Designing Safer Alternatives: Chemicals, Materials and Products Final Report

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Preface – Moving Towards Safer Alternatives

There is growing international interest in the development of safer alternatives to problematic chemicals, materials, and products. For example, a central goal of the European Commission's proposed regulation on Registration, Evaluation, and Authorization of Chemicals (REACH) is the substitution of problem chemicals with safer alternatives. However, several questions arise in the context of finding safer substitutes: How do we know they are safer?; Are there lifecycle implications we should know about?; What are potential unintended consequences of substitutes?; Could they shift risks from consumers to workers, for example.

In recent years, various research projects around the globe have been undertaken to develop frameworks, approaches, and tools for assessment of substitutes at the chemical, material, and product levels. For example, even within the single institution of the University of Massachusetts Lowell, we identified several overlapping approaches to alternatives assessment in research projects. However, no consistent frameworks or methodologies have been proposed. This is a problem in that many governments and firms (particularly small and medium sized ones), even when they want to move towards safer materials, often lack tools or guidance on what they should look at in assessing alternatives.

For over a year, experts at the Lowell Center for Sustainable Production gathered regularly to discuss alternatives assessment processes and methods. Yet, we realized that we needed to engage a broader group of experts in this process who had been struggling with the same issues but had not been in contact with each other. To address the need for new, sufficiently flexible yet consistent tools for conducting alternatives assessment, the Lowell Center for Sustainable Production at the University of Massachusetts Lowell convened a group of 40 North American and European experts in chemicals substitution, alternatives assessment, life cycle assessment and product policy from government, industry, academia, and the nonprofit sector to discuss ways to improve and coordinate alternatives assessment processes. The overall goal of the workshop on Designing Safer Alternatives: Chemicals, Materials and Products**,** held from December 2-4, 2004 was to support the development of safer chemicals and products. The particular objective was to convene leading experts in substitution and alternatives assessment and advance its practice by diffusing knowledge of existing methods, creating as well as strengthening expert networks, and crafting protocols for performing alternatives assessments.

The following report contains the background papers on alternatives assessment prepared for the December 2004 meeting, as well as a summary of the meeting as well as notes from each of three breakout sessions addressing alternatives assessment tools for chemicals, materials and products. These documents were prepared by Mark Rossi, PhD, with the support of Joel Tickner, ScD, Sally Edwards, Ken Geiser, PhD, and with extensive input from other staff of the Lowell Center for Sustainable Production.

Based on these discussions, the Lowell Center for Sustainable Production is currently preparing a draft methodology and framework for alternatives assessment that it will broadly disseminate for comments and revision at the end of summer 2005. We believe that these documents provide useful background and support to on-going discussions aimed at improving processes to design and assess alternative chemicals, materials and products.

Setting the Context for the Lowell Workshop on:

Designing Safer Alternatives: Chemicals, Materials + Products

"Can one distinguish and define the specific properties of a technics directed toward the service of life: properties that distinguish it morally, socially, politically, esthetically from the cruder forms that preceded it? Let us make the attempt."

Lewis Mumford, *Technics and Civilization*, 1934 (p.7)

To create an economy that sustains life we need a material economy that nourishes ecosystems and human health, in addition to preventing damage to these systems. We need products made from renewable materials that biodegrade into healthy nutrients, materials that can be closed loop recycled, and processes powered by renewable energy. And we need production systems that sustain life, where the outputs from extracting or growing raw materials, manufacturing chemicals and materials, and manufacturing products are healthy inputs into ecological cycles. Reconfiguring our material economy will require changes in chemicals, materials, products (including services) and product function, systems (e.g., transportation systems, building systems, production systems, etc.), and our culture.

The Lowell three-day workshop on "Designing Safer Alternatives" was held to identify challenges, link together different initiatives (in government, business, academia, and the environmental movement), and advance our work and thinking on the methods and tools that help us identify environmentally preferable chemicals, materials, and products.

Given that the current economic system in developed countries economies so distant from our vision of an economy that supports life, a challenge that confronts those of us who want to reverse this trend is learning how to make decisions that do in fact move us towards sustainable materials.

As physical matter in our economy, chemicals, materials, and products are interrelated (for definitions of these terms see Box 0). Typical solid consumer products, such as the chairs we sit upon, are manufactured from materials, which in turn are constituted from chemicals. In some cases, chemicals are the product.[1] Thus products consist of materials and/or chemicals, materials consist of chemicals, and chemicals are constituents of materials or products.

Figure 1 illustrates the nested relationships between these types of matter.

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

Most products have this nested relationship. For example, consider the product, carpet tiles. Carpet tiles are made from a combination of backing and face materials. The face material is typically a nylon[2] and common backing materials include polypropylene, styrene butadiene rubber (SBR) and polyvinyl chloride (PVC). Nylon 6 is made from the chemical caprolactum; 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.

Box 0. Clarifying Terms

Chemical is "any element, chemical compound or mixture of elements and/or compounds."[1] Chemicals are the constituents of materials. A chemical "mixture," also known as a chemical "preparation," includes multiple chemicals.

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."[2] Human-made materials like petroleum-based plastics are synthesized from chemicals.

Product is "something produced by physical labor or intellectual effort."[3] 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.

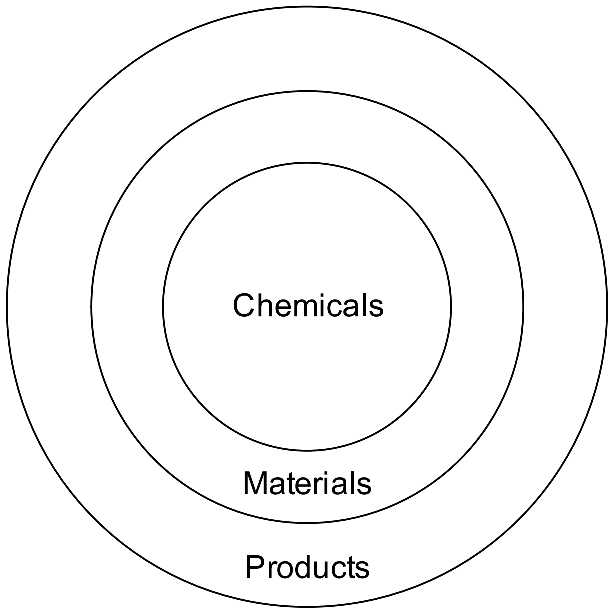
The **"material economy"** is the physical matter upon which we base our lives.

[1] OSHA Hazard Communication Standard (HCS), Subpart Z, Toxic and Hazardous Substances, 29 CFR 1910.1200, Section "c", "Definitions."
[2 + 3] G&C Merriam Company, 1976, *Webster's Third New International Dictionary* (Springfield, MA: G&C Merriam

What we have found is that the method used to evaluate each of these types of matter varies widely. There is no common agreement on how to do relatively quick environmental assessments of chemicals, materials, or products. What is common is the complexity of the evaluative task increases as we move from chemical to material to product. Table 1 depicts typical endpoints included in alternatives assessments of chemicals, materials, and products.

[2] The two nylons are nylon 6 and nylon 6,6.

Figure 1. Layers of Physical Matter in Our Economy



A key question for participants at the Lowell workshop is: what principles are common within or across chemical, material, and product assessments? Potential principles for designing and selecting safer alternatives, include:

- Apply life cycle thinking.
- Act in a precautionary manner (i.e., act on inherent hazard data, even though comprehensive data are unavailable).
- Treat chemicals and materials with missing data as chemicals/material of very high concern until data are available.
- Consider worker hazards -- chemical and physical hazards -- as well as environmental hazards.

Table 1. Physical Matter and Typical Endpoints included in Environmental Assessments

	Endpoints included in Environmental Assessments							
Type of Physical Matter	Inherent hazards of a chemical	Environ-mental hazards from use	Environ-mental hazards from extraction, processing, & production	Environ-mental hazards from disposal	Recycl-ability / degrad-ability	Design for dis-assembly	Use fewer materials, com-ponents	Remove hazard-ous sub-stances
Chemical	X	X						
Material	X	X	X	X	X			
Product	X	X	X	X	X	X	X	X
X = Has been included in assessments of that type of physical matter.								

In chemical assessments the emphasis is on the inherent hazards associated with the chemical, with modest attempts to incorporate proxies for exposure (e.g., end uses of a chemical). Additionally. many chemical assessments penalize chemicals that lack hazard data, assuming they are very high hazard chemicals until data demonstrates otherwise. We look forward to identifying "principles" of alternatives assessment with meeting participants.

Due to limited time and an already packed agenda we have drawn boundaries around the scope of the two and a half day meeting in Lowell. The meeting will focus on enhancing methods for alternatives assessment of chemicals, materials, and products. We recognize that two significant components of alternatives assessment are not on the agenda.

The first missing component is a discussion of the methods needed to facilitate more fundamental changes in the selection of physical matter; specifically changes in systems and culture. For example, more fundamental solutions to carpet tiles include creating less demand for carpets in the first place by redesigning office buildings (systems change) and altering consumer perceptions of carpets (cultural change).

Systems -- such as building, production, or transportation systems -- are complex mixtures of products and human activities. Culture is the complex mixture of human products, activities, and desires.[3] Lewis Mumford (a prominent American scholar of technology and society), for example, saw cultural norms as having a profound impact upon our use and employ of physical matter:

> Our goal is not *increased* consumption but a vital standard: less in the preparatory means, more in the ends, less in the mechanical apparatus, more in the organic fulfillment. When we have such a norm, our success in life will not be judged by the size of the rubbish heaps we have produced: it will be judged by the immaterial and non-consumable goods we have learned to enjoy, and by our biological fulfillment as lovers, mates, parents and by our personal fulfillment as thinking, feeling men and women.[4]

As we move from products to systems to culture, the complexity of change increases along with the opportunities for creating more fundamental change in creating an economy in service of life (see Figure 2).

The second missing component is a discussion of how the "environmental health and safety" factor is integrated with other factors that organizations typically consider when selecting for an alternative chemical, material, or product. These other factors are: the costs of change (i.e., economic factor) and the technical performance of the alternative (i.e., technical performance and feasibility factor). Related to performance, is whether a viable alternative even exists. Increasingly social factors, including employment conditions and economic justice considerations, are being incorporated into product selections as well (see Figure 3). The report -- *Substitution of hazardous chemicals in products and processes* -- by Ökopol and

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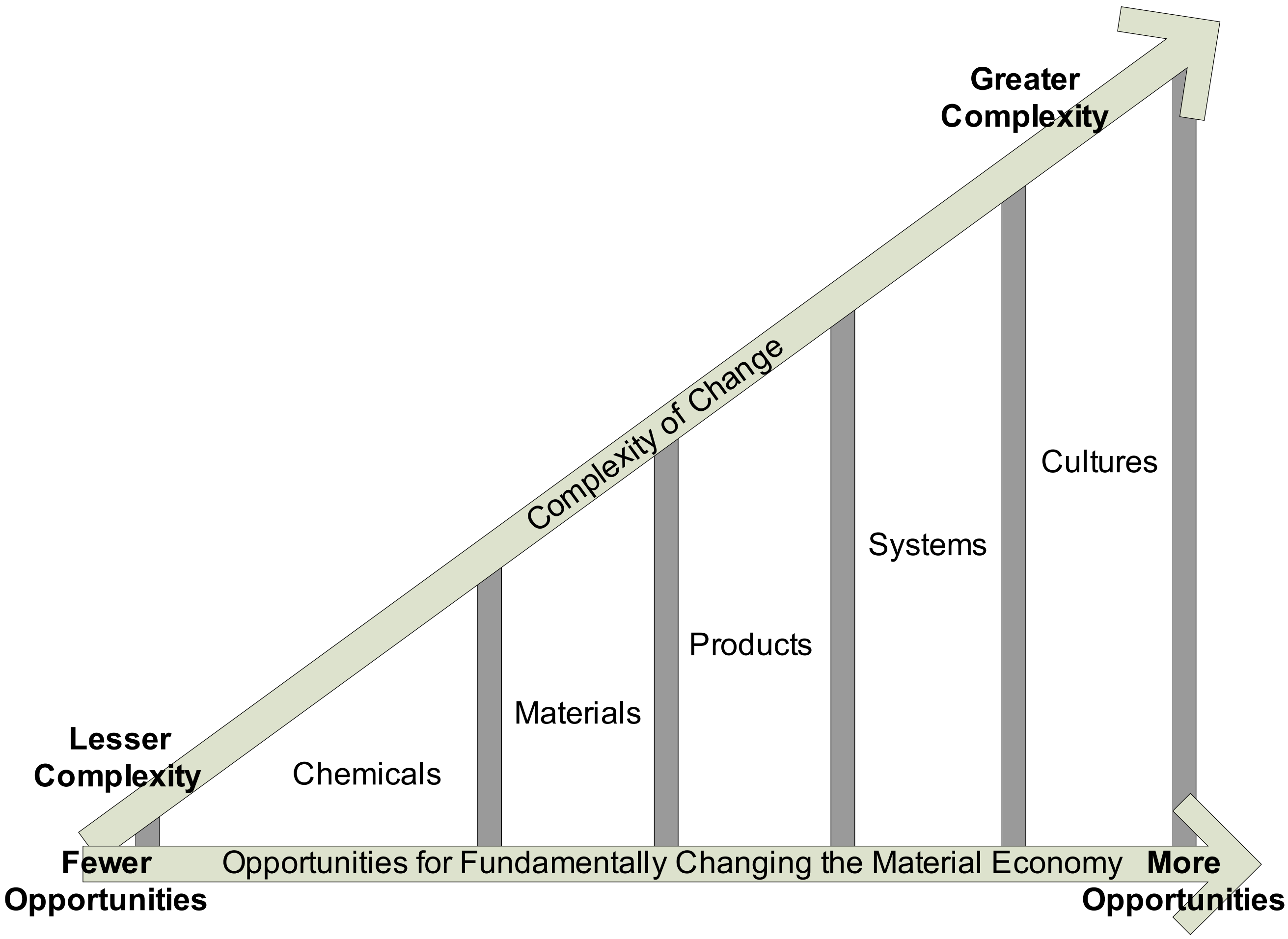
[3] Webster's dictionary defines "culture" as: "the total pattern of human behavior and its products embodied in thought, speech, action, and artifacts and dependent upon" the human " capacity for learning and transmitting knowledge to succeeding generations through the use of tools, language, and systems of abstract thought" (G&C Merriam Company, 1976, *Webster's Third New International Dictionary*, Springfield, MA: G&C Merriam Company).
[4] Lewis Mumford, 1934, *Technics and Civilization* (New York: Harcourt Brace Jovanovich), p.399.

