessment (EIO-LCA)	Carnegie Mellon University, Green Design Initiative	The economic input-output analysis-based life-cycle analysis (EIO-LCA) method involves augmenting conventional economic input-output tables with appropriate sector environ-mental impact indices which can then be used to analyze economy-wide environmental impacts of changes in the out-put of selected industrial sectors.	Methodology with software available	env, econ, hh	products, processes, services	The environmental effects estimated include: Resource Inputs: electricity consumption, fuel use, ore consumption, fertilizer use, water consumption; Environmental outputs: Toxic emissions from the Toxics release Toxicity-weighted chemical emissions, RCRA hazardous waste generation, ozone depletion potential, global warming potential, conventional pollutant emissions, also social costs						http://www.epp.cmu.edu/; http://216.239.53.104/search?q=cache:qtHt_5ERtV0J:www.ce.cmu.edu/GreenDesign/gd/Research/eio-lca-99.pdf+economic+analysis+of+alternative+materials+or+products+or+processes&hl=en&ie=UTF-8	
Eco-Value Analysis	Electronics Goes Green; Darmstadt University of Technology: Christof Oberender and Herbert Birkhofer	not yet completed	method "derived from the value analysis according to EN 12973 with the aim of consider-ing environ-mental and economical aspects"	econ								Electronics Goes Green 2004 Abstract	
Eco-Value'21	Innovest Strategic Value Advisors Inc.	Environmental performance rating system for investors		econ	company financial performance							PP presentation from 2000 in Paris: http://www.oecd.org/dataoecd/41/51/1859721.ppt; http://216.239.41.104/search?q=cache:Rzxvb623ZRIJ:www.ahcgroup.com/Chemical%2520Sector%2520Report%25204-02%2520excerpt.PDF+Eco-Value+Analysis&hl=en&ie=UTF-8	
Economic Selection of Manufacturing Processes	SAE (Society of Automotive Engineers) International seminar (automotive)	material and process selection in manufacturing (auto industry and suppliers)	Seminar (one given May 2003)	econ	processes	economics (incorporates life-cycle cost analysis)						www.sae.org/calendar/semmfg.htm	
Financial Feasibility Analysis of Alternative Potential Biomass-based Products	Karl A. McArthur & Matt Frolich, June, 1996. University of Nevada, Reno, Center for Economic Development in the Department of Applied Economics and Statistics.	Specific to biomass-based products, this is a typical economic analysis with text-based descriptions. Pulled from various financial textbooks (e.g., Barry et al. 1983), the analysis consists of two alternatives: (1) substituting biomass to process fuels and/or industrial chemicals for commodities market or direct use as heat; and (2) using biomass as filler in polypropylene-biomass composite material.	Specific report on evaluating two alternative biomass-based products	econ	biomass-based products	Payback period (P) = I/E; where I=initial investment, E=Estimated annual cash flow; Simple state of return (SSR) = Y/I; where Y=average annual profits, I=initial investment.						http://www.ag.unr.edu/uced/reports/technicalreports/fy1995_1996/9596_12rpt.pdf	
Waste Reduction Model (WARM)	EPA Environmentally Preferable Purchasing (EPP)	WARM was developed to assist solid waste managers in determining the GHG impacts of their waste management practices.	Web-based calculator and Microsoft Excel spreadsheet	env	waste management practices	global warming						http://yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsWasteTools.html	

