SAFER CONSUMER PRODUCTS ALTERNATIVES ANALYSIS DEVELOPMENT

Developing a framework for the incorporation of life cycle considerations into Alternatives Analysis

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California Department of Toxic Substances Control

Bren School of Environmental Science & Management
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Signature Page

Safer Consumer Products Alternatives Analysis Development

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

______________________________ ______________________________

Arturo Keller Date

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Acronyms

CoC—Chemical of Concern
DfE—Design for the Environment
DMA—Dimethyl adipate
DTSC—Department of Toxic Substances Control
LCA—Life Cycle Assessment
SCP—Safer Consumer Products

Definitions

Alternatives Analysis—Systematic comparison of alternative chemicals and/or products; distinguished from an Alternatives Assessment by the inclusion of life cycle considerations.

Chemical of Concern—A chemical that has a hazard trait that can harm people and the environment.

First Stage—The screening stage of an Alternatives Analysis with a focus on: (1) identifying potential alternatives; (2) screening alternatives; and (3) identifying factors relevant for further consideration.

Responsible Entity—A manufacturer, importer, assembler or retailer for a listed Priority Product (note: only one company along a particular Priority Product's supply chain must conduct an Alternatives Analysis).

Relevant Factor—An impact that makes a significant contribution to the overall impact of the Priority Product and/or one or more alternatives or an impact for which there is a significant difference between alternatives.

Second Stage—The investigation stage of an Alternatives Analysis with a focus on: (1) thorough investigation of relevant factors; (2) final comparison; and (3) final selection decision.

Priority Product—A consumer product containing one or more chemicals that have a hazard trait that can harm people and the environment.

Abstract

The California Safer Consumer Products Regulations, passed in 2013, require manufacturers of products containing Chemicals of Concern to identify and assess potential alternatives through an Alternatives Analysis. The Regulations require the incorporation of life cycle thinking into this Analysis. Typical life cycle assessments are data-intensive; gathering data under the time constraints of these Regulations requires a screening approach to identify those areas that most contribute to a product's impacts.

This project: (1) developed a framework for incorporating life cycle thinking into a screening level Alternatives Analysis; (2) tested this framework with a case study of methylene chloride-based paint strippers and three alternatives; and (3) developed an approach for visually communicating results. The steps of the developed framework include: (1) determining the function of the product and Chemical of Concern; (2) identifying potential alternatives; (3) defining a functional unit; (4) brainstorming questions to consider; (5) conducting research; and (6) evaluating data.

While this framework is only one of many potential methods for bringing life cycle considerations into an Alternatives Analysis, it will provide guidance for practitioners unsure of how to conduct such an assessment.

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Executive Summary

Many consumer products contain chemicals that are known to be detrimental to human health and the environment. However, due to the current lack of regulation, and the lack of chemical content disclosure and consumer awareness, most manufacturers have little incentive to replace Chemicals of Concern (CoCs) with safer alternatives. AB 1879, signed into law by Governor Schwarzenegger in 2008, required the California Department of Toxic Substances Control (DTSC) to develop the Safer Consumer Products (SCP) Regulations. These Regulations established a process for identifying Priority Products—products that pose high risk to human health and the environment. The Regulations also require manufacturers to evaluate safer alternatives to these Priority Products by following an Alternatives Analysis protocol that incorporates a life cycle perspective to account for impacts throughout the production, use, and disposal of a product.

By integrating life cycle thinking into the Alternatives Analysis, manufacturers can avoid shifting environmental burdens and making environmentally unfavorable substitutions. Although well-developed guidelines exist for conducting appraisals for chemical substitutes (e.g. GreenScreen and EPA's Design for the Environment (DfE) program), and multiple case studies are available for those protocols, little guidance exists for fully incorporating life cycle considerations into a comprehensive Alternatives Analysis.