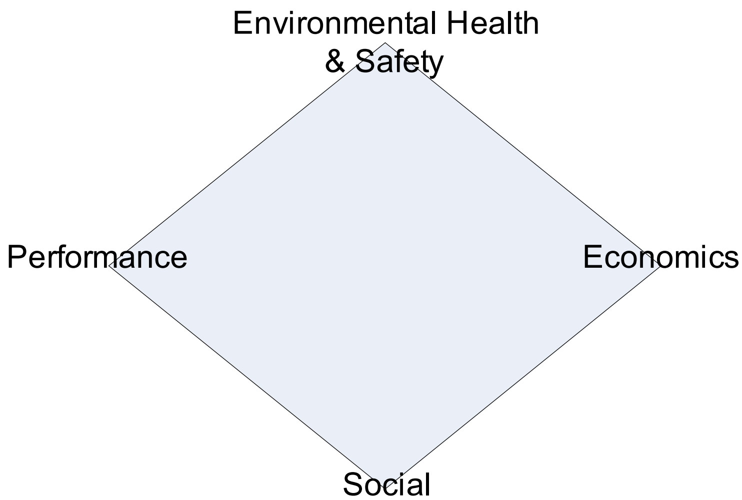
Kooperationsstelle Hamburg for the Directorate General Environment, Nuclear Safety and Civil Protection of the Commission of the European Communities (2003) includes case studies on how organizations are integrating environmental health concerns with economic, social, and technical performance factors.

Figure 2. Opportunities and Complexity of Changing the Material Economy



The terrain for designing and selecting for safer alternatives is wide and varied. We recognize the importance of integrating environmental health and safety concerns with performance, economic, and social factors and we also are aware of the need for fundamental cultural and societal change in order to move toward a sustainable society. At our meeting in Lowell we need to keep these broader issues in mind as we focus on improving methods for designing and selecting safer chemicals, products, and materials.

Figure 3. Selecting for Safer Alternatives: Factors Organizations Evaluate



Workshop Summary:

Designing Safer Alternatives: Chemicals, Materials + Products

To advance the work and thinking on the methods and tools used to identify and compare r substitute, or alternative, chemicals, materials, and products, the Lowell Center for Sustainable Production convened a three-day workshop in December 2004 titled, “Designing Safer Alternatives: Chemicals, Materials, and Products.” The participants were North American and European experts on alternatives and substitution assessment from governments, businesses, academia, and environmental groups.

The outcomes from the meeting are:

1. This workshop summary.
2. A set of papers prepared prior to the meeting to set the context for the workshop discussions: a) “Setting the Context for the Lowell Workshop on Designing Safer Alternatives,” b) “Chemical Hazard Assessment Methods,” c) “Material Assessment Methods,” and d) “Product Assessment Methods.”
3. Notes from the three break-out discussions at the workshop on Chemical, Material, and Product Assessment Methods and Tools.
4. Slides from the presentations made at the workshop.

Presented below are prominent themes that emerged over the course of the workshop. They are <u>not</u> agreements or consensus statements. This summary highlights the meeting organizers’ interpretation of the prominent themes.

Underlying Themes / Principles for Alternatives Assessment

<u>Develop methods and tools for making, not delaying, decisions</u>. Methods and tools that facilitate making relatively quick decisions based upon robust data are needed.

<u>Creating safer products is a journey.</u> Decisions are not final, they are steps along the path. Successful implementation requires continuous improvement and planning: “Don’t let the best be the enemy of the good.”

<u>Define clear long term goals.</u> For example, in Sweden has established a set of generational goals to achieve by 2020, including the goal of a non-toxic environment. Once clear, long-term goals are set, developing and identifying the appropriate methods and tools for achieving the goals becomes clearer.

<u>Values matter.</u> Be explicit about values. Methods developed, tools used, and how data are analyzed are affected by values. Examples of value judgments that emerge in alternative assessments include:

- whether to emphasize the hazards or risks of chemicals

- whether to emphasize pollution prevention or pollution control measures to manage toxic chemicals
- long-term goals and steps necessary to achieve them
- threshold of harm needed to trigger action
- priority action areas
- whether to aggregate data
- how to aggregate data

Note that value conflicts are likely across the course of any public alternatives assessment process since optimal solutions that address all concerns are seldom available.

Engage stakeholders in discussion of values, methods, and tools to define common ground as well as areas of difference.

Transparency. Methods and tools must be transparent. To achieve greater transparency need:

- Publicly available data, including full disclosure of chemicals and materials in products.
- Clearly stated methodological steps, scope of analysis, data sources, assumptions, and value judgments.

Define Alternatives Assessment

There is a need for a **definition of alternatives assessment**. One option is to build from European definition of substitution:

> "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."[5]

Move to "Positive Criteria" for Evaluating Safer Alternatives

To date, the definition of safer chemicals and materials has primarily been on identifying chemicals of high concern that need to be avoided. For example, carcinogens, OSPAR (Oslo-Paris Convention) priority chemicals, and persistent, bioaccumulative toxics (PBTs). These chemicals of high concern for elimination are useful because they create clear goals and bound the alternatives assessment process . Yet targeting chemicals of high concern for elimination operates from defining negatives, what we don't want, rather than defining positives, what we want.

At the meeting there was a clear desire to take the next step and specify positive criteria. Positive criteria are available and have been used in identifying environmentally preferable

[5] Ökopol and Kooperationsstelle Hamburg. 2003. Prepared for the Directorate General Environment, Nuclear Safety and Civil Protection of the Commission of the European Communities. *Substitution of hazardous chemicals in products and processes*. Hamburg: DG Environment.

alternatives. For example, preferring: renewable materials, products with high recycled content, biodegradable materials/products, chemicals that meet the 12 principles of green chemistry, durable products, etc. To date positive criteria have not been systematically combined into a method for evaluating safer tools. It was agreed, the time is now for developing such a methodology.

Moving Forward: Modular Approach

There is no single alternatives assessment method or tool available to meet all needs, to fit all applications. Alternatives assessment methods and tools need to be flexible, adaptive, and probably modularized. The appropriate methods and tools will vary depending on:

- Goal: market transformation, competitive advantage, bringing up the laggards, internal behavioral change, achieving a non-toxic environment, etc.
- Audience: marketing, design, product development, senior management, supply chain, customers, communities, government, etc.
- Level of assessment: chemical, material, product, etc.

Especially notable throughout the two days was the need for methods and tools that foster behavioral change within organizations. That we need to move beyond just technically advanced tools to socially advanced tools.

Challenges

Many challenges to advancing alternatives assessment were raised, including:

- Avoiding risk shifting -- for example, from developed to developing nations.
- Managing tradeoffs -- for example, switching to a less toxic chemical that causes greater global warming or creates new workplace hazards.
- Addressing value conflicts.
- Choosing which approach -- hazard or risk assessment -- to use in defining problems; and which approach is appropriate under what circumstances.
- Addressing data gaps and uncertainty and how to act on uncertainties.
- Deciding whether to aggregate data.

"Bike Rack" Issues (i.e., issues we did not address at the meeting, but that need to be addressed at a later date)

The full range of issues related to alternatives assessment were not covered at the meeting. Missing elements that are important to comprehensive alternatives assessment include:

- Incorporating social sustainability into methods and tools.
- Evaluating technical and economic performance.

- Achieving organizational buy-in and implementation.

Next Steps

At the close of the meeting participants brainstormed a list of next steps needed for advancing alternatives assessment. That list:

- Produce final report from the meeting
- Write, publish, and collect: case studies of use of innovative alternatives assessment methods
- Create an alternatives assessment network
- Host future meetings that include designers and/or addresses the "bike rack" issues
- Produce material flows with use level data
- Compare and evaluate existing methods and tools to develop more comprehensive and adaptable tools.

There was no agreement on who would address these issues, other than the first bullet, which the Lowell Center for Sustainable Production agreed to produce.

With the goal of using green chemicals and avoiding hazardous chemicals, governments and businesses are developing and using methods to inform their chemical policies and purchasing choices. And businesses are using methods to inform chemical choices in manufacturing as well as in material and product selection. We call these methods "chemical hazard assessments" because they assist in the design and selection of safer chemicals by evaluating the relative hazards and/or greenness of chemicals. Hazards refer to the negative attributes of chemicals, such as carcinogenicity or flammability. "Greenness" refers to positive environmental attributes, such as biodegradability or safe for aquatic organisms. The focus here is not on quantitative risk assessment (a quantitative evaluation of hazard and exposure), but rather on methods that allow for relatively quick assessments of the hazards/greenness of chemicals.[6] Prominent examples of chemical hazard assessment methods include:

- The "Evaluation Matrix" developed for the German Federal Environmental Agency.
- "Quick Scan" developed by The Netherlands.
- "PRIO" developed by the Swedish Chemicals Inspectorate (KemI).
- "The Column Model" developed by the German Institute for Occupational Safety (BIA).

Chemical hazard assessments are often part of broader evaluations that include the economic costs, social implications, and technical performance characteristics of alternatives. The linkages between chemical hazard assessments and these additional factors are not addressed in this background paper. For a discussion of the differences and overlaps between chemical, material, and product assessments see the Lowell background paper included in your packet: "Setting the Context for the Lowell Workshop on Designing and Selecting Safer Alternatives: Chemicals, Materials, and Products."

[6] Chemical hazard assessments are a type of hazard assessment. They address the inherent properties of a substance that give it the potential to cause adverse effects and sometimes the potential magnitude of those effects (be they physical hazards, toxicological, etc.). Such assessments do not generally address whether there is sufficient exposure to cause the effect from that substance in a particular situation. However, some chemical hazard assessments do combine hazard determinations with some qualitative assessment of exposure (for example use category) resulting in a qualitative risk estimate.

This background paper highlights:

- Specific tools and approaches to evaluate chemicals.
- Analytic methods used to select less hazardous chemicals.
- The core elements of chemical hazard assessments

Not included in this background paper are approaches that overlap, but are broader than chemical assessments, such as life cycle assessments (which are discussed in the background paper on product assessments).

1. Defining Substitution

Chemical hazard assessments are often part of a broader review of substitution; broader than simply switching from Chemical X to Chemical Y. In Europe, for example, where the substitution principle has a much longer history of use, the term "substitution" encompasses a broader framework than simply moving from one chemical to another. For example, in their report to the European Commission's Directorate General Environment, Nuclear Safety and Civil Protection, Ökopol and Kooperationsstelle Hamburg defined "substitution" as meaning:

> 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 (DG Environment, 2003, p. i).