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Name of Tool/ Method	**Author/ Organiza-tion**	**Description/ Application**	**Format**	**Analysis Type (a)**	**Compara-tive Focus**	**Parameters (risks/impacts) Analyzed**	**Users**	**Accepta-bility/Use by others**	**Applica-tion PROS**	**Applica-tion CONS**	**Relative Useful-ness**	**References/ Sources**	**Contact(s)**
Recycled Content (ReCon) Tool	EPA EPP	The ReCon Tool was developed to assist companies and individuals in estimating the life-cycle GHG and energy impacts of purchasing or manufacturing certain materials. ReCon is available for free download in Microsoft Excel.		env	materials							http://yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsWasteTools.html	
Environmental Benefits Calculator	National Recycling Coalition	The Environmental Benefits Calculator is designed to help recycling organizations measure and demonstrate the positive environmental impact recycling is having in their state. Based on material recovery and disposal data inputted by the user, the calculator provides detailed information on recycling's environmental benefits in four key areas (see next column). The calculator incorporates the EPA EPP WARM model	Web link to calculator; for NRC members only; Microsoft Excel spreadsheet	env	recycling processes	energy savings reduction in GHG emissions, reduction in emissions of air and water pollutants, and conservation of natural resources				"do not calculate the life-cycle environmental benefits of purchasing, using, and managing EOL electronic equipment"		http://www.nrc-recycle.org/	
Environmental benefits calculator	Northeast Recycling Council (NERC)	Measures benefits of computer recycling in several areas (see parameters column)	Excel spreadsheet, available on the Web	env, energy	recycling processes	several areas, including GHG, air emissions and energy savings				"do not calculate the life-cycle environmental benefits of purchasing, using, and managing EOL electronic equipment"		http://www.nerc.org/documents/aboutcalc1003.html; http://www.crra.com/nrcfiles/calculator/coverletter.html	
Energy Star tool	EPA/Energy Star	Tools to estimate financial and environmental benefits from energy reductions; calculator to compare energy impacts and cost of conventional office equipment – PC/Monitors, faxes, printers, and copiers – to "Energy Star" equipment	Web-based calculator	financial, env/energy	products	energy and cost				"do not calculate the life-cycle environmental benefits of purchasing, using, and managing EOL electronic equipment"		http://www.seda.nsw.gov.au/estar_calculator_body.asp	
Greenhouse gas calculator		For a calculator and tools on how to conduct a Greenhouse Gas Inventory and Calculate direct and indirect emissions go to website		env								http://www.cleanair-coolplanet.org/for_campuses.php	
Paper Calculator®	Developed by The U.S. Postal Service, EPA, and Environmental Defense.	Evaluates the life cycle environmental impacts associated with using different grades (e.g., recycled content) of paper and paperboard. The tool calculates the U.S. average energy and wood consumption and environmental releases across the full "life cycle" of each of five major grades of paper and paperboard. It compares production of virgin paper/paperboard in each grade, and its subsequent disposal in landfills and incinerators, to production of recycled paper/paperboard in the same grade, and its subsequent recovery for recycling.	Web-based tool	env	paper products	energy, wood consumption						http://www.ofee.gov/gp/papercal.html	

Alternatives Assessments Methods and Tools	Methods and tools currently being developed or used that relate to the analysis of alternative materials, products and/or processes from an environmental, human health, technological and/or economic standpoint (March 2005)												
Name of Tool/ Method	**Author/ Organiza-tion**	**Description/ Application**	**Format**	**Analysis Type (a)**	**Compara-tive Focus**	**Parameters (risks/impacts) Analyzed**	**Users**	**Accepta-bility/Use by others**	**Applica-tion PROS**	**Applica-tion CONS**	**Relative Useful-ness**	**References/ Sources**	**Contact(s)**
CURC recycling calculator tool	CURC (College and University Recycling Council) of the NRC (National Recycling Coalition)	The College and University Recycling Council (CURC) is a technical council of the National Recycling Coalition. CURC is a network of campus-based recycling professionals who face similar challenges and opportunities in managing college and university recycling programs (as do state and local governments, for whom the NERC calculator is available).	Excel spreadsheet, available on the Web	recycling	recycling activities	data collection on recycling capabilities and other institutional data						The CURC home page is: http://www.nrc-recycle.org/councils/CURC/default.htm; The calculator tool is http://www.nrc-recycle.org/councils/CURC/curcmembers/benchmark/CRP_Inpt.xls	
EcoScan-Life and EcoScan-Dare (Disassembly and Recycling)	Electronics Goes Green 2004 abstract #4												
Rideshare Calculator		The Rideshare Calculator generates daily, monthly and yearly air emissions (i.e., criteria pollutants) for an average vehicle, based on roundtrip mileage to campus. This is not necessarily an alternatives assessment tool; however, it evaluates air emissions from transportation, which could be used in an alternatives assessment.		env (air emissions)	transportation	air emissions							
Environmental Management System	multiple	EMS focuses company efforts on identifying and managing their various impacts on the environment (including workers). An outcome of this effort is often the identification of safer alternatives to the chemicals, materials or processes currently employed		env	processes and industrial/mfg facilities								
IEMS (Integrated Environmental Management Systems)	EPA DfE	Step-by-step approach to help organizations develop and implement an IEMS. The IEMS approach follows the guidelines of ISO 14001 — the official International standard for EMS — but enhances this standard by emphasizing chemical risk management, use of cleaner technologies, and pollution prevention. Also, a template (Company Manual Template: EPA/744-R-00-012) offers an example of how the fictional Smith Corporation documented its IEMS. The template contains text, tables, and other features that companies can tailor to their own unique circumstances, along with procedures and associated formats for developing a customized IEMS.	Guidance document (IEMS Implementation Guide: EPA/744-R-00-011) also used with Company Manual Template (EPA/744-R-00-012)	env/hh	chemicals in processes or industrial/mfg facilities							http://www.epa.gov/dfe/pubs/index.htm#form	
Comparative evaluation of CRS				hh	chemicals							eerc.ra.utk.edu/ccpct/pdfs/CECRSM.pdf	