The focus of this group master's thesis project was to determine the best available methods for incorporating life cycle considerations into the Alternatives Analysis process required by the SCP Regulations. A framework for incorporating life cycle considerations was developed and tested using a case study of methylene chloride-based paint strippers and three alternatives. This report provides the objectives and significance of this project, describes the methods, results, discussion and conclusions for developing a life cycle screening approach, and provides a supplementary analysis of economic considerations. A review of relevant literature is included to provide a background on both Alternatives Assessment and Life Cycle Assessment (LCA) as they pertain to this project's development of the life cycle screening framework.

Incorporating life cycle considerations into the Alternatives Analysis involved a comprehensive assessment of available data, methods, and case studies regarding CoCs identified under the SCP Regulations. For the case study, the following actions were taken:

- Identification of methylene chloride in paint stripper as an appropriate example for the life cycle considerations case study;
- Obtainment and analysis of data and LCA methods relevant to the chosen product and potential alternatives; and

- Development of guidelines and suggestions for the incorporation of life cycle considerations into a First Stage Alternatives Analysis.

Our team researched industry, state, and international case studies of Alternatives Assessments pertaining to hazardous chemicals in products. Instances of life cycle thinking incorporated into these assessments were noted for further analysis. The team researched and assessed available methods for life cycle screening and their potential for incorporation into the DTSC Alternatives Analysis guidelines. Externalities not incorporated into companies' analysis processes were also identified and are reported in this document. Considerations for economic valuation of these externalities were explored through a cost benefit analysis and a comparison of net present value for several alternatives.

After reviewing relevant literature, the group developed a life cycle screening case study using methylene chloride in paint strippers and three potential alternatives: (1) benzyl alcohol, to represent a chemical substitution; (2) dimethyl adipate, to represent a 'green' chemical substitution; and (3) sanding, to represent a process substitution. These three diverse alternatives allowed the case study to incorporate a breadth of factors that must be considered in an Alternatives Analysis. Through the case study, key elements of life cycle consideration were identified. Important aspects of conducting an effective assessment were also identified, including:

- Ensuring that methods for research and ranking of impacts are standardized across the working group.
- Developing a systematic way to manage data gaps and uncertainty.
- Devising a system for documenting sources and specific data points.

Heat maps, modeled after examples in hazard assessments, were used to display the results of the methylene chloride case study. A heat map provides a condensed, easy to understand visualization of results from a life cycle screening. Comparing the maps by product allows for screening of alternatives that appear worse than the CoC. Alternatively, the maps can be compared by impact category (e.g. air quality) to help identify which impact categories are of the greatest concern for the product, chemical and alternatives.

To conduct the case study, a framework for life cycle screening was developed. The framework includes six primary steps:

1) Determine the function of the product and CoC
2) Identify potential alternatives
3) Define the functional unit
4) Brainstorm questions to consider
5) Research

6) Evaluate

These steps capture the need for an assessment to consider a breadth of alternatives and potentially relevant factors by requiring practitioners to assess functionality of both the product and the CoC prior to identifying potential alternatives. Defining a set quantity of a service to be delivered by a product or product system (i.e. functional unit) provides a standard for comparing impacts and exposure across alternatives. Brainstorming questions to consider prior to researching provides direction for the research and ensures that the scope of consideration includes all potentially relevant factors.

The research step of the framework contains two parts: (1) qualitative research and (2) quantitative research. Qualitative data is often more readily available and can be more easily understood by individuals new to life cycle concepts. Starting with qualitative data allows for relatively rapid data acquisition of life cycle impacts as they pertain to the product, CoC and alternatives. Quantitative data, when available, can improve the robustness of results by providing numerical data that are easier to compare directly across alternatives. When researching, it is encouraged to acquire as much quantitative information as possible, supplemented with qualitative data, and when necessary, to cycle between the two types of research to ensure that enough information is available for comparison.

The final stage of the framework requires practitioners to evaluate the compiled information and synthesize it into communicable results that allow for comparison of impacts across products. Two key aspects of the evaluation phase addressed at the end of the framework were not incorporated into the methylene chloride case study due to time and resource limitations:

1. Standardization of results by the functional unit, meaning the quantity of a chemical or product used to compare data points.
2. Normalization of results across impact categories to compare the different types of impacts.