Thus implementing the substitution principle can occur at a variety of levels: the chemical, material, product, system, or even cultural level.

For example, the persistent, bioaccumulative toxicant penta-brominated diphenyl ether (penta-BDE) has been used as a flame retardant in the manufacture of plastic foam. In pursuing alternatives to penta-BDE manufacturers and consumers in the foam supply chain have a variety of choices. Foam manufacturers can choose a chemical substitute (e.g., another flame retardant) or could develop alternative cushioning materials, such as cotton. Manufacturers of products containing foam can purchase foam with a different chemical flame retardant, purchase a different cushioning material, or re-design their product so that foam is no longer necessary.

This background paper on chemical hazard assessments focuses on how to select among chemicals, a considerable task on its own. The broader concept of substitution is carried through in the other Lowell Center background papers on materials and product assessments.

2. Chemical hazard Assessment Methods

Among the array of chemical hazard assessment models in use, this paper highlights several that illustrate three different methods in use: hazard data display methods, screening methods, and numeric methods.

2.1. Hazard Data Display Methods: Creating Templates, Leaving Data Analysis to Users (e.g., The Column Model)

The Column Model is an informational tool on chemical hazards. Developed by the Institute for Occupational Safety (BIA) of the German Federation of Institutions for Statutory Accident Insurance and Prevention, The Column Model presents data on chemical hazards in a tabular format. The columns are six hazard endpoints: acute health risk, chronic health risk, environmental risk, fire and explosion, liberation properties, and risks by technology. The rows are divided into five hazard levels: very high, high, medium, low, and negligible risks (see Table 2).

Table 2. The Column Model (by BIA in Germany)

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						

The criteria for each cell in the table are determined primarily by risk phrases (R-phrase). For example, in the "Fire and Explosion Hazards" column, the criteria for the very high risk cell are: "explosive substances / preparations" (R2, R3); "extremely flammable gases and liquids (R12): and "spontaneously flammable substances/preparations" (R17).[7]

The Column Model creates a framework for presenting data by hazard category and potential risk level. Users of the model are responsible for collecting and analyzing the data. How chemicals are compared is left up to the user of the model. Users of the model can use "dominance analysis" and/or "positional analysis" to compare the data.

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 analyst obtains a set on non-dominated alternatives" (Nordic Council of Ministers, 1997).

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" (Nordic Council of Ministers, 1997).

[7] R-phrases are defined in the EU by Directive 2001/59/EC, starting on page 82, Annex III.

In The Column Model chemicals are compared based upon which cell they fall into for each column. Dominance analysis would be used first to assess whether, for example, Chemical X scores better or equal than Chemical Y for all columns. 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 choosing one or more columns (e.g., only acute and chronic health hazards) for comparison.

Other models that create templates and leave analysis to the user include the German Federal Environmental Agency's "Evaluation Matrix" (see Section 2.3) and the Pollution Prevention Options Analysis System ("P2OASys" - developed by the Massachusetts Toxics Use Reduction Institute and Mission Research; see Section 2.3).

The advantages of data display models are 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 see potential risk trade-offs between chemicals, and to incorporate their values into deciding which columns (hazard endpoints) are most important to their decision making processes. Values and subjective decisions are embedded in The Column Model in specifying the hazard levels and defining the criteria for each cell. Users in turn overlay their values and priorities when prioritizing among endpoints (i.e., columns).

The interpretive flexibility of data display models, however, is also a disadvantage because they do not specify which hazard endpoint(s) are of greatest concern to governments, industry, or environmental organizations.

2.2. Screening Methods: Creating Categories of Concern, Recommending Actions (e.g., Quick Scan)

Developed by the Dutch Ministry of Housing, Spatial Planning and the Environment, the **"Quick Scan"** method forms an integral part of the Dutch Government's initiative to implement a chemicals substitution policy for high hazard chemicals and chemical mixtures.[8] The goals of Quick Scan are to:

- Develop substance profiles based on hazard information.
- Classify chemicals into categories of concern.
- Direct the industrial community to appropriate actions for chemicals of high concern.

The steps in the Quick Scan method are:

- Gather hazard data on chemicals.
- Use criteria to assign chemicals to hazard levels.
- Use decision making rules to determine concern categories.
- Revise concern categories based upon use data.

[8] Unless otherwise cited, all the data in this section that relates to Quick Scan are from SOMS, 2001.

The responsibility for implementing Quick Scan resides with the industrial community.

Similar to The Column Model, Quick Scan specifies criteria for determining hazard levels of a chemical for specific hazard endpoints (see
Appendix **2** for the spreadsheet format). The hazard endpoints for Quick Scan are slightly narrower than The Column Model, with Quick Scan excluding "fire and explosion" and "risks by technology."

More significantly, Quick Scan differs from The Column Model in that it:

- Develops decision making rules for converting hazard levels into concern categories (see Appendix 3)
- Develops criteria for revising concern categories based upon potential for exposure (based upon use categories) as well as availability of alternatives.
- Specifies required industrial actions related to concern categories.

The decision making rules for converting hazard levels into concern categories are straightforward for the human health hazards,[9] where a high hazard level (e.g., carcinogenicity "C1") translates into a "very high concern" category (see Appendix 3). The decision making rules for PBTs are more complex, where the assigning of a chemical to a concern category is based upon the chemical's combined hazard level for P (persistence) and B (bioaccumulative capacity) and T (eco-toxicity). For example, a P1 + B1b + T2 = "very high concern," while P2 + B2 + T3 = "concern" (see Appendix 3 for further details).

The concern categories are then adjusted for based upon potential for exposure -- as determined by chemical uses (see

Table 3) -- and the availability of alternatives.

Finally the classification of a chemical as "very high concern" or "high concern" has specific actions associated with it:

- "Substances giving rise to Very High Concern must, in principle, no longer be used" (SOMS, 2001, p.39).
- Substances of High Concern "are not to be permitted for consumer purposes and in open profession use, unless certain preconditions are satisfied" (SOMS, 2001, p.40).

Substances of Concern are "permitted, provided that certain limit conditions are satisfied" (SOMS, 2001, p.40).

[9] The five human health hazards addressed are: toxicity for humans, carcinogenicity, mutagenicity, reprotoxicity, and hormone disruption.

Table 3. The Dutch "Quick Scan" Method for Substances of Concern

Concern on Basis of Hazard	**Use of Substances as Indication of Exposure**			
	Site limited intermediate substances	**Substances in industrial applications**	**Open professional use of substances**	**Substances in consumer applications**
	Low exposure	***Exposure***	***High Exposure***	***Very high exposure***
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: SOMS, 2002

The Quick Scan Model is designed to de-select chemicals, those that are categorized as Very High Concern and High Concern but can also be used to allow continued use of chemicals identified as low concern. In this vein, the analytic method behind Quick Scan is similar to what the Council of Nordic Ministers report on decision aid methods calls the “elimination by aspects” procedure, where choices are made by defining threshold criteria that eliminate chemicals/substances as options for use (Council of Nordic Ministers, 1997).

Quick Scan differs from the elimination by aspects procedure (as defined by the Council of Nordic Ministers report) in that it does not lead to a final selection. Instead, Quick Scan screens chemicals into broad categories -- e.g., very high concern, concern, etc. -- but does not create a mechanism, for example, for selecting among chemicals that fall into the “Concern” category.

Values and subjective decisions enter into Quick Scan when defining criteria, decision making rules, and revising concern categories based upon use data.

2.3. Numeric Methods: Aggregating Data into Common Units, Ranking Chemicals

The screening and hazard data display methods discussed above create tools that allow users to make decisions based upon disaggregated data: the methods convert hazard data into categories without converting the data into a common unit. Methods that aggregate data take an additional step of combining all the data into a single numerical value.

An example of an aggregated data method is the German Federal Environmental Agency’s Evaluation Matrix. The Evaluation Matrix is similar to The Column Model in that it also defines risk levels for specific endpoints as well as uses (see Table 4). Users of the Evaluation Matrix can review the disaggregated data, comparing the various endpoints based on dominance/positional analyses as with The Column Model, and/or they can aggregate the data by weighting the endpoints to create a risk index:

> 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 (German EPA, 2003a, p.19).

Table 4. The Evaluation Matrix (developed by Ökopol and Fraunhofer for the German Federal Environmental Agency)

Extent of Risk Contribution	Substance Properties					Use Pattern			Risk Index
	Persist.	Bioaccum.	Aquatic tox.	Chronic tox.	Mobility	Amount	Mobilizing Conditions	Indirect Releases	
Very High									
High									
Medium									
Low									
Very Low									
Weighting									

The Pollution Prevention Options Analysis System -- "P2OASys" (developed by the Massachusetts Toxics Use Reduction Institute and Mission Research) -- converts data for each hazard category into a numeric scale of 2, 4, 6, 8, or 10 -- with the lowest score representing the lowest hazard and the highest score representing the highest hazard (see

Appendix 4 for the P2OASys algorithm table). P2OASys works on the basis of a maxi-min principle, meaning that the highest value dominates any category of analysis (e.g., chronic toxicity, aquatic toxicity, etc.). P2OASys also allows disaggregated comparisons of scores across hazard categories. `Similar to the Evaluation Matrix, users can stop at the disaggregated data level, comparing the various endpoints based on dominance/positional analyses. While the online version of P2OASys does not automatically aggregate the numeric scores, users could easily do that.

The OSPAR Chemical Hazard Assessment and Risk Management (CHARM) model goes further towards risk assessment. CHARM calculates a Hazard or Risk Quotient (HQ or RQ) for a chemical, which is used to determine the use of chemicals in oilfield operations. The HQ is the ratio of expected environmental exposure (Predicted Environmental Concentration - PEC) to eco-toxicity (Predicted No Effect Concentration - PNEC). "If the PEC:PNEC ratio is larger than 1, an environmental effect may be expected" (Payne and Thatcher, 2003).

Aggregated methods have the advantage of distilling highly complex data into a single number, allowing for chemical comparisons across many endpoints and allowing each chemical within a category, such as a Quick Scan chemical of "concern," to be compared to each other.

The convenience of aggregated methods, however, is also a downside. As emphasized in the report by Ökopol and Kooperationsstelle Hamburg (for the European Commission's Directorate General Environment), in aggregated methods "the subjective human factor of setting priorities based on valuation and personal judgments can be 'hidden' in certain stages of the assessment which are not immediately transparent for an outside observer" (DG Environment, 2003, p.36). The Council of Nordic Ministers report on decision aid methods concurred, concluding that complex tools (i.e., tools that aggregate data) should be excluded if other simple tools (i.e., tools based upon disaggregated data) will lead to consistent and transparent decisions (DG Environment, 2003, p.43).

Table 5 summarizes points in each of the methods where subjective / value-based decisions do arise. As the complexity of the methods increases, so does the number of subjective

Table 5. Key Points in Chemical hazard Assessments where Subjective / Value-based Decisions May Happen

Key Decision Points in Chemical hazard Assessment Methods	Disaggregated Data Methods		Aggregated Data Methods
	Data Display Methods	Screening Methods	
Selecting of endpoints	X	X	X
Specifying criteria for endpoints	X	X	X
Defining risk proxies (e.g., types of end uses)	X	X	X
Prioritizing hazard endpoints		X	X
Specifying decision making rules		X	X
Recommending actions		X	X
Translating criteria into common values			X
Weighting of values			X

decision making points. Transparency is critical to alleviating these concerns. Unfortunately in proprietary databases, criteria and algorithms are often not specified to the general public.

3. Core Elements of Chemical hazard Assessment Methods

The chemical hazard assessment methods discussed above include some or all of the following elements. They:

Specify hazard endpoints (e.g., carcinogenicity, reproductive toxicity, mutagenicity, persistence, etc.) by which a chemical's hazards will be determined. Appendix 5 lists many of the endpoints that have been used in chemical hazard assessments.

Develop criteria for defining each endpoint. The typical approaches taken for determining hazards (in chemical hazard assessments) are:

- Using an already existing list. For example, carcinogenicity is determined by the carcinogen lists developed by IARC, US EPA, and the EU.
- Defining critical thresholds for determining specific properties. For example, define persistence as a chemical with a half life of > 60 days (marine) or > 40 days (freshwater).
- Using models to forecast the likely thresholds for that chemical. For example, use the PBT Profiler to determine a chemical's likely bioaccumulation factor.