Alternatives Assessments Methods and Tools	Methods and tools currently being developed or used that relate to the analysis of alternative materials, products and/or processes from an environmental, human health, technological and/or economic standpoint (March 2005)												
Name of Tool/ Method	**Author/ Organiza-tion**	**Description/ Application**	**Format**	**Analysis Type (a)**	**Compara-tive Focus**	**Parameters (risks/impacts) Analyzed**	**Users**	**Accepta-bility/Use by others**	**Applica-tion PROS**	**Applica-tion CONS**	**Relative Useful-ness**	**References/ Sources**	**Contact(s)**
Lead Spread	California DTSC (Dept of Toxic Substances Control)	A tool for evaluating lead exposure and the potential for adverse health effects resulting from exposure to lead in the environment. LeadSpread 7 is the latest version of the DTSC Lead Risk Assessment Spreadsheet. This is not necessarily an alternatives assessment; however it could be used to evaluate lead exposure of alternatives.	Spreadsheet (Microsoft Excel)	hh	lead exposure (lead in the environment)	Blood lead concentrations estimated from exposure to lead via dietary intake, drinking water, soil and dust ingestion, inhalation, and dermal contact. Each of these pathways is represented by an equation relating incremental blood lead increase to a concentration in an environmental medium, using contact rates and empirically determined ratios. The contributions via the five pathways are added to arrive at an estimate of median blood lead concentration resulting from the multi-pathway exposure. Ninetieth, ninety-fifth, ninety-eighth, and ninety-ninth percentile concentrations are estimated from the median by assuming a log-normal distribution with a geometric standard deviation (GSD) of 1.6.						http://www.dtsc.ca.gov/ScienceTechnology/ledspred.html	

Notes:

(a) Analysis type refers to whether or not the method includes environmental (env), human health (hh), technology (tech) and/or economic/cost (econ) considerations.

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Appendix C: Compendium of Nine Assessment Methods

1. Pollution Prevention Options Analysis System (P_2OASys)

Where to locate: Go to http://www.turi.org/content/content/view/full/1125/ to access the free electronic version, or go to http://sbso2.mrcnh.com/DesktopDefault.aspx?tabindex=0&tabid=1, Click on Advisors tab, then click on P_2OASys for the web-enabled version.

Fee for use: No. A web-enabled version is available for a fee.

Purpose of Tool/background: The P_2OASys (Pollution Prevention Options Analysis System) was developed by the Toxics Use Reduction Institute is designed to help companies to conduct comprehensive and systematic environmental and worker health and safety analyses of their pollution prevention and toxics use reduction (P2/TUR) options. A private organization called Mission Research has further developed this tool. It is primarily intended to assist companies in identifying potential hazards associated with current or proposed processes and choosing the alternative that is most protective of worker health and safety and the environment.

Criteria/categories of hazard considered: Categories of hazard that are evaluated in P_2OASys include: acute and chronic human toxicity; physical/ergonomic; chemical (such as flammability and reactivity); persistence and bioaccumulation; atmospheric (ozone depletion and greenhouse gases); aquatic/eco toxicity; disposal hazard; and, energy, water and resource use.

The P_2OASys database was compiled from validated references only. The National Library of Medicine's ToxNet database (www.toxnet.nlm.nih.gov) is the principal source used. Currently, the database contains over 2,000 hazard properties for 778 chemicals and species. Users must enter many parameters that are process specific or subjective such as: noise generation, lifting hazard, psychosocial hazard, water and energy use.

Exposure considered: Potential exposure is qualitatively evaluated as low, medium or high.

Qualitative/quantitative: This tool utilizes quantitative, semi-empirical, and qualitative data from multiple data sources. These data are converted to numerical scores in which the lower number represents the safer alternative. Because of the mix of data used, these scores cannot be collapsed to provide a final score that is valid for comparing alternatives. The interpretation of the side-by-side comparison is left to the user.