From the case study, several key data gaps were identified, including: lack of human health data for less-studied alternatives; and lack of upstream, or pre-use phase, data (i.e. raw material extraction and production). To address lack of human health data, information from animal studies (e.g. lethal dose for rats) can be extrapolated to inform human health hazards; ideally, comparable studies should be used for all alternatives. To address the lack of data for upstream impacts, it is helpful to trace the compounds used to produce a given chemical or product and search for the impacts of these compounds. In the methylene chloride case study, data gaps in raw material extraction and production were a weakness in the results, and further research should be conducted to address these data gaps.

To complete the methylene chloride case study, additional quantitative information should be gathered to allow for standardization of results and a normalization technique should be selected to allow for comparison of results across impact categories. It is recommended that an existing normalization method, such as the US Environmental Protection Agency's (EPA's) Tool for the Reduction of Chemical and other environmental Impacts (TRACI), be adapted to fit the SCP requirements for consideration and be used to improve the comparison of methylene chloride paint strippers and alternatives. Additionally, for the methylene chloride case study to serve as a comprehensive example, all of the alternatives identified should be included in the First Stage analysis.

The Safer Consumer Products Alternatives Analysis Development master's thesis project ultimately furthered the potential for incorporation of life cycle considerations in the analysis of hazardous chemicals in products and their potential alternatives.

Project Objectives

The Bren Group Project team worked with the Department of Toxic Substances Control (DTSC) to develop guidelines for considering life cycle impacts in Alternatives Analyses and to prepare a framework document and visualization surrounding one of the three initial Priority Products and Candidate Chemicals covered under the Safer Consumer Products Regulations.[1] Paint stripper containing methylene chloride was chosen as the ideal Priority Product for developing a life cycle consideration framework due to the availability of alternatives that include chemical substitutes and full process substitutes (e.g. power sander). Assessment of the life cycle implications for the chosen product and chemical combination helped differentiate the steps and procedures outlined in the guidance.

Specific objectives included:

1. Developing a life cycle screening framework and testing that framework with a case study of methylene chloride in paint strippers and alternatives.
2. Designing a document explaining the steps for the developed life cycle screening framework and a visual presentation to communicate evaluations to public and corporate audiences.

Significance

The results of this project are expected to play a role in supporting the implementation of the Safer Consumer Products Regulations. Given the limited practical experience conducting an Alternatives Analysis, the completed case study and the findings of the Group Project will help the Department of Toxic Substances Control (DTSC) develop guidance documents for industry.

The creative approaches that Group Project members provided, with advice from experts including Dr. Arturo Keller and Dr. Sangwon Suh, will be valuable for DTSC. This group had the opportunity to work with DTSC to contribute to the Alternatives Analysis guidelines as public policy.

By collecting and using available data and evaluating life cycle impacts of alternative formulations or designs for paint strippers, the Bren Group Project team aimed to use the case study of alternatives to methylene chloride-based paint strippers to inform the development of life cycle guidelines for conducting Alternatives Analysis. This project provided an opportunity to strengthen a unique, progressive environmental policy aimed at reducing the use of toxic substances and systematically integrating life cycle thinking into manufacturing decisions. This work is important for reducing unintended consequences of alternatives and improving the ability of responsible entities to conduct a practical study in a reasonable time frame.

Background & Literature Review

General Background

1. DTSC

The California Department of Toxic Substances Control (DTSC) is a government agency that is part of the Cal/EPA. Its mission is to:

> Protect California's people and environment from harmful effects of toxic substances by restoring contaminated resources, enforcing hazardous waste laws, reducing hazardous waste generation, and encouraging the manufacture of chemically safer products…[DTSC] regulates hazardous waste, cleans up existing contamination, and looks for ways to reduce the hazardous waste produced in California.[2]