Define the method used for determining how a chemical will be categorized or scored and then compared. For example, the Dutch "Quick Scan" method assigns a chemical to one of five levels of concern: very high concern, high concern, concern, low concern, and no data - very high concern. Specific subsets of a method may include:

- Adjusting the chemical assessment based upon risks of exposures. Some assessments adjust the chemical hazards based upon the opportunity for exposure. For example, the Dutch Quick Scan method has four proxies for likelihood of exposure based upon chemical use: intermediates, industrial applications, professional use, and consumer use (see
-
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- Table 3). And the German Federal Environmental Agency's Evaluation Matrix uses amount, mobilizing conditions, and indirect releases as exposure proxies.

- Addressing missing and uncertain data. Recognizing that toxicity data is lacking for many chemicals, chemical assessments are now accounting for the lack of data for chemicals. For example, in Quick Scan, "In cases where P, B or T data are missing, the substance will be classed in the Very High Concern category as a measure of precaution."

4. Green Chemistry: Defining the Positive, What we want in Chemicals

In substitution assessments a "greener" chemical is one that has been comprehensively tested and lacks all of the negative criteria for which it has been evaluated. We define a "greener" chemical through negative criteria; by attributes we don't want in a chemical. A challenge that confronts us in alternatives assessments is how to define the positive attributes of a chemical and to translate those attributes into measurable/definable criteria that can be used in chemical selection.

Fortunately, green chemists are creating frameworks for defining the positive attributes of chemicals. For example, the "12 Principles of Green Chemistry" developed by John Warner and Paul Anastas define principles for chemical life cycles that prevent waste and accidents, have little to no toxicity, are energy efficient, and use renewable resources (see Appendix 6). And Kenneth Geiser in his book Materials Matter (2001) defines safer chemicals and materials as being: inherently safer, non-bioavailable, physically benign, biodegradable, generated on demand, and manufactured in contained systems under ambient conditions (p.361).

Certainly there are overlaps between hazard assessments and green chemistry, as green chemistry continues to use the absence of negative attributes to define the positive. For example, Principle 2 (of the 12 Principles of Green Chemistry) is to design chemical products to have little or no toxicity. And to ascertain "little of or no toxicity" will require substitution assessments. And Kenneth Geiser defines inherently safer chemicals as "nonflammable, nonexplosive, nonvolatile, and noncorrosive" (p.361).

Examples of defining positive attributes include chemicals that:

- are "composed of large, dissociated, nonlipophilic molecules" because they "less likely to cross the cellular membranes of organisms" (Geiser, 2001, pp.362-363).
- are manufactured at room temperature and pressures (Principles of Green Chemistry, Principle #9; and Geiser, 2001, p.364).
- are manufactured with catalysts not stoichiometric reagents (Principles of Green Chemistry, Principle #5).
- will degrade into innocuous molecules after use (Principles of Green Chemistry, Principle #10; and Geiser, 2001, p.363)

These positive attributes need to be translated into criteria by which chemicals can be evaluated. To date, we don't have a level of specificity on the positive attributes of chemicals equivalent to the negative attributes.

The criteria developed by the Oslo-Paris (OSPAR) Commission for defining substances/preparations used and discharged offshore that pose little or no risk (PLONOR) to the environment are an example of the use of both negative and positive criteria. Providing that the data required for assessment have been submitted, the OSPAR PLONOR list includes:

- 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 CMR (carcinogen, mutagen, reproductive toxicity) properties and
    - LC50 or EC50 > 100 mg/L and
    - Log Pow <3 or BCR <100 or MW>1,000 and
    - substance is readily biodegradable according to OECD 306 or equivalent (seawater biodegradation tests).
- Other organic substances that are non-water soluble (e.g., nutshells and fibers).

The OSPAR PLONOR criteria include both negative (e.g., no CMR properties) and positive criteria, e.g., acute toxicity of LC50 (lethal concentration) or EC50 (effective concentration) > 100 mg/L.

An important distinction between the principles of green chemistry and substance assessments is: green chemists are expanding the scope of chemical assessment by bringing a life cycle framework to how we define greener chemicals. They are looking beyond the inherent hazards of a chemical to upstream conditions -- to how the chemical is manufactured (e.g., under ambient conditions) -- and to downstream conditions (what it degrades into). The use of life cycle frameworks is common to material and product assessments, but not to chemical assessments. This raises another challenge, which is, how to incorporate the life cycle perspective that is common to green chemistry in our chemical assessments.

5. Conclusion

A variety of methods are in use by governments, researchers, and businesses to choose safer chemicals. These tools address a range of questions, including:

- What is a safer chemical for this manufacturing process?
- What is a safer chemical for this product?
- What is a green chemical?
- Which chemicals should be avoided immediately, and in the near-, mid-, and long-term?
- When moving away from a chemical, how can we think beyond chemical substitution?
- What is the role of the government in fostering safer chemicals?

The audiences for these assessments include workers, manufacturers, governments, institutional consumers, students, and researchers.

Given the potentially disparate audiences for and questions asked of chemical hazard assessments, it becomes clear that no single method is likely to answer all questions. Thus the interested parties in chemical hazard assessments may need multiple methods and tools to choose from given their research question.

What is needed is to look across these methods and to evaluate where the common ground is across the methods? Are there: Common questions? Common criteria? Common hazard levels? Common hazard endpoints? Common framing themes, such as, high hazard identification is sufficient for action?

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Appendix 1. Clarification of Hazard Assessment and Risk Assessment Definitions

"Risk assessment" is:

> "A process intended to calculate or estimate the risk to a given target organism, system or (sub)population , including the identification of attendant uncertainties, following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system. The Risk Assessment process includes four steps: hazard identification, hazard characterisation, exposure assessment, and risk characterization. It is the first component in a risk analysis process" (OCED, 2003).

Risk assessment is generally synonymous with quantitative risk assessment, a quantitative estimate of the probability of an adverse effect following exposure to a particular hazardous material. In other words, it is a function of hazard and exposure. However, qualitative risk assessment – where exposure and hazard information are not combined into a final risk estimate or when the risk estimate is qualitatively described is also sometimes conducted.

In the risk assessment literature, "hazard assessment" is defined as:

> A process designed to determine the possible adverse effects of an agent or situation to which an organism, system or (sub) population could be exposed. The process includes hazard identification and hazard characterization. The process focuses on the hazard in contrast to risk assessment where exposure assessment is a distinct additional step (OECD, 2003).

Where "hazard identification" is:

> The identification of the type and nature of adverse effects that an agent has an inherent capacity to cause in an organism, system or (sub) population. Hazard identification is the first stage in hazard assessment and the first step in the process of Risk Assessment" (OECD, 2003).

And "hazard characterization" is:

> The qualitative and, wherever possible, quantitative description of the inherent properties of an agent or situation having the potential to cause adverse effects.

Hazard characterizations can include a dose-response assessment and its attendant uncertainties.

Chemical assessments discussed in this background paper do not tend to include considerations of dose-response (though dose response may be inherent in some categorization) or exposure but rather the inherent hazards of the substance that could give rise to adverse effects under specific conditions. While it is clear that different uses of a substance pose differing levels of risk, very few of these systems consider calculated risk in their comparisons, though some do consider qualitatively defined use (use categories, high/low use, etc.).

Appendix 2. Quick Scan criteria template for classifying substances according to hazardous properties on the basis of hazards posed to the environment and (in)direct hazards for humans

Note in the table below that the lower the hazard level number, e.g., "P1," the higher the level of hazard; and vice-versa, the higher the number, e.g., "P4," the lower the level of hazard.

Quick Scan criteria template

Property	**Hazard Level**	**Criteria**
Persistence (P)	P1	
	P2	
	P3	
	P4	
Bioaccumulation (B)	B1a	
	B1b	
	B2	
	B3	
	B4	
(Eco)Toxicity (T)	T1	
	T2	
	T3	
	T4	
Property	**Hazard Level**	**Criteria**
Toxicity for Humans (He)	G1	
	G2	
	G3	
	G4	
Carcinogenicity (C)	C1	
	C2	
	C4	
Mutagenicity (M)	M1	
	M4	
Reprotoxicity (R)	R1	
	R2	
	R4	
Hormone Disruption (Ho)	H2	
	H4	

Source: SOMS, 2001, p.36

Appendix 3. Quick Scan Decision Making Rules for PBTs and Human Health Hazards

Quick Scan Decision-Making Rules for PBTs

Hazard Class	Hazard Class	T1	T2	T3	T4
P1	B1a	VHC	VHC	VHC	VHC
	B1b	VHC	VHC	HC	C
	B2	HC	HC	C	LC
	B3	HC	C	C	LC
	B4	HC	C	C	LC
P2	B1	HC	HC	C	C
	B2	HC	HC	C	LC
	B3	C	C	C	LC
	B4	C	C	C	LC
P3	B1	HC	C	C	LC
	B2	C	C	C	LC
	B3	C	C	C	LC
	B4	C	C	C	LC
P4	B1	HC	C	C	LC
	B2	C	C	C	LC
	B3	C	C	C	LC
	B4	C	C	LC	LC

Abbreviations:
P = Persistence
B = Bioaccumulation tendency
T = Eco-toxicity
VHC = Very High Concern
HC = High Concern
C = Concern
LC = Low Concern

Source: SOMS, 2001, p.38.

Quick Scan Decision-Making Rules for Human Health Hazards

Hazard Class	Hazard Class	Category of Concern
G	G1	VHC
	G2	HC
	G3	C
	G4	LC
C	C1	VHC
	C2	HC
	C4	LC
M	M1	VHC
	M4	LCH
R	R1	VHC
	R2	HC
	R4	LC
H	H1	HC
	H4	LC

Abbreviations:
G = Toxicity to Humans
C = Carcinogenicity
M = Mutagenicity
R = Reprotoxicity
H = Hormonal disruption
VHC = Very High Concern
HC = High Concern
C = Concern
LC = Low Concern

Source: SOMS, 2001, p.39.

Appendix 4. P2OASys Algorithm Table.

Standardized Hazard Score Database						
		Score				
	Units	2	4	6	8	10
Worker Exposure and Protection						
Exposure Potential	1,2,3	1		2		3
Worker Training / Education	1,2,3	1		2		3
Personal Protective Equipment	1,2,3	1		2		3
Acute Human Factors						
TLV/PEL	mg/m3 or ppm	200	100	25	5	<5
IDLH	ppm	1000	500	50	10	< 10
Oral LD 50	mg/kg	5000	500	50	5	< 5
Inhalation LC 50	ppm	10000	1000	150	15	< 15
Respitatory Irritation	1,2,3	1		2		3
Dermal Irritation	1,2,3	1		2		3
Eye Irritation	1,2,3	1		2		3
Chronic Human Effects						
Reference Dose (RFD)	mg/kg/day	0.1	0.05	0.01	0.001	< 0.001
Carcinogen Rating	IARC/EPA Class	4,E	3,D	2B,C	2A,B	1,A
Respiratory Sensitivity / Disease	1,2,3	1		2		3
Reproductive Effects	1,2,3	1		2		3
Other Chronic Organ Effects	1,2,3	1		2		3
Physical Hazards						
Noise Generation (dBA)	dBA	80	85	85	90	>90
Repetition	1,2,3	1		2		3
Vibration	m/S2	4	6	8	12	>12
Heat (Thermal Stress)	WBGT, Degrees C	25	27	30	32	>32
Lifting Hazard	1,2,3	1		2		3
Materials Handling	1,2,3	1		2		3
Psychosocial Hazard (Stress)	1,2,3	1		2		3
Chemical Hazard						
Vapor Pressure	mmHg	0.1	1	10	100	>100
Flash Point	Degrees C	100	75	25	10	<10
NFPA Reactivity	0,1,2,3,4	0	1	2	3	4
NFPA Flammability Rating	0,1,2,3,4	0	1	2	3	4
pH (units)	ph units	7	6-7,7-8	5-6,8-3	3-5,9-11	1-3,11-14
High Pressure System	1,2,3	1		2		3
High Temperature System	1,2,3	1		2		3
VOC	1,2,3	1		2		3

Persistence/Bioaccumulation						
BOD Half-Life	days	4	10	100	500	>500
Bioconcentration Factor	kg/l	10	100	200	1000	>1000
Atmospheric Hazard						
NESHAP Listed	1,3	1				3
Greenhouse Gas	1,3	1				3
Ozone Depleter	ODP Units					
Observed Ecological Effects	1,2,3	1		2		3
Disposal Hazard						
EPCRA RQ	lbs	5000	1000	100	10	1
Recyclable	1,2,3	1		2		3
Consumer Hazard	1,2,3	1		2		3
Energy and Resource Use						
Non-Renewable resource	1,2,3	1		2		3
Water Use	1,2,3	1		2		3
Energy Use	1,2,3	1		2		3

Appendix 5. List of Potential Hazard Endpoints for Chemicals

Chronic Toxicity
- Carcinogenicity
- Mutagenicity
- Reproductive/developmental toxicity
- Teratogenicity
- Neurotoxicity
- Endocrine disruption
- Respiratory sensitization/disease
- Other chronic organ effects (liver, kidneys, heart, etc.)