Best for which applications: This tool is most useful for side-by-side comparisons of current processes/chemicals and potential alternatives. A color-coding scheme makes the process visually simple. For categories in which there is no difference between the current and alternative process both fields will be colored yellow. For those in which one is safer, that field will be green, and the other will be red. For fields with no contrasting data or blank fields, no color will be added. By arraying a wide range of criteria the user can make judgments about categories of particular concern.

Limitations: Although P_2OASys contains hazard data for over 700 chemicals, there are thousands of chemicals that are not included in the database either because experimental data does not exist or the existing data have not been entered into the system. The user can research the hazard data on a particular chemical and enter it into the database. The user also must enter a variety of data on factors such as ergonomic hazards and exposure, making the use of this tool potentially time and labor intensive.

The bottom line: This tool is useful for side-by-side alternatives assessment; however, it cannot be accessed for free and requires time and effort of the user in entering relevant data.

2. Column Model

Where to locate: http://www.hvbg.de/e/bia/pra/spalte/index.html

Fee for use: No

Purpose of Tool/background: The German ordinance on hazardous substances requires employers to substitute hazardous chemicals with other substances that pose a lower risk to workers' health. The Institute for Occupational Safety (BIA) of the German Federation of Institutions for Statutory Accident Insurance and Prevention developed the column model to provide industry with a practical tool for identification of alternative substances.

Categories of hazard considered: The Column Model considers acute hazards including toxicity, reactivity, corrosivity, skin sensitization, ocular hazards and irritants; chronic hazards including but not limited to carcinogenicity, mutagenicity, reproductive toxicity; environmental hazards that pollute water; and, fire and explosion hazards.

Users are referred to Material Safety Data Sheets for each alternative to find the information needed to complete the column model. German Material Safety Data Sheets include R-phrases (risk phrases are a European system which indicates different types of hazards using the letter R and a number), German water pollution classes and German classification of flammable liquids.

Exposure considered: The model includes a column called "exposure potential" which ranks chemicals according to vapor pressure (higher vapor pressure equals higher exposure risk). In addition, a final column, labeled "hazards caused by procedures", considers whether there is open or closed processing of the chemical, which is also a proxy for exposure.

Qualitative/quantitative: This is a qualitative tool that allows the user to compare alternatives within each column.

Best for which applications: If data are available, the Column Model provides a useful way to array data and compare hazards. If the proposed substitute ranks as a lower risk in all five columns, then the decision to make this change is straightforward. If the potential substitute ranks higher in some columns and lower in others, the user must do additional analysis and consider which column or columns are of greatest concern in a particular production process or processes.

Limitations: The Column Model can only be used if the data in the Material Safety Data Sheets are sufficient to fill out the columns. According to the German ordinance, if test data is not available on toxicity or mutagenicity, then the substances should be scored as a high risk for acute and chronic health hazards.

The bottom line: Useful tool for side-by-side comparison of alternatives.

3. Five Step Evaluation Matrix

Where to locate: www.umweltdaten.de/umweltvertraegliche-stoffe-e/part1.pdf and www.umweltdaten.de/umweltvertraegliche-stoffe-e/part2.pdf

Fee for use: No

Purpose of Tool/background: This matrix was developed by the German Ökopol Institute for Environmental Strategies and the Fraunhofer Institute for Systems and Innovation Research, under contract to the German Federal Environmental Agency, to assist industry in finding substitutes for substances that exhibit hazardous characteristics in the aquatic environment. The guide describes a five-step process to assess environmental risks: inventory chemicals; determine risk profiles for substances; estimate potential releases; characterize hazardous properties; and, select an appropriate management strategy. The method does not evaluate workplace exposure risks. The guide contains recommendations for inventorying substances and comparing risks in a qualitative manner.

Categories of hazard considered: Persistence, bioaccumulation, aquatic toxicity and chronic toxicity to vertebrates are evaluated. In addition, intrinsic mobility (as determined by vapor pressure, water solubility and other factors) and mobilizing conditions of use (as determined by temperature during application, water contact, abrasion and atmospheric influences) are considered.

Exposure considered: To evaluate potential exposure, conditions of use are examined. The substance is ranked according to amount used, application in industrial and consumer settings, degree of containment and whether the substance is mobile under use conditions. If indirect releases are likely (e.g., because the of the widespread consumer use of the product containing the substance), the risk contribution would be considered to be high.