2. AB 1879

In 2008, Governor Arnold Schwarzenegger signed AB 1879 as part of California's Green Chemistry Initiative. AB 1879 increases regulatory authority over Chemicals of Concern (CoCs) in consumer products. It requires DTSC to assess and prioritize the most toxic chemicals in consumer products for potential restrictions or bans.[3] Furthermore, DTSC is tasked with evaluating alternatives. It also established an advisory panel of scientists called the Green Ribbon Science Panel to guide research, set up an Internet database of toxins, and create regulations.[3]

3. Safer Consumer Products Regulations

Federal and state laws often ban the use of certain chemicals in consumer products as their danger becomes evident. However, these laws frequently result in a switch to chemicals that still share many of the toxic effects of the banned substance. In an attempt to avoid these regrettable substitutions, the State of California passed the Safer Consumer Products (SCP) Regulations to encourage manufacturers to eliminate CoCs and to create products that are safer for consumers and the environment throughout their entire life cycles, including impacts that occur through the production, use, and disposal of the product.[4] Traditional assessments of human health and environmental impacts focus on the hazardous impacts generated only during the use phase of a product. Considering the entire life cycle of a product widens the scope of consideration for the environmental and human health impacts of a product to include all relevant impacts generated, from raw material extraction to end of life disposal.

Under the SCP Regulations, manufacturers are required to conduct an Alternatives Analysis to determine if there are feasible, safer substitutes for the CoC. When DTSC lists a CoC as part of a Priority Product, an Alternatives Analysis must be conducted to assess public health, environmental, and waste impacts. The Alternatives Analysis is broken into two stages: the First Stage focuses on the identification of potential alternatives, the screening of those alternatives, and the identification of factors relevant for consideration; the Second Stage focuses on thoroughly investigating relevant factors, conducting a final comparison of alternatives, and making a decision. Upon completion of an Alternatives Analysis, manufacturers are not required to remove the CoC if the comparison does not support a switch.

Existing Methodologies Background

1. Life Cycle Assessment

Companies are encouraged to partake in life cycle thinking because information about the environmental impacts of one stage of a life cycle does not provide a sufficient basis for understanding the environmental performance of a product. Life Cycle Assessment (LCA) is "a compilation and evaluation of inputs, outputs, and potential impacts of a product system throughout its life cycle."[5] The life cycle of a product incorporates the processes that occur upstream (pre-use) and downstream (post-use) of a product's use. It is intended to provide a scope of assessment that includes all of the impacts generated by a product as opposed to only the impacts generated by a product's use. See Figure 1 for an example of a life cycle flow chart.