Acute Toxicity - Humans
- Dermal irritation
- Respiratory system irritation
- Skin absorption
- Occular irritation
- Poisoning potential

Atmospheric Hazards
- Global warming potential
- Ozone depletion potential
- Acid rain formation

Chemical Properties
- Corrosivity
- Flammability
- Reactivity

Ecological Toxicity
- Aquatic toxicity - acute
- Aquatic toxicity - chronic
- Eutrophication

Persistence

Bioaccumulative capacity

Hazard Data are Missing

Appendix 6. 12 Principles of Green Chemistry

By: John Warner and Paul Anastas

Prevent Waste (Principles #1,#5-#7, #11)

- Prevent waste: Design chemical syntheses to prevent waste, leaving no waste to treat or clean up (Principle #1).
- Use catalysts, not stoichiometric reagents: Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once. (Principle #5).
- Avoid chemical derivatives: Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste (Principle #6).
- Maximize atom economy: Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms (Principle #7).
- Analyze in real time to prevent pollution: Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts (Principle #11).

Little to No Toxicity (Principles #2,#3,#8,#10)

- Design safer chemicals and products: Design chemical products to be fully effective, yet have little or no toxicity (Principle #2). Design less hazardous chemical syntheses: Design syntheses to use and generate substances with little or no toxicity to humans and the environment (Principle #3).
- Use safer solvents and reaction conditions: Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals (Principle #8).
- Design chemicals and products to degrade after use: Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment (Principle #10).

Renewable Materials (Principle #4)

- Use renewable feedstocks: Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined (Principle #4).

Energy Efficiency (Principle #9)

- Increase energy efficiency: Run chemical reactions at ambient temperature and pressure whenever possible (Principle #9).

Accident Prevention (Principle #12)

- Minimize the potential for accidents: Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment (Principle #12).

Chemicals Assessment Workgroup Summary:

Designing Safer Alternatives: Chemicals, Materials + Products

Overview

Alternatives assessment methods need to:

- Provide a flexible, holistic analysis of alternatives and opportunities which prevent impacts from potentially harmful activities.
- Focus on solutions rather than problems; opportunities rather than inevitabilities.
- Drive governments or proponents of an activity to focus on solutions rather than the “acceptability” of potentially harmful activities.
- Avoid never-ending discussions of “how risky.”
- Stress that uncertainties should be made explicit.
- Transparent & inclusive -- involve stakeholders, including for advice on endpoints
- Clearly state the reason for the process, including “Prevent potentially harmful impacts.”
- Address risk shifting.
- Emphasize the full range of alternatives, including how to deliver the desired function.
- Include stakeholder advice on endpoints.
- Values need to be explicit.

Existing Approaches to Chemicals Assessment

A few approaches were discussed at the meeting, including:

- PRIO Tool developed by the Swedish Chemicals Inspectorate recommends phasing out high priority chemicals such as PBTs to achieve non-toxic environment.
- U.S. EPA: New chemical substances program evaluates 1500-2000 chemicals per year. Have reliable approaches for evaluating many hazard endpoints, including persistence, bioaccumulative capacity, aquatic toxicity, carcinogenicity, and reproductive toxicity. For other endpoints, such as endocrine disruption, evaluation methods are less developed.
- P_2 OASYS (Pollution Prevention Options Analysis System) allows user to weight data as desired. Qualitative data may be as important as quantitative data. Start with disaggregated data that users / stakeholders can aggregate as needed. A value of P_2OASYS is that toxics use reduction should not shift risks, e.g., from the environment to workers.

Defining Appropriate Methods & Tools

- Eliminate PBTs at the beginning. PBTs are high priorities for elimination.
- Start with disaggregated data that users / stakeholders can aggregate as needed.

- Only aggregate data if absolutely necessary.
- Priorities, and therefore weighting, will vary across methods and end users.
- Aggregation methods need to be flexible to meet the needs of different analysts & decision makers.
- Methods should help guide and promote safer design.
- Design challenge: durable in product but degrades in the environment

Values

- Incorporate social as well as environmental dimensions into alternatives assessment methods. Need to explicitly acknowledge that future generations matter, and we need to make changes for them. For example, the Swedish generational goals for environmental protection.
- Provide full disclosure of chemicals in products. People -- including retail consumers and institutional purchasers -- need the information to make better choices.
- Responsibility to act when clear evidence of harm.
- Reduce exposure whenever possible.
- Outcomes from alternatives assessments should not shift risks.
- No inherent right for hazardous substances to be in commerce
- Tools should foster substitution policies.
- Be transparent about value judgments.

Define Positive Criteria

- Define positive criteria for green chemicals, e.g., 12 Principles of Green Chemistry.
- Evaluate positive criteria against use data to see what chemicals meet the criteria.
- Beware of saying something is "safe" it can only be "safer" in meeting specified criteria.
- Work to identify chemical structures that are likely to be "safer."
- Ultimately "positive criteria" are a mix of positive and negative criteria.
- Negative lists are useful for the worst chemicals.
- "GRAS" (Generally Recognized As Safe) list -- used for food safety -- is an example of a list of safer chemicals
- For positive lists need assurance that the chemical has been adequately tested.
- Disadvantage of short negative lists, such as PBTs, is that chemicals not on list are assumed to be safer, when they may not have been tested.

Next Steps

- Develop transparent, web-based tool, where data can be accessed by chemical or endpoints of concern (e.g., carcinogenicity).
- Require full chemical disclosure -- listing of chemicals in products -- by vendors.
- Compile list of all tools discussed at the meeting, their uses and limitations.

- Create a central, online depository of case studies and resources on alternatives assessment from all over world; including experiences and case studies from non-English speaking countries. Existing resources include: OECD database portal of EU +
- US databases (in development), EUCLID database, Pesticide Action Network (PAN), website of 500 worker safety and health cases already developed for Europe.
- Provide list of lists (e.g., carcinogenicity lists) that would be helpful for non-specialists.
- Identify training for companies on tools.
- Develop tools for iterative learning and improvement.

The "current patterns of material production, use, and disposal cannot continue unaltered if we wish to ensure an ample and safe array of materials for the future. These patterns are simply not sustainable. We need to use fewer materials and we need to be more careful about what kinds of materials we use."
Kenneth Geiser, 2001, Materials Matter (p.390)

Everyday the natural cycle of materials showcases a sustainable materials economy. Trees create wood from sunlight, soil, atmospheric gases. They release needed oxygen into the air. And they decompose into healthy nutrients for soil. The challenge for humans is how to transform our environmentally unsustainable material economy to better mimic nature. Actions necessary for transitioning to environmentally sustainable materials include:

- closing the loop on materials flows,
- increasing the intensity of materials use (use less material per product),
- substituting services for products (less material demand),
- reducing the dissipation of toxic chemicals from materials,
- reducing the use of materials that contribute to the formation of persistent, bioaccumulative, and toxic chemicals, and
- developing more environmentally appropriate materials (see Geiser, 2000, p.368).

The role of material assessments is to help decision-makers identify the materials that will move humans to a more environmentally sustainable economy. Materials are defined in this paper as: "the basic matter (as metal, wood, plastic, fiber) from which the whole or the greater part of something physical (as a machine, tool, building, fabric) is made."[10] Material assessments for the environment are methods that identify and evaluate the environmental and human health hazards associated with materials across their life cycle.

The methods for performing material assessments are still in their infancy of development. This paper presents two material assessment methods. One has its roots in chemical hazard assessments, and has been called by McDonough and Braungart, "material assessments." Another has its roots in systems thinking, and is called "materials flow analysis."

[10] G&C Merriam Company, 1976, *Webster's Third New International Dictionary* (Springfield, MA: G&C Merriam Company).

1. Material Assessments (as rooted in chemical hazard assessments)

As governments require manufacturers to take responsibility for their products at the end of their useful lives and as consumers challenge manufacturers to be better environmental stewards, manufacturers are assessing the environmental performance of the materials they use. The auto sector is an example of the emerging trend in material assessments and change.

The Ford Motor Company, for example, has committed to using more sustainable materials:

"The Model U [prototype vehicle] is helping to encourage development of materials that are safe to produce, use and recycle over and over again in a cradle-to-cradle cycle. These materials never become waste, but instead are nutrients that either feed healthy soil or the manufacturing processes without moving down the value chain" (Ford Motor Company, *2002 Corporate Citizenship Report: Our Principles, Progress and Performance*, p.72).

Similarly, Toyota has committed to the:

- "Reduction of substances of environmental concern (SOCs) [such as lead]"
- "Use of recycled material".
- "Use of renewable resources (plants, etc.)" (Toyota, 2003. Toyota, *Environmental & Social Report 2003*, p. 36).

These three areas -- chemical hazards, end-of-life use options (recyclability and degradability), and renewable inputs -- frame how firms are approaching material assessments for the environment.

McDonough Braungart Design Chemistry (MBDC) has taken a lead role in defining a method for transitioning from chemical hazards to material hazards, calling their method a "materials assessment protocol." At the heart of MBDC's materials assessment protocol is its "chemical assessment" screening tool, which screens chemicals into categories of green, yellow, red, and orange depending upon the hazards associated with the chemical (see Appendix 7) (McDonough, et al., 2003).

Companies like the furniture maker Herman Miller begin with MBDC's chemical assessment tool to evaluate the chemical hazards of a material, extend it to include recyclability and recycled/renewable content at the material level; and extend it to the product level to include disassembly (McDonough, et al., 2003).

The MBDC chemical assessment method mirrors other chemical hazard assessment screening methods discussed in the "Chemical Hazard Assessment" background paper included for the Lowell Workshop. Being a proprietary database and method, the algorithms used by MBDC to screen chemicals and materials into the different color codes are not publicly available. [Note: Lauren Heine of GreenBlue will present on the MBDC method at the Lowell Workshop.]

Another method developed for companies and governments to benchmark movement towards sustainable materials is the system conditions of The Natural Step. These systems conditions define basic properties of a material for it to be compatible with sustainability and set forth a benchmark or goal of the ideal materials from which a firm or government can "backcast" to determine if materials choices are going in the direction of sustainability. These systems conditions are defined as:

In a sustainable society, nature is NOT subject to systematically increasing:

- Concentrations of substances extracted from earth's crust.
- Concentrations of substances produced by society.
- Degradation by physical means.
- And in that society human needs are met worldwide.

To our knowledge The Natural Step has yet to translate these system conditions into a method for evaluating materials.

Other material assessment methods are in use or under development. Unfortunately, for many of these methods only the end results are available, not the specific methods used. Examples include the Greenpeace "Plastics Pyramid" (see Section 1.1 below) and the Opel, a General Motors subsidiary, plastics recyclability assessment (see Section 1.2 below). [Note: Mark Rossi of Clean Production Action and a research fellow at the Lowell Center of Sustainable Production will present at the Lowell Workshop a draft materials assessment method under development for the City of San Francisco.]

The next three sections address the three core areas of material assessments: chemical hazards, end-of-life use options (recyclability and degradability), and renewable inputs.