Qualitative/quantitative: The evaluation results in a matrix that allows for qualitative comparison of alternatives. One axis of the matrix ranks the extent of risk contribution in five categories from very high to very low. The other axis describes the type of contribution to risk, including: persistence, bioaccumulation, aquatic toxicity, chronic toxicity of vertebrates, intrinsic mobility, amount, mobilizing conditions of use and indirect releases. A weight can be assigned to the various components to prioritize certain hazards, e.g., persistence.

Best for which applications: Good for qualitative comparisons of chemicals with PBT properties.

Limitations: This method does not directly evaluate human health risks. As with other methods, risk can be profiled only for chemicals for which data are available.

The bottom line: This method provides a useful framework for qualitative comparisons of chemicals that may be persistent, bioaccumulative and toxic.

4. Chemical Assessment and Ranking System (CARS)

Where to locate: http://www.zerowaste.org/cars/

Fee for use: Yes

Purpose of Tool/background: The Zero Waste Alliance (ZWA) based in Portland, Oregon developed CARS as a decision support tool for assessing chemicals and planning for elimination or substitution of hazardous materials and processes. The staff at ZWA provides consulting assistance in the use of this tool. The CARS database contains publicly available and well-documented information on chemicals that pose risks to human health and the environment. Chemicals are listed by CAS number and include data from the US EPA, the National Toxicology Program, the International Agency for Research on Cancer, NIOSH and other US government and international sources.

Categories of hazard considered: CARS database includes substances listed as carcinogens, teratogens, hazardous air pollutants, greenhouse gases, ozone depleting substances, persistent, bioaccumulative and toxic substances, extremely hazardous substances, endocrine disrupters, and chemicals that are regulated independent of quantity.

Exposure considered: Initial screening of chemicals is done without considering exposure. However, the prioritization process may include the gathering of additional data such as quantity and frequency of use, which can be considered proxies for exposure.

Qualitative/quantitative: This is a qualitative screening tool that flags chemicals that exhibit the hazard properties listed above. In order to set priorities the user is asked to develop "importance weights" for each hazard category. These weights are used to develop a final ranking of chemicals and set priorities for substitution and improvement of chemicals management.

Best for which applications: CARS may be a useful first step for companies undertaking an inventory of their chemical use.

Limitations: CARS database includes chemicals for which hazards are well documented; however, for many chemicals these data do not exist. In addition, CARS relies on information contained in Material Safety Data Sheets that may not fully disclose chemical ingredients. The CARS database does not directly aid in identifying non-hazardous alternatives, though ZWA offers a service to assist with this process.

The bottom line: Useful screening tool for flagging hazards of well studied chemicals.

5. Quick Scan

Where to locate: http://www2.vrom.nl/pagina.html?id=7386

Fee for use: No

Purpose of Tool/background: The Dutch Ministry of Housing, Spatial Planning and the Environment developed the Quick Scan method as a means of prioritizing the management and evaluation of approximately 100,000 substances in use. The method uses existing data, criteria and decision-making rules to evaluate substances and locate them in five categories: *very high concern; high concern; concern; low concern; and, provisionally very high concern* because no data is available. The Quick Scan, which considers risks to workers, consumers and environment, is designed to fill the knowledge gap that exists about chemical risks and must be completed by industry for all substances produced, traded or used in the Netherlands. The Quick Scan was developed in part to avoid a large increase in animal testing for toxicity, by evaluating existing data where possible. Both "hard" (animal testing results) and "soft" (scientific literature, expert judgment and structure-activity models) data are used in the evaluation.

Categories of hazard considered: Persistence, bioaccumulation, ecotoxicity, health damage to humans, carcinogenicity, mutagenicity, reproductive toxicity and hormone disruptive effects are evaluated. Criteria used to assign substances to one of four hazard levels are based on international agreements. Persistence, bioaccumulation and ecotoxicity are assigned to hazard levels according to threshold values. These three elements are then combined in a matrix to locate the substance into one of the five categories of concern. In contrast, the hazard elements used to evaluate human health concerns (health damage to humans, carcinogenicity, mutagenicity, reproductive toxicity and hormone disruptive effects) are not combined; rather, if any one of these elements is assigned to the highest hazard class that substance is automatically placed into the *very high concern* category.

In order to classify a substance into a single overall category of concern, the category arrived at for environmental hazard (PBT) is compared to the category arrived at for human health hazard. The overall category of concern will reflect the highest category; that is, a substance that is *high concern* for humans and *low concern* for the environment will be placed in the overall *high concern* category. Protection measures taken should reflect the differences in hazard classification for human and environmental concerns.