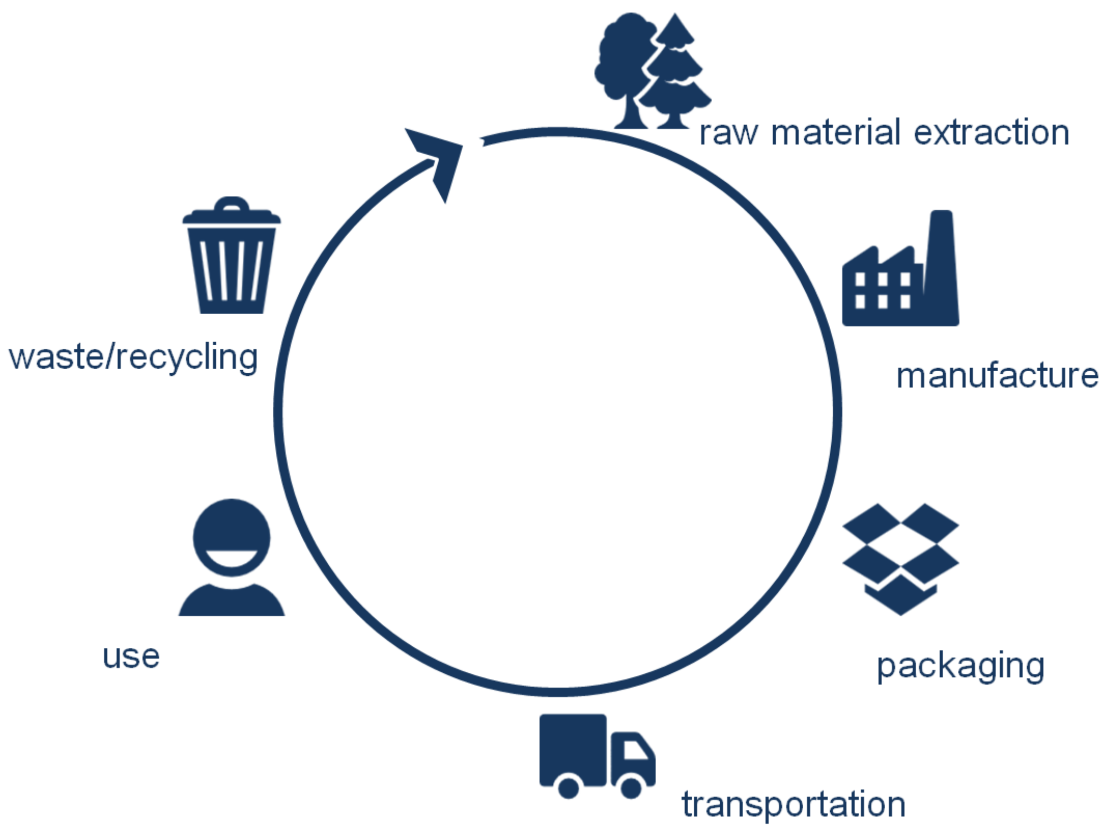

Figure 1. Generic life cycle flow diagram indicating phases of a product's life cycle, from raw material extraction through manufacturing and use, into disposal.
Icons by Icons8

Life cycle phases that must be considered for the Safer Consumer Products Regulations include:

- Raw material extraction
- Resource inputs and consumption
- Intermediate material processes
- Manufacturing
- Packaging
- Transportation
- Distribution
- Use
- Operation and maintenance
- Waste generation and management
- Reuse and recycling
- Waste disposal and end-of-life

LCA avoids problem shifting from one issue to another by addressing a broad spectrum of environmental impacts. However, despite being science-based, it is not free from subjective judgment. Moreover, it has barriers to progress such as low level of experience, undue expectations, and over-assumption.[6] These barriers inhibit LCA from being a perfect solution to considering life cycle impacts. Further challenges include cost, data, need for methodological expertise, and lack of communication to a broader audience.[7] LCA standards are presented as the ISO 14040 and 14044 standards. The four parts of an LCA are (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation.

An LCA begins by defining a functional unit. A functional unit is "a quantified performance of a product system for use as a reference unit;" it should be directly defined in the goal and scope, and should be measurable.[5] An impact category is "a class representing environmental issues of concern to which life cycle inventory analysis results may be assigned".[5] The impact categories to be considered under the SCP Regulations are: public health; environmental: air quality, soil quality, water quality, ecological; and waste and end-of-life.

Attributional LCAs are the most common life cycle approach. An attributional LCA uses historical data to describe energy and material flows into and out of a product or process.[8,9] However, this approach is simplified and is not predictive of real world impacts.

A consequential LCA model incorporates how a new product or product system would alter future material supplies and impacts. The consequential LCA aims to incorporate changes in the real world and is thus scenario-dependent and uncertain.[8,9] It shows how flows to and from the environment would be affected by different potential decisions, and estimates the effects of a specific action.[8,9] For example, a consequential LCA for a switch from a scarce to a non-scarce metal would consider the possibility of the non-scarce metal becoming scarce due to increased demand and the potential increase in mining impact.

Both attributional and consequential LCAs are subjective; results will be affected by the data and assessment strategy used, and are at risk for truncation errors that occur when the scope of an assessment is too narrow to include all major impacts.

a. Life Cycle Considerations

In many instances, a full LCA is not a viable option. With new or less-distributed products and components, there may be a lack of information in existing LCA databases to perform an assessment. Additionally, completing a comprehensive LCA can be time consuming. There may not be the available time to complete an LCA during the span provided for an Alternatives Analysis, particularly if datasets must be created for some of the alternatives.