1.1. Evaluate the Environmental and Human Health Hazards of a Material across its Life Cycle

Evaluating the environmental and human health hazards of a material involves some or all of the following steps:

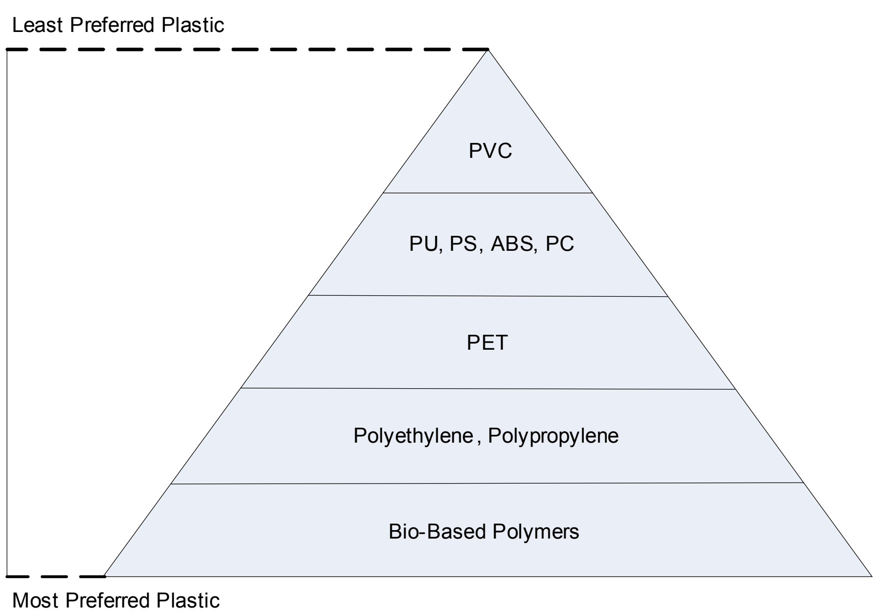
1. identify the material's chemical constituents,
2. evaluate the inherent hazards associated with each chemical constituent (i.e., perform a chemical hazards assessment for each of those constituents),
3. identify and evaluate the pollutants that arise from the
   a. extraction,
   b. production,
   c. use, and/or
   d. disposal of the material, and
4. finalize the assessment for the material based upon all chemical constituents.

From this context, a hazard assessment for a material differs from a chemical hazard assessment because it includes pollutants that arise across the material's life cycle as well as the multiple chemicals that constitute a material.

For example, as part of its design for environment program the office furniture maker Herman Miller evaluates the potential hazards of its materials by first identifying all the chemical constituents that are present in each material at amounts of greater than or equal to 100 parts per million. Then, using the McDonough Braungart Design Chemistry (MBDC) Protocol, Herman Miller evaluates the hazards associated with each chemical. The combination of the hazards of each chemical in the material is aggregated to develop a "material hazard assessment" color score: green (environmentally preferable), yellow (moderate hazard), red (high hazard), or orange (no or missing data). It is unclear whether the final material color score incorporates life cycle concerns associated with the chemicals in the material.

An example of an outcome of a material assessment is Greenpeace's "plastics pyramid." Greenpeace assessed a handful of commodity plastics based upon the life cycle hazards -- chemical hazards associated with production, use, and disposal. The result is the Plastics Pyramid, which divides plastics into five levels (see Figure 4) with bio-based plastics ranked most, and PVC ranked least, environmentally preferable. The algorithms or decision-making criteria used to separate plastics into the different levels are not specified (see Van Der Naald and Thorpe, 1998).

Figure 4. Plastics Pyramid (developed by Greenpeace)



ABS = acrylonitrile butadiene styrene; PC = polycarbonate; PET = polyethylene terephthalate;
PS = polystyrene; PU = polyurethane; PVC = Polyvinyl chloride

Source: Van Der Naald and Thorpe, 1998

1.2. Evaluating Generic End-of-Life Material Options: Recyclability and Degradability

The ideals for end of life material handling are:

- reuse the material in or as the same product (the reusable glass beverage bottle),
- recycle the material in a closed loop (from aluminum can to aluminum can), or
- biodegrade the material into healthy nutrients for the soil.

Since a material is part of a product at the end of its useful life, end of life material handling options ultimately depend upon the product it is contained in. This is especially true of product reusability, which is a function of both product and material. Additional product-specific factors include the ease of separating a material from the product (product disassembly) and the ability to recycle the material back into the same product (closed-loop recycling).

Yet there is general data on the end of life handling of materials that is relevant for distinguishing among materials. For example, the generic recyclability of a material is a function of the properties of the material, the consistency (i.e., similarities or differences) of a material's composition in the market economy, the level of contamination or degradation of the material in a product, value of the material as a recycled commodity, and existing infrastructure for recycling the material. All of these factors contribute to an overall data point for a material: its annual recycling rate -- expressed as a percent of the material recycled in relation to a nation's or region's total disposal (or consumption) of the material.

As European and Japanese manufacturers are required to take back their products, they are evaluating the generic recyclability of the materials they use. Opel, for example, evaluated the recyclability of plastics used in its vehicles. The outcome of Opel's analysis is contained in **Table 6**. The criteria Opel used to develop its plastics recyclability hierarchy are not publicly available.

Table 6. Opel Priority List for Plastics with regard to Recycling Aspects

Prefer		
Increasing Priority	▲	Polypropylene, Polyethylene
	▲	Polyoxymethylene (POM), Polyamide, Thermoplastic Urethane (TPU)
	▲	Acrylonitrile Butadiene Styrene (ABS), Polymethylmethacrylate (PMMA, i.e., acrylic), Styrene Maleic Anhydride (SMA) copolymer, Acrylonitrile Styrene Acrylate (ASA), Styrene Acrylonitrile (SAN)
	▲	Polycarbonate, Polyethylene Terephthalate (PET), Polybutylene Terephthalate (PBT)
	▲	Thermoplastic Elastomer (TPE)
	▲	Polyurethane
	▲	Sheet Molding Compound (SMC), Phenol-Formaldehyde (PF)
	▲	Elastomer
	▲	Polyvinyl Chloride (PVC)
	▲	Mixture of incompatible materials
Avoid		

Source: Opel Environmental Report 2000/2001

In addition to selecting for recyclable materials, manufacturers are selecting for biodegradable materials. Toyota, Steelcase (through its Designtex subsidiary), and Herman Miller are among the firms selecting for materials -- primarily fabrics -- that are biodegradable. Polylactic acid, a polymer made from plant sugars (e.g., corn or sugar beets), is at the core of many of these new biodegradable fabrics.

Criteria for assessing the biodegradability of materials are established by standard setting organizations, including the American Society for Testing and Materials (ASTM) in the U.S., the European Committee for Standardization in Europe, and the International Standards Organization (ISO) which reconciles differences among these and other standard setting organizations. For example, the ASTM has established definitions and criteria for evaluating the biodegradability of a plastic material. ASTM defines "biodegradable plastic" as a plastic "in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae" (Stevens, 2002, p.74).

1.3. Evaluating Renewable Inputs

The use of renewable (and degradable) materials is on the rise as noted above in the case of polylactic acid. Polylactic acid is an example of a plastic made from renewable resources rather than non-renewable, fossil fuel-based petrochemicals. While renewable/bio-based materials have advantages over petrochemicals, their life cycles still pose environmental (and occupational) challenges. Farming has its own set of environmental impacts, including: sufficient land space, habitat degradation; soil erosion; and fertilizer, pesticide, and genetically modified organism (GMO) use. In addition, natural materials can cause/exacerbate allergic reactions, as is the case with powdered latex gloves.

Criteria need to be developed for defining environmentally sustainable renewable materials. At this juncture in materials development, where manufacturers are returning to renewable feedstocks for material, there is need to link material assessments with developments and research in the sustainable agriculture community.

2. Material Flow Analyses

Material flow analysis is the quantitative evaluation of the movement of materials through different levels of the economy, ranging from an individual production facility to a nation-state to the global economy. Depending on the purpose of the analysis, it may include inputs, outputs, or both inputs and outputs.

Material flows inform us about trends in material use, scarcity of materials, efficiency of materials use, and potential adverse environment effects of materials use (Matos and Wagner, 1998). For example, at the macro-level of national economies, material flow analyses over time show a clear trend away from renewable materials -- which were the dominant materials in the American economy until the turn of the 20th century -- to non-renewable materials in the 20th century (Matos and Wagner, 1998). At the production level, a materials balance model can be applied at the level of a manufacturing facility where: raw materials + energy in = finished products and byproducts out (Geiser, 2000, p.58).

For individual or groups' of firms making a material choice, the scarcity / abundance of a material in the economy matters. For example, the electronics sector is evaluating the material flows for silver to better understand the consequences of shifting from lead-based solder to a solder that contain silver.

As a method, material flow analysis benefits from the decades-long collection and assessment of material flow data by government agencies (such as the U.S. Geological Survey) and by the more recent activities of organizations like the Wüppertal Institute (Germany) and the World Resources Institute (U.S.) to clarify terms and methods. [Note: Fran Irwin of the World Resources Institute will present on WRI's material flow analysis method at the Lowell Workshop.] Box 0 details some of the common terms and definitions that are emerging in the field of material flow analysis. The methodological development surrounding material flows is more mature than material assessments, with common framework language and methods for calculating flows.

Examples of the findings from economy-wide material flow analyses include:

- The retention time of materials in the economy is a critical variable affecting material flows. Roughly 50%-75% of direct material inputs pass through the economy and into the environment in less than one year (Matthews, et al., 2000, p.6).
- The "extraction and use of fossil energy resources dominate output flows in all industrial countries" (Matthews, et al., 2000, p.xii). "Emissions from all fuel combustion account for between approximately 80 and 90 percent of domestic processed output in the study countries" (Matthews, et al., 2000, p.23). "The role of energy consumption is central, given the dominance of carbon dioxide emissions in DPO across virtually all sectors" (Matthews, et al., 2000, p.24).
- Germany has reduced CO_2 emissions by improving energy efficiency and reducing its use of high carbon lignite fuels (Matthews, et al., 2000, p.21).

Box 0. Material Flow Analysis: Sample Definitions of Terms

TMR The Total Material Requirement for a national economy is the "sum of the direct material input [DMI] and the hidden or indirect material flows, including deliberate landscape alterations." "The hidden material flows are the portion of the total material requirement that is not included in the commodity itself. The hidden material flow of primary materials comprises two components: ancillary flows and excavated or disturbed flows" (Schütz and Welfrens, 2000, pp.16-17).

DMI Direct Material Input = domestic extraction + imports (Matthews, et al., 2000, p.5).

DPO Domestic Processed Output = DMI – (Net Additions to Stock – Exports). DPO is the "total weight of materials, extracted from the domestic environment and imported from other countries, which have been *used in the domestic economy*, then flow to the domestic environment" (Matthews, et al., 2000, p.7)

To evaluate the material flow profiles of specific products the Wuppertal Institute developed the analytic concept of Material Input Per Service unit or MIPS. MIPS is a "proxy for the quantitative dimension of the ecological impact potential of human activities. MIPS is calculated over the whole life-cycle of goods and adds up to the overall material input which humans move or extract for the production of products and the delivery of services" (Stiller, 1999, p.5). The material inputs included are:

- Abiotic raw materials, including minerals, ores, fossil fuels, and overburden from mining operations.
- Biotic raw materials, including products of agriculture, forestry, and biomass that is cut but not used during processing.
- Erosion, which reflects the quantitative dimension of change to nature due to agriculture and forestry.
- Water flows, including extraction of ground and surface water, cooling water, and water for irrigation.
- All air chemically processed or converted into another physical state. "This figure is strongly correlated with the CO_2-emissions as principal gaseous output of processes" (Stiller, 1999, p.6).

The per service unit varies depending on the product. For example, the per service unit for a catamaran passenger ship (a ferry) is: "300 days per year, 10 hours per day, for a period of 35 years" (Stiller, 1999, p.26).

In a product with a long use life, especially one like a catamaran that impacts energy use, energy consumption over the life of a product emerges as the principal factor affecting MIPS. "Obviously, accumulated material input [from energy consumption] during operation is far larger than [material input] during production" (Stiller, 1999, p.26). Thus the lightest weight material for making hulls (a composite plastic that included glass fibers for reinforcement), which led to a smaller engine design, performed better on MIPS than aluminum or steel (Stiller, 1999).

Material flow analyses can influence material choices by defining the relative material intensity of inputs/outputs for a product and the relative abundance/scarcity of a material. Material flows do not touch upon the hazards associated with a material's chemical constituents, rather they reflect the mass of material used and consumed within a given system.

3. Material Flow Analyses and Material Assessments

The MBDC color-coded materials assessment, the Greenpeace Plastics Pyramid, and the Opel recyclability table all illustrate the explanatory power of a material assessment: to create guides for selecting more sustainable materials. And material flow analyses illustrate the power of understanding the sources of the greatest mass, both in terms of inputs and outputs, within the economy.

The MIPS assessment of materials used to make the hull of catamarans demonstrates, however, a concern with generic material assessments: they fail to address issues that arise during the use of a product, especially energy consumption, which may lead to environmentally less preferable decisions.

The MIPS catamaran hull example from above demonstrates the need to re-think life cycle comparisons of materials. If analysts choose to compare materials with different energy consumption profiles during product use (when energy use is the dominant factor affecting outcome), then the answer is clear: the material with the best energy performance (during product use) will likely be the environmentally preferable material.