Exposure considered: The concern categories are adjusted based upon potential for exposure as determined by chemical uses and the availability of alternatives. Four areas of substance use are evaluated: industrial use; site-limited intermediate use (in confined areas); open applications/professional use; and, consumer applications.

Qualitative/quantitative: This is a qualitative screening tool. If available, experimental data are used in the evaluation process for each substance to determine hazard levels for each of the hazard categories listed above. These hazard levels locate the substance of concern in one of five categories. A matrix is then created that considers both the degree of hazard and how these substances are used. According to Dutch government policy, management decisions should made as follows: substances in the *very high concern* category should no longer be used in any application unless very stringent conditions are followed to prevent exposure; substances of *high concern* cannot be used in consumer and open applications; and, substances of *concern* and low *concern* can be used in all applications, as long as certain requirements are met. In accordance with the precautionary principle substances with no data are considered *very high concern* and should not be used under any of the exposure conditions, without further information.

Best for which applications: This method can be used to evaluate and compare human health and environmental risks from chemicals provided sufficient data is available so that substances can be properly placed into the evaluation matrix.

Limitations: Exposure is not directly measured; use is a proxy for exposure levels.

Chemicals for which no data exists are placed into the very high concern category

The bottom line: This is a detailed method for evaluating chemical risks using existing data.

6. PRIO

Where to locate: http://www.kemi.se/templates/PRIOframes____4045.aspx

Fee for use: No

Purpose of tool/background: PRIO is a web-based tool developed by the Swedish Chemicals Inspectorate (KemI) that is designed help environmental managers, purchasers and product developers reduce risk to human health and the environment from chemical exposures.

The Swedish parliament has adopted an environmental quality objective of "a non-toxic environment". The PRIO tool is designed to aid in decision-making to reduce risk from chemicals. The PRIO database contains chemicals that the Swedish government has identified as being of high concern to human health or the environment. All chemicals in the database are identified as "phase out" or "risk reduction" substances.

Users can:

- Search for substances and obtain information on properties hazardous to the environment and human health
- Obtain information on prioritized health and environmental properties
- Identify substances contained in chemically characterized substance groups and product types
- Obtain help in developing routines for purchasing, product development, and risk management

Criteria/categories of hazard considered:

The PRIO database is divided into two categories including: "phase out" substances and "risk reduction" substances. PRIO recommends that the user replace any substances identified as "phase out substances" because these substances have properties of high concern. For substances in the "risk reduction" category, PRIO recommends that exposure be evaluated and a risk assessment be conducted to determine how to reduce risk from this substance.

"Phase out" chemical criteria include: carcinogenic, mutagenic (may cause heritable genetic damage) or toxic to reproduction; persistent, bioaccumulative and toxic; very persistent; very bioaccumulating; particularly hazardous metals – mercury, cadmium, lead and their compounds; endocrine disrupters; and ozone-depleting substances.

"Risk reduction" criteria include: very high acute toxicity; allergenic; mutagenic (possible risk of irreversible effects); high chronic toxicity; environmentally hazardous long-term effects; potential to be persistent, bioaccumulative and toxic; potential to be very persistent; and, potential to be very bioaccumulating.

Exposure considered: For "risk reduction" substances, PRIO recommends that the user conduct a risk assessment by evaluating potential exposure during production, product use and waste handling. The tool guides the user through a five step process to evaluate risk over the lifecycle of a product containing the "risk reduction" substance, including: a consideration of risk from this chemical in the production process, use phase, and in disposal; a weighing together of the risks; and, finally, a decision on continued use of the "risk reduction" substance.

Qualitative/quantitative: This is a qualitative tool.

Best for which applications: This tool can be used to help prioritize chemicals for elimination and risk reduction. Searches can be done in various ways, such as by product type, hazardous properties, substance group, or using the chemical name or CAS number.

Limitations: The database is not complete. It contains example substances for which data exists for the particular criteria (usually because these substances have been classified in the EU). A large number of chemical substances currently in use are not included in the database. If the chemical of concern is not in the database, however, the criteria in PRIO can be used to help determine whether this substance meets the criteria listed above and therefore should be targeted for "phase out" or "risk reduction". In order to conduct this evaluation, environmental and health effects data must be available for the chemical of concern, and the user must conduct this assessment.

The database does not consider all types of hazards. For example, explosiveness and flammability are not included. Information on quantities and areas of use relate only to use in Sweden.