When a full LCA cannot be completed, there are varying depths to which life cycle considerations can be taken into account. A common tool used to quickly gauge the environmental impacts of a given product is the Economic Input-Output (EIO) LCA tool.[10] The tool can output data in terms of air pollution, greenhouse gases, energy, hazardous waste, toxic releases, water withdrawals, transportation, land use, or impact categories from the US EPA's TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts). Values generated from EIO-LCA are on the industry-level and based on monetary value or mass of a product used. While this tool can be helpful in gauging general impacts, it is not an ideal option for comparing alternatives because it will not adequately differentiate between similar alternatives (e.g. multiple alternatives may be categorized by the same industry).

A 2014 article in the International Journal of Life Cycle Assessment explored the potential to simplify the LCA process using the case study of a mobile phone.[11] The paper explored five methods for simplifying an LCA: (1) exclude certain environmental impact categories or life cycle stages/processes; (2) use secondary process data from a commercial LCA database; (3) use economic input-output data from national environmental accounts; (4) use a linear model; and (5) exclude life cycle stages/processes from consideration. The study found that for mobile phones and similar technical devices, the methods for simplification that most accurately maintained the impact results were those using LCA database information and EIO data when primary or secondary data was not available. Using the best available data and supplementing with less specific or precise data when necessary is a way to address information gaps.

2. *Alternatives Assessment*

Alternatives Assessment refers to the systematic comparison of safer alternatives to an existing process, product, or product component. Alternatives Assessments traditionally focus on hazard and exposure effects. Determination of potential alternatives for a given process or product is based on the functional use of the process or product needing amendment as opposed to the specific component being assessed. This widens the scope of potential alternatives and opens the assessment up to systems-based thinking.[12] Qualitative and quantitative information are used in an iterative process to ensure a thorough assessment with continuous improvement.[12] The overall goal of performing an Alternatives Assessment is similar to that of an LCA: to avoid shifting from one negative human health or environmental impact to another when switching to an alternative process, product, or product component. Alternatives Assessments, while based on scientific data, are subjective in the selection and application of data, methods, and scope.

Many frameworks currently exist for performing Alternatives Assessments on hazardous chemicals. Several prominent methods include: the Interstate Chemicals Clearinghouse (IC2); EPA's Design for the Environment (DfE); and Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). Additional frameworks include: (1) BizNGO; (2) German Guide on Sustainable Chemicals; (3) Lowell Center AA Framework; (4) UNEP Persistent Organic Pollutants Review Committee General Guidance on Alternatives; (5) TURI Alternatives Assessment Process; and (6) UCLA Multi-Criteria Decision Analysis.[13] None of these frameworks have established methods for incorporating life cycle considerations into an Alternatives Assessment. As frameworks are tested, they continue to grow and improve. Some of the common frameworks are explored below:

Interstate chemicals Clearinghouse (IC2)

The stated goal of IC2 is to protect and enhance human health and the environment by ensuring that CoCs within a product or process are replaced by an inherently safer alternative. The primary steps for performing an IC2 assessment are: (1) identification of the CoC; (2) initial evaluation; (3) scoping; (4) identification of alternatives; and (5) evaluation of alternatives. These steps work to identify a CoC that is in need of replacement based on existing regulations, consumer concern, business concern or other reasons. During the initial evaluation phase, it is determined if the product needs an Alternatives Assessment to eliminate the CoC based on the existence of feasible alternatives. Only if it is determined that an assessment could yield a viable alternative is the process taken through the final evaluation step.[14]

Design for Environment (DfE)

The Environmental Protection Agency (EPA) developed DfE for the assessment of hazardous Chemicals of Concern within the United States. Primary steps of a DfE assessment include: (1) determining feasibility of the Alternatives Assessment; (2) collecting information on chemical alternatives; (3) convening stakeholders; (4) identifying viable alternatives; (5) conducting the hazard assessment; (6) applying economic and life cycle context; and (7) applying results to decision-making for safer chemical substitutes.[15] DfE brings life cycle thinking into the guidelines; however, it only calls for such considerations after viable alternatives have been identified. Waiting to bring life cycle considerations in at the end of the assessment prevents the functional unit approach to finding alternatives; it limits consideration of alternatives beyond drop-in substitutes.[12] DfE has assessed alternatives for flame-retardants in furniture and printed circuit boards as well as Nonylphenol ethoxylate (NPE) in surfactants.[15]

Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)

The REACH guidelines focus on exposure scenarios for a CoC and how to find an alternative that reduces impacts at the points of exposure. The steps of a Chemical Safety Assessment (CSA) through REACH are: (1) compiling and assessing available information; (2) conducting a hazard assessment; and (3) decision-making on refining the assessment, at which point iteration may begin. The European Chemical Agency (ECHA), responsible for developing REACH, is working to incorporate economic considerations into its assessment model. This would make REACH one of the more comprehensive Alternatives Assessment methodologies available[16].

Alternatives Analysis

The DTSC Alternatives Analysis framework incorporates aspects of these existing Alternatives Assessment methodologies. Based on the requirements of the Safer Consumer Products (SCP) Regulations, which states that human health and environmental impacts must be considered at every stage of a product's life cycle, the Alternatives Analysis process will be more comprehensive and wide-reaching than a traditional Alternatives Assessment. However, these existing assessment methodologies are useful for informing the hazard assessment and the economic considerations aspects of an Alternatives Analysis. Combining these materials with the life cycle considerations processes currently in development will help in making well-informed Alternatives Analysis reports.

3. Hotspot Analysis

Hotspot analysis, an Alternatives Assessment approach, is defined as a methodological framework that allows rapid assimilation and analysis of large volumes of information to identify and prioritize hotspots—the most significant economic, environmental, ethical, and social impacts of a product. The results deduced from hotspot analysis can be used to identify opportunities for impact improvement and to prioritize impact reduction actions. It boasts a user-friendly format and can be accessed by both technical and non-technical audiences. It also serves as a precursor for further investigation or action by industry, governments and other stakeholders. Unlike the life cycle approaches that base their evaluation on tools with limited outputs, hotspot analysis adopts a materiality-focused approach, often absorbing a range of research inputs and stakeholder views.

Four common methodological steps in conducting a hotspot analysis have been identified: (1) goal and scope definition; (2) data gathering, expert insight and analysis; (3) hotspot identification and validation; and (4) prioritizing action. However, there is a lack of a generic approach to hotspotting; no effort has been made to consolidate or share best practices amongst those organizations or initiatives currently developing and deploying these methods. No accepted guidance on how to convert the findings of hotspot analysis into meaningful sustainability information and render them applicable in practice within industry, governments and other stakeholders has been developed.

The benefits of hotspot analysis are: (1) rapid assimilation and processing of voluminous evidence threads and the creation of accessible outputs to facilitate the decision-making required to eliminate, reduce or mitigate identified hotspots; (2) provision of a highly cost-effective approach with life cycle thinking as a management tool to be applied across multiple impact categories and issues, sectors or product categories; (3) bearing a “beyond LCA” view of hotspots that helps users to surpass the boundary inherent in traditional LCA (e.g., the assessment of various, cumulative impacts from different activities within fixated geographical location; better understanding of wasted resources in an industrial sector or production cycle; and the considerations of ethical and governance issues); and (4) offering both technical and non-technical information in an easy-to-interpret format to decision-makers in government, business and civil society.[17]

Paint Stripper Chemical of Concern & Alternatives Background

Due to the availability of chemical substitutes and full product replacements, paint strippers containing methylene chloride were chosen as the ideal Priority Product to inform the development of life cycle framework for Alternatives Analysis.

Paint strippers are chemical or physical products used to remove paint from a particular substrate such as wood or metal. They may be used to restore the substrate to its original condition or to prepare it for new paint or varnish. Chemical products cause the paint to "bubble" and separate from the substrate, allowing for easier removal using a paint scraper. Physical products such as manual or mechanical sanding scrape the paint off the substrate. In reality, stripping a painted substrate may combine chemical and physical methods in order to achieve a 100% paint-free surface. Alternative products should, however, achieve the same function as the Priority Product alone, and in the same time period. For paint strippers, in the case of a chemical substitute, the alternative chemical is likely to be another solvent.