The inclusion of energy consumption during use is an important criterion for evaluating materials. If it is the most important factor affecting a product's environmental profile, then the energy profile of a material must be controlled. For example, if minimal or even maximum energy performance specifications are defined in advance of a material assessment, then only materials/products that met the pre-specified level of energy performance would be evaluated. Then the question becomes which materials/products (that achieve the specified level of energy performance) have the best the environmental performance.

In addition, we need to develop methods that allow for comparing the performance of similar materials to each other, with the goal of moving to sustainable materials by type (which was the goal of both Opel's and Greenpeace's analyses of plastics). For example, we need to define the criteria for what is a more sustainable plastic and a sustainable metal. Thus if we want to select for lightweight materials, let us develop criteria that allow for comprehensive comparisons of plastics (and other relevant materials). Or if we want to select for closed loop recyclable materials, let's develop criteria that allow for comprehensive comparisons of metals (and other relevant materials).

Missing from both material flow analyses and material assessments is addressing how economies transition from interlocking material systems. For example, the production of PVC plastic depends upon chlorine gas as one of its feedstocks. Chlorine gas is the byproduct of the splitting of salt water to create sodium hydroxide. PVC is the largest material sink for chlorine. Thus an economy in transition away from PVC would need to address how it produces sodium hydroxide and/or how it disposes of unwanted chlorine gas from the manufacture of sodium hydroxide. The same issue exists for many metals, such as lead, whose material cycle is interwoven with the extraction of other metals.

4. References

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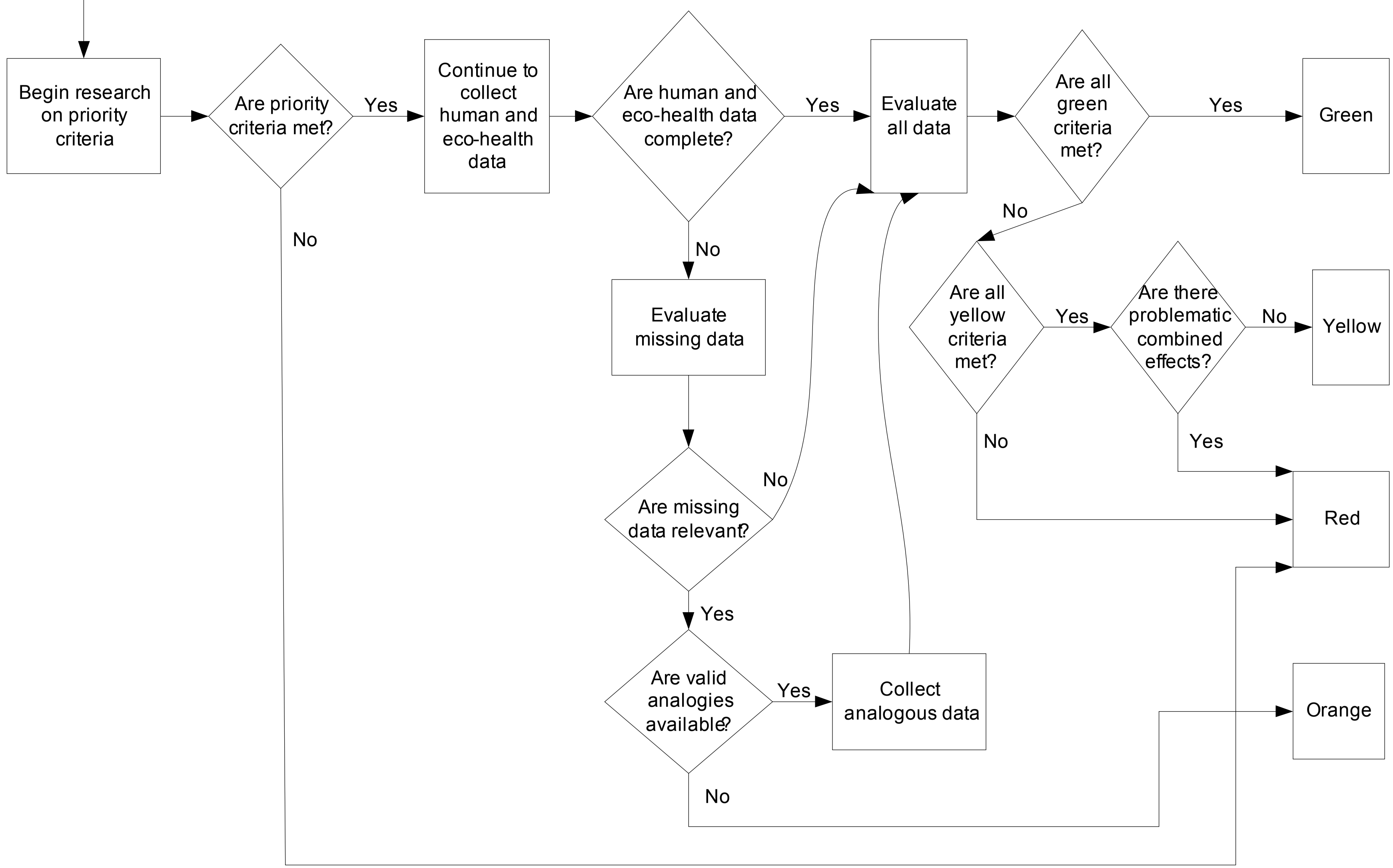
Appendix 7. MBDC Chemical Assessment Screening Method



Materials Workgroup Summary:

Designing Safer Alternatives: Chemicals, Materials + Products

Potential Evaluation End Points for Materials

- Rate of flow in comparison to natural systems
- Environmental impacts from extraction, manufacturing, and disposal
- Recyclability
- Renewability
- Degradability
- Distance materials travel to end use
- Unintended impacts on other parts of the system
- Flows: water flow, overburden from mining
- Maintenance of materials, especially building materials
- Energy: embodied energy and consumption of energy
- Impacts: eutrophication, ozone depletion, habitat degradation, climate change, etc.

Assessment Issues

Audience
- Environmentally preferable purchasers in large institutions
- Tool Builders - consider level of sophistication required
- Public
- NGOs
- Design Engineers

Political Context
- Policy Makers
- Activist / Lobby list Concerns

Context of Use
- Goal
- Look at material within system context
- Continual improvement opportunities

Driver for Change

Purpose of Assessment Tool
- Make Current Decisions
- Defend Our Decisions
- Drive Future Decisions

- Drive Market Change
- Frame Future Decisions

Positive Criteria for Identifying Safer Materials

- Closed loop recyclable
- Renewable material as input - sustainably grown
- Biodegradable outputs, i.e., compostable within a certain time frame
- Made with renewable energy
- Low processing impacts: emissions, energy use, other endpoints
- Climate neutral
- Suitable to application - i.e., "appropriate" to function
- Proximity of origin
- Elegance of design / manufacturing
- Favorable economics
- Positive societal impacts

Future Activities Needed

- Detail Materials Assessment Process (see flowchart at the end of this paper)
- Stakeholder Engagement
- Find Ways to Communicate Complex Ideas Simply
- Build in Flexibility to Allow for Different Valuations
- Identify Limitations
- Link Tool to Desired Output
- Define What we Consider "Appropriate"
- Develop Database of Available / Useable Information eg-Inventory Update
- Test with Case Studies
- Create a Modular set of Tools Associated with Users' Priority End Points
- Create an Array of Modules and have Different Groups Develop Them
- Show Relationship Between Flows
- Engage Regulators & Standards Setting Organizations
- Create Standard Reporting Format
- Evaluate why other models failed. Who do we leverage for effective dissemination and how? How do we assure credibility
- Ask companies what they are doing for materials assessment.
- Create standard that creates incentive to report more fully and transparently.

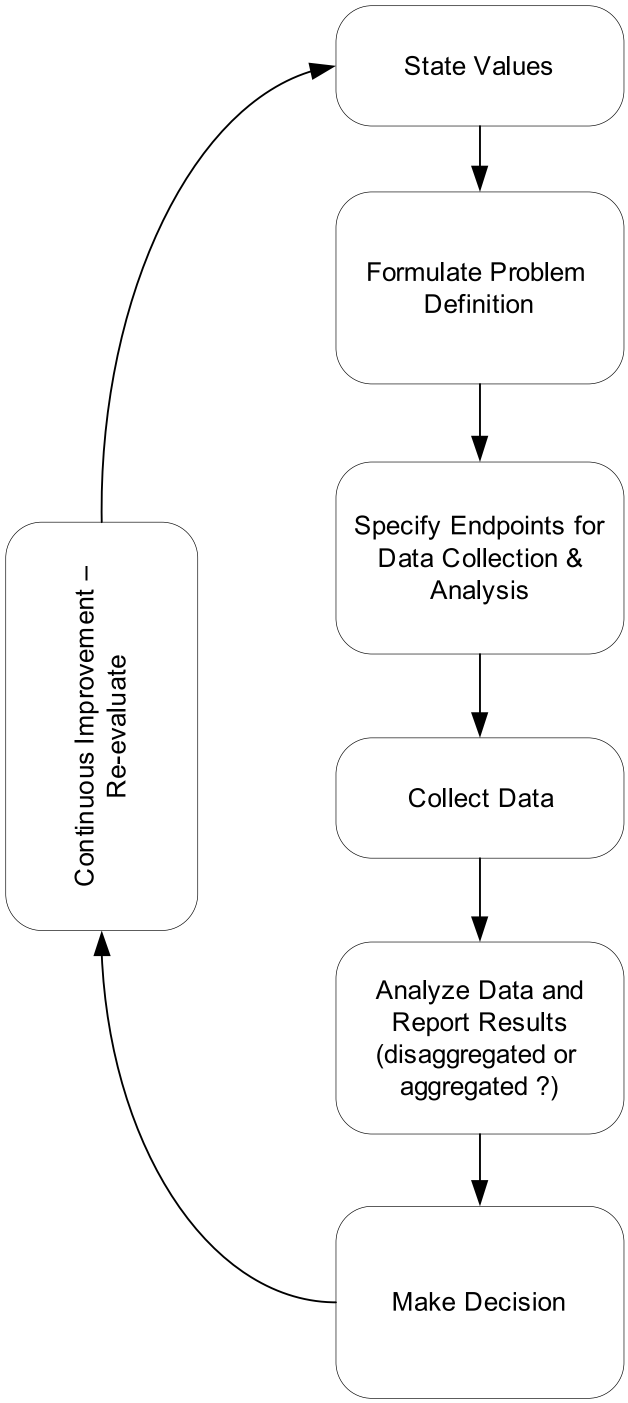
Information Sources for Evaluating Material Impacts

<u>Danish Assessment of Plastics</u>

<u>Norm Thompson Sustainability Toolkit, which includes:</u>

- materials used in Norm Thompson products
- boundaries of analysis
- criteria used to evaluate materials
- corporate values
- expert judgment

Materials Assessment Process:



Herman Miller, Collins & Aikman, Skanska, Shaw Carpets, Electrolux, Dell, Ikea, Interface, Steelcase, Boots, and Kaiser Permanente are among the firms that are evaluating the products they purchase and use for environmental performance. To better meet consumer needs, to maintain and grow market share, to enhance employee satisfaction and health, and to advance beyond regulatory compliance these firms are re-designing and re-specifying their products for the environment. They are engaged in design for environment or DfE.

DfE is any design change -- be it related to production processes, chemical selection, material selection, or product re-design (e.g., eliminate foam in office chairs) -- that improves the environmental performance of a product. The power of DfE is the focus on the design stage, the moment in a product's life when the opportunity for achieving environmental benefits is the greatest. The suite of factors encompassed by DfE is framed in the "12 Principles of Green Engineering" (developed by Anastas and Zimmerman, 2003).

A challenge businesses face in implementing DfE is finding a common method with supporting tools and databases that enable a relatively quick assessment of products and their material and chemical constituents. The lack of such a method has led many of these firms to develop, often in conjunction with consultants, their own methods for evaluating products.

Life cycle assessment (LCA) represents a well-defined, codified by the International Standards Organization (ISO) and Society for Ecological Toxicology and Chemistry (SETAC), method for evaluating the life cycle concerns. But some firms veer away from it because of costs, time, and/or concerns with the limits of the method and accompanying databases.

This background paper explores the terrain of methods to support product design for the environment, including: LCAs, current practice in firms, and eco-labeling.

5. Life Cycle Assessments (LCAs)

"Life cycle assessment" (LCA) can have different connotations depending on the user of the term, ranging from applying cradle-to-grave thinking to applying cradle-to-grave quantitative methods to product assessments. In this background paper "LCA" means the quantitative LCA method.