The bottom line: PRIO is a useful on-line tool for screening out hazardous chemicals. .

This database helps users determine what chemicals NOT to use, but does not directly provide information on safe alternatives.

7. Norwegian Guidelines

Where to locate: http://www.sft.no/publikasjoner/kjemikalier/2007/ta2007.html

Fee for use: No

Purpose of Tool/background: The Norwegian Pollution Control Authority has developed guidelines to explain the substitution process and encourage industry to evaluate its chemical use. A new section of Norway's Product Control Act came into force in January 2000, requiring enterprises that use chemicals for occupational purposes to evaluate the substitution of substances that are hazardous to health and the environment. This evaluation must consider whether the same result could be achieved using a less dangerous substance, eliminating chemicals or using a different method. If less hazardous alternatives exist, industry must use them provided that this "does not cause unreasonable cost or inconvenience". Under Norwegian law, commercial users of chemicals are responsible for preventing pollution and reducing risks associated with their use. This guidance describes a 7-step process for considering substitution.

Categories of hazard considered: The Norwegian government has identified undesirable properties and developed criteria for each of these hazards. Environmental hazards include: bioaccumulative/low biodegradability; bioaccumulative/high acute toxicity; low biodegradability/high acute toxicity; very high acute aquatic toxicity; bioaccumulative/very high chronic toxicity; low biodegradability/very high chronic toxicity; very high chronic toxicity; and, ozone depleting. Human health hazards include: acute toxicity; sensitizing properties; chronic toxicity; reprotoxicity or effects during lactation; mutagenicity; carcinogenicity; and, other undesirable properties (e.g., endocrine disruptors, immunotoxins, greenhouse gases).

Using these criteria, the Norwegian Pollution Control Authority has drawn up a list of "Dangerous Substances" and an "Observation List". The Dangerous Substances List provides information about the environmental and health hazards of approximately 3000 substances. The Observation List is a subset of the Dangerous Substances List and includes approximately 250 substances that are particularly hazardous and are used widely or in large amounts. Specific targets have been set for the reduction or elimination of emissions of these substances.

Exposure considered: Substances were placed on the Observation List if they meet one or more of the criteria listed above and are used in a way and in amounts (greater than 10 tons/year) that expose people or the environment to risk.

Qualitative/quantitative: The 7-step process guides users to evaluate current chemical use and find safer alternatives. The Observation List is intended to be used as a tool by industry to prioritize substances that should be eliminated from use. This is a qualitative evaluation, which relies on experimental data to determine whether hazard criteria are met.

Best for which applications: The Observation List is useful in determining which chemicals NOT to use.

Limitations: Because no data exists for many chemicals, it remains difficult to determine the relative safety of alternatives.

The bottom line: The 7-Step process provides guidelines for substitution. The Observation List can be used as a prioritization tool to eliminate the use of hazardous chemicals.

8. Cradle to Cradle Design Protocol

Where to locate: www.mbdc.com

Fee for use: Yes

Purpose of Tool/background: MBDC has developed the "Cradle to Cradle Design Protocol" to assess materials used in products and processes in order to assist companies in designing eco-effective products. The protocol is founded on the "Intelligent Products System" developed by Michael Braungart and his colleagues at the research institute EPEA in Hamburg, Germany.

Categories of hazard considered: The Cradle to Cradle Design Protocol considers human health and ecological health endpoints. Human health criteria include: carcinogenicity, teratogenicity, reproductive toxicity, mutagenicity, endocrine disruption, acute toxicity, chronic toxicity, irritation of skin, mucous membranes, sensitization, and other relevant data, e.g., skin penetration potential or flammability. Ecological health criteria include: algae toxicity, bioaccumulation, climatic relevance/ozone depletion potential, content of halogenated organic compounds, daphnia toxicity, fish toxicity, heavy metal content, persistence/biodegradation, and toxicity to soil organisms.

Exposure considered: This protocol is a hazard assessment only and does not evaluate exposure potential.

Qualitative/quantitative: The assessment results are used to qualitatively evaluate chemicals and rate them as follows:

Green rating: chemical presents little or no risk and is acceptable for the desired application

Yellow rating: low to moderate risk and chemical can be used acceptably until a green alternative is found

Orange rating: chemical is not necessarily high risk but lack of information prevents a complete assessment

Red rating: chemical is high risk – includes all known or suspected carcinogens, endocrine disrupters, mutagens, reproductive toxins, teratogens, and chemicals that do not meet other human health or environmental relevance criteria

Best for which applications: This assessment can be used to evaluate existing or new products, processes and designs to determine the most eco-effective materials.

Limitations: Experimental data is not available for many chemicals and materials. This method does not provide an evaluation process in the absence of data; however, it flags chemicals as Orange if data are missing.

The bottom line: This protocol has been used effectively by a number of companies to make materials choices that are environmentally sound. The protocol is accessible only through the consulting services of MBDC.

9. PBT Profiler

Where to locate: www.pbtprofiler.net

Fee for use: no

Purpose of tool/background: The US EPA has developed the P2 Framework as a risk screening approach that incorporates pollution prevention in the design and development of new chemicals. The P2 Framework is a compilation of many of EPA's Office of Pollution Prevention and Toxic's (OPPT) computer based methods for predicting chemical risks. These methods focus on hazard identification, exposure assessment, or a combination of these elements. Some of these models provide quantitative estimates of risk, while others are qualitative assessments. The P2 Framework models can be divided into four categories according to what they estimate: physical/chemical properties; chemical fate in the environment; hazards to humans and the environment; and, exposure and/or risk. EPA has developed a P2 Framework Manual that describes the various models in the P2 Framework: see http://www.epa.gov/oppt/p2framework/docs/p2manua.htm.

The PBT Profiler is an online tool made up of a subset of the P2 Framework models. It evaluates organic chemicals without experimental data for persistence, bioaccumulation and chronic fish toxicity. The software program requires a unique identifier such as CAS registry number or product ID and a chemical structure. The CAS registry number automatically retrieves information on chemical structure. The program provides easy to read color-coded comparisons of predicted values to PBT criteria. If the chemical exceeds thresholds for persistence, bioaccumulation or chronic fish toxicity, the designators are shaded red or orange. If thresholds are not exceeded the designators are shaded green.

Criteria/categories of hazard considered: persistence, bioaccumulation and chronic fish toxicity.

Exposure considered: no

Qualitative/quantitative: This is a qualitative tool.

Best for which applications: This is a quick and easy tool to use to get screening level information on persistence, bioaccumulation and chronic fish toxicity for chemicals lacking experimental data. It fills a basic gap as most databases provide information only on well-studied chemicals.

Limitations: The PBT Profiler is a screening level predictive tool that should only be used when experimental data are not available. In addition, the following chemicals should not be profiled using this tool: inorganic chemicals, reactive chemicals, organic salts, high molecular weight compounds, chemicals with unknown or variable composition, mixtures, surfactants, and highly fluorinated compounds.

By evaluating persistence, bioaccumulation and chronic fish toxicity, this tool indirectly considers risks to human health. However, this tool does not directly evaluate health or environmental effects such as carcinogenicity, mutagenicity, mammalian toxicity, endocrine disruption, or ozone depletion.

The bottom line: A quick screening level tool for evaluating persistence, bioaccumulation and chronic fish toxicity for chemicals that lack experimental data.

Appendix D: P2OASys Matrix
Screen Shot of Matrix Layout

(go to http://www.turi.org/content/content/view/full/1133/ to download full matrix)

Help !!!

To ——> Alternative 1

Fill out only the green cells; do not forget the component %

Current Technology												
Category	Units	Cert.	Score	Component 1			Component 2			Component 3		
				Type name here			Type name here			Type name here		
				%	100		%			%	100	
Acute human effects		Cert	Score	Val	Sco	Cert	Val	Sco	Cert	Val	Sco	Cert
Inhalation LC50	ppm											
PEL/TLV	ppm											
PEL/TLV (dusts/particles)	mg/m3											
IDLH	ppm											
Respiratory irritation	L/M/H											
Oral LD50	mg/kg											
dermal irritation	L/M/H											
skin absorption	L/M/H											
dermal LD50	mg/kg											
ocular irritation	L/M/H											
Chronic human effects		Cert	Score	Val	Sco	Cert	Val	Sco	Cert	Val	Sco	Cert
Reference Dose RfD	mg/kg/day											
carcinogen	IARC/EPA Class											
mutagen	L/M/H											
reproductive effects	L/M/H											
neurotoxicity	L/M/H											
developmental effects	L/M/H											
respir. sensistivity/disease	L/M/H											
other chronic organ effects	L/M/H											
Physical hazards		Cert	Score	Val	Sco	Cert	Val	Sco	Cert	Val	Sco	Cert
heat	WBGT, °C											
noise generation	dBA											
vibration	m/S^2											
ergonomic hazard	L/M/H											