LCAs take a functional unit (such as a cubic meter of resilient flooring) and evaluate the outputs associated with different products (that encompass the same functional unit) across their life cycle. These quantitative outputs are often converted into a single number.

The International Standards Organization (ISO) defined LCA method has four phases: scoping, inventory development, impact assessment, and interpretation. "Scoping" is where the key facets of the study are defined, including system boundaries, environmental indicators (e.g., global warming), and functional unit. "Inventory development" is the collection of the output data from across the life of the product, including pollution from energy generation, transportation, manufacturing, use, and disposal.

"Impact assessment" aggregates all of the data into environmental impact indicators. Common indicators assessed are: global climate change, ozone depletion, smog, acidification, eutrophication, land degradation, human toxicity, and ecotoxicity. Each indicator is aggregated into a common unit. For example, global warming potential is determined by a) assigning a CO2 equivalent factor for global warming gas, b) adding up total emissions for each global warming gas, c) multiplying the gas by its CO2 equivalency factor, and d) adding up all the products for all the global warming gases to arrive at the product's (functional unit's) global warming potential. In some LCAs these indicators are "normalized" to arrive at a single number for the product. A common method for developing a reference value is to take the average yearly environmental load in a country and divide it by the country's population.[11]

Since the LCA method requires intensive data collection and manipulation, most LCAs are performed for corporations by consulting groups that have developed LCA software and gathered the data. Thus much of the data and details behind the numbers are proprietary.

The strengths of LCAs include: applying a life cycle perspective -- from cradle to grave -- to products and having very good data on emissions that relate to the consumption of energy. Since pollution from the combustion of fuels is generally well understood and documented, the calculations of environmental indicators that are heavily influenced by energy consumption -- global climate change, smog, and acidification -- are likely to be robust. In addition, equivalency factors for these indicators as well as ozone depletion are well developed; thus aggregating data into a single data point for each of these indicators is relatively straightforward. Having standardized impact factors for different materials, allows for rapid comparisons of how impacts change with changing materials. The Okala Ecological Design curriculum applies this sort of approach to assist designers in choosing less impacting materials.

The weaknesses of LCA grow as the method moves further afield of energy and ozone depletion. Factors for land use degradation, human toxicity, ecotoxicity, hazardous waste generation, and solid waste generation are poorly developed. "Human toxicity" takes multiple indicator categories -- carcinogenicity, mutagenicity, reproductive toxicity, neurotoxicity, endocrine disruption, etc. -- and lumps them into a single factor. No well established or adhered to method exists for aggregating this myriad of factors. Also, small amounts of very toxic emissions are likely to be missed altogether or discounted because their quantities are small and poorly documented.

Additional concerns with LCAs include the transparency of the method and data used, whether value-based/subjective decisions are made explicit, and the tendency of LCA practitioners to aggregate all data into a single number, which further obscures methodological choices and weighting decisions and hides the nuanced trade-offs between materials.

[11] The summary of LCA is from: Rita Schenck, "Life Cycle Assessment: the Environmental Performance Yardstick," 2002, see www.lcacenter.org.

Due to the costs, amount of time necessary to complete them, and methodological and data limitations, many firms (at least in the U.S.) engaged in assessing the environmental performance of their products decide not to use LCAs.[12]

6. Product Assessments for the Environment

Environmental assessments of products are often done outside the confines of the LCA method as defined by ISO. These assessments apply a life cycle framework, but not as specified by ISO. These approaches have been called "streamlined LCAs" because they limit the scope of the assessment.[13] To avoid confusion with the term "LCA", this background paper uses the term "product assessments for the environment" (or "product assessments" for short) rather than "streamlined LCA."

More data needs to be collected on the current state of product assessments. Two examples include the methods used by Herman Miller and Kaiser Permanente (a health maintenance organization or HMO). Kaiser Permanente now evaluates the environmental performance of many of its products, especially building products. Kaiser uses a life cycle approach when evaluating materials. The environmental criteria used by Kaiser vary depending on the product under consideration. Criteria include: life cycle hazards associated with product content (product inputs), sustainable manufacturing practices (of the product supplier), indoor air quality (VOCs), recyclability, product maintenance/use concerns, renewable content, green innovation, and occupational concerns. The data complied for all the criteria (for a product) are evaluated and ranked by a team of experts (internal and external to Kaiser). [Note: Lynn Garske will present the Kaiser method at the workshop.]

Herman Miller has three core analytic elements in its DfE program:

1. Chemical hazards assessment for each material
2. Recyclability / recycled content assessment for material / product
3. Disassembly assessment for each component of the product

The first two elements were described in the "materials assessment white paper." The third, "disassembly," is the time it takes for an experienced disassembler to break down the product into its constituent parts. Each of these three analytic elements is rated and weighted. Material and design selections are made that reduce the chemical hazards of materials (no "red" materials based on the MBDC protocol), increase the recyclability and recycled content of products, and enhance disassembly rates. Herman Miller has not performed an LCA for its product or for products from its suppliers.

[12] Graedel, TE, BR Allenby, and PR Comrie, 1995, "Matrix Approaches to Abridged Life Cycle Assessment," *Environmental Science and Technology*, vol. 29, no. 3: 134A-139A.
[13] For example, see Todd, JA and MA Curran (eds.). 1999. Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup.

7. Eco-labels

Eco-labels define the criteria for environmentally friendly products. Eco-labels include Green Seal (U.S.), Scientific Certification Systems (U.S.), Blue Angel (Germany), Nordic Swan (Nordic countries), European Flower (European Union), and Eco Mark (Japan). The criteria for any product include life cycle concerns, ranging from sources of energy to chemical content (including no persistent, bioaccumulative toxics such as mercury; and low to no volatile organic compounds -- VOCs) to material content (including recycled content, recyclability, and renewable materials) to pollutants. The methods used to evaluate products can vary both within and across the various eco-labeling programs.

The Blue Angel, for example, "does not always consider complete environmental impacts during the use life cycle of a product, but sets a focus on a 'main reason for award.'"[14]. This approach leads to a methodology and criteria that differ across product groups.[15]

Another example is the Nordic Swan, which is "based on ISO standards 14020 and 14024 which define general conditions and procedures for the development of environmental labels considering the whole life cycle of a product."[16]

Eco-labels enable firms to benchmark their products to a certain level of performance. To the extent that any chemical or material is not covered by an eco-label, the labeling criteria do not assist in making chemical or material selections for a product. In addition, because eco-label criteria must be agreed to by a group that may include businesses with an economic interest in the criteria, debates on "whether a whole group of substances or materials should be excluded from a labelled product (e.g. brominated flame retardants in general) is often a very difficult point before label criteria are finally agreed upon by all parties involved."[17]

8. In Conclusion

The scope and complexity of product assessments can be intimidating to even for firms with substantial resources. In developing "quick scan" methods for products we need to begin exploring the development of common language and criteria for performing these assessments. Similar questions as raised in quantitative LCAs need to be answered, including:

- What's included in the assessment?
- What are the boundaries of the assessment? How far upstream and downstream from the product are environmental concerns evaluated?
- How are environmental and human health concerns addressed?
- How are data presented?
- How are data evaluated?

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[14] Ökopol and Kooperationsstelle Hamburg for the Directorate General Environment, Nuclear Safety and Civil Protection of the Commission of the European Communities, 2003, *Substitution of hazardous chemicals in products and processes* (Hamburg: DG Environment), p.51.
[15] Ibid.
[16] Ibid.
[17] Ibid., p.49.

- Are data aggregated and/or weighted?

Despite the limitations in available methodologies to assess alternative products, it is clear that product assessments should include life-cycle thinking. By this we mean:

- Consideration of the total impacts of a product, service or other activity from "cradle-to-grave" – examining the whole of its impacts;
- Consideration of the full range of inputs, outputs of direct and subsidiary processes involved in making a final product (including its packaging, transport, etc.); and
- Identifying opportunities throughout product life cycle for minimizing overall impacts, identifying hot-spots and avoiding trade-offs.

We look forward to addressing these substantive questions at the Lowell Workshop.

Appendix 8. 12 Principles of Green Engineering

Principle 1. Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible.

Principle 2. It is better to prevent waste than to treat or clean up waste after it is formed.

Principle 3. Separation and purification operations should be designed to minimize energy consumption and materials used.

Principle 4. Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.

Principle 5. Products, processes, and systems should be 'output pulled' rather than 'input pushed' through the use of energy and materials.

Principle 6. Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.

Principle 7. Targeted durability, not immortality, should be a design goal.

Principle 8. Design for unnecessary capacity or capability (e.g., one size fits all) solutions should be considered a design flaw.

Principle 9. Material diversity in multicomponent products should be minimized to promote disassembly and value retention.

Principle 10. Design of products, processes, and systems must include integration and interconnectivity with available energy and material flows.

Principle 11. Products, processes, and systems should be designed for performance in a commercial 'afterlife.'

Principle 12. Material and energy inputs should be renewable rather than depleting.

Source: P.T. Anastas and J.B. Zimmerman, 2003

Products Assessment Workgroup Summary:

Designing Safer Alternatives: Chemicals, Materials + Products

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Alternatives Assessment Framework

Alternatives Assessment (AA) – "Optimizing Environmental and Safety/Health performance of products and materials in specified applications. "

Also referred to in our group as: "substitution," "architecture not a hammer," "integrated product policy," "a bridge between science and values," "umbrella process," and "problem-solving approach". It was stated that "AA" is well-understood by the public more easily than "substitution".

Questions and Comments

1. Who's initiating and who's using the framework and tools? Producer, purchaser, specialist or non specialist, industrial hygienist or policymaker? Are they interested in a problem material or in designing optimized products? Does it matter who is initiating or using if the stakeholder process is robust? (See Step Two of the AA framework.)

2. How to communicate the iterative and evolving nature of the process while showing and working the framework steps. Honest statements of AA weaknesses should be connected to common goals and building trust. This is related to implementation of results.

3. Need a matrix of tools, their strengths and weaknesses, data needs, cost, comparables available.

4. For industry, innovation is an integrated process and the goal is survival.

5. Business to business markets are less about owning things than the consumer market. Functionality will be differently described.

AA Framework: Eight Step Proposal

<u>Step One - Define Function and Scope</u>
Function - Description of the product or service that defines design parameters. There are two levels - broad (e.g., floor covering) and more detailed (muffles sound, aesthetics, provides friction, etc.).

Scope - Defines the AA project. Done well, defining the boundaries can broaden thinking and inspire creativity. At first cut, who are the stakeholders and what are their issues? What are the goals of the project? For example, avoid PVC, recycle at end of life, good environmental performance, high quality, and good market potential are issues for mnaufacturers.

<u>Step Two - Create a Stakeholder Process with Clear Decision and Value Clarification Mechanisms</u>

Stakeholder - Internal and external, with careful selection of advocates who can participate, truly represent, and be empowered by their group.

Process - A controlled and facilitated program of iterative communication, relationship, and decision support. Ensure the right skills are in the room to lead this. The process involves space, time, resources, focus, crowds, and documentation.

Decision mechanism - Who decides what? When? Technical group, core group, client, etc.

Value clarification - Common understanding of criteria for decisions. This mechanism will operate throughout the project and build trust in decisions.

<u>Step Three - List Optimization Requirements</u>

Values plus criteria yield metrics. What are important issues for values and design? What other drivers are surfacing, such as regulatory concerns or new technologies? Life cycle thinking applied here.

<u>Step Four - List Alternative Product or Services</u>

Research or Brainstorm. This was offered as a chart of possibilities along two dimensions, e.g., cost and recyclability, with business parameters establishing the range.

<u>Step Five - Screen the Alternatives</u>

Make a shorter list. This was offered as a chart as described above, with selected points now defined within the range, their location yielding some useful comparisons between choices.

This is a back of the envelop, rule of thumb look at technological fit, performance, cost and effectiveness issues. It is also time to look at AA tools and resources. Consider confidentiality issues. There is a need for ways to do this quickly but with validity.

<u>Step Six - Plan the AA project</u>

Decide which AA tools and associated expertise and data are needed. This could be a big or small project.

Here is our draft list of AA tools:

Criteria Screen (PBT profiler, etc)
Black and grey lists
Check lists
Specific property measure
Risk Assessment/analysis
Life Cycle Assessment (LCA)
Screening level LCA

Comparable LCA
Labeling criteria and Labels (Might be two separate tools)
TCA
Network of experts

<u>Step Seven - Work the Tools</u>

<u>Step Eight - Determine Results</u>
Report and communicate results, and evaluate and decide to restart the process or create a label.

Alternatives Assessment Framework : Products Workgroup