1. *Methylene Chloride (Current Chemical)*

Methylene chloride is highly volatile liquid that is a probable human carcinogen.[18] Acute exposure to methylene chloride can lead to dermal, ocular, liver, cardiovascular, or respiratory toxicity, and can even result in death.[18] As a volatile organic compound (VOC), methylene chloride is considered a toxic air pollutant under the 1990 Amendments to the Clean Air Act. Despite its health concerns, it is the most widely used solvent in chemical paint and varnish removers because it is the fastest-working and most effective solvent and has low flammability hazard.[19] A study by W.M. Barr and Company, Inc., a manufacturer of paint stripper containing methylene chloride, has concluded there is no alternative product as effective that is also non-flammable.[19] Based on consumer surveys, it is estimated that a typical household consumer's annual exposure time to methylene chloride in paint strippers is approximately 2 hours and 25 minutes per year.[20] Air purifiers, masks and gloves may not provide adequate personal protection. An estimated 9.68 tons of methylene chloride are emitted to the air every day from consumer paint strippers.[21]

2. *Chemical Substitutes*

a. Benzyl Alcohol

Benzyl alcohol is a chemical alternative to methylene chloride. Benzyl alcohol is produced commercially by the catalytic hydrolysis of benzyl chloride.[22] It is a colorless liquid with a mild aromatic odor and sharp burning taste.[23] It is a mild acute toxin (LD50 of 1.2 g/kg in rats, LD50 of 100 mg/kg bw for 2 species of birds and LD50 of 150-160 l/hectare for mosquitos),[24] contact allergen, and is severely toxic and irritating to the eyes.[22] It is harmful by inhalation and has sensitizing properties if swallowed.[23] Benzyl alcohol is not classifiable as to its carcinogenicity.[22]

Benzyl alcohol has low volatility and is not expected to be an air pollutant. The half-life for the gas-phase reaction of benzyl alcohol with photochemically produced hydroxyl radicals can be estimated at 2 days.[22] The half-life for oxidation (reaction of benzyl alcohol with alkylperoxy radicals) is 9 days.[22] It is not persistent and is readily biodegradable.[23] It is not expected to bioaccumulate.[23] Its bioconcentration factor

(BCF) is 4.04.[22] It is highly mobile and readily leaches in soil, and adsorption is not expected to be an important fate process.[22] Benzyl alcohol underwent 60.8% degradation in a 5-day test under aerobic conditions, and anaerobic degradation was complete within 2 weeks.[22] It is moderately soluble in water and soluble in most organic solvents. It is more toxic to the aquatic environment than methylene chloride.[23] While benzyl alcohol itself is a VOC, some products may be labeled as a VOC-free.[23] The MSDS for Dumond's Peel Away Smart Strip, a paint stripper containing 30-50% benzyl alcohol, labels it as highly biodegradable, water-based and containing no VOCs.[25]

Between 2000 and 2007, the use of benzyl alcohol increased significantly.[23] Benzyl alcohol is commonly used in the aircraft stripping industry.[23] It adheres well to vertical surfaces and remains active for approximately four hours.[23] However, it takes longer—by approximately 25%—to strip paint and is also more labor intensive than methylene chloride.[23]

b. Dimethyl Adipate

Dimethyl adipate (DMA), also known as hexanedioic acid, is marketed as a "green" chemical alternative to methylene chloride. Some concerns for human health and the environment do exist for this alternative, particularly when the product contains a high loading level of DMA. These concerns include reports of blurred vision and lung irritation when workers are exposed to high concentrations of DMA. These reports are likely also linked to poor ventilation in work areas. Animal studies performed on rats indicate mild irritation to skin and eyes upon contact exposure and minimal toxicity from oral exposure. The low vapor pressure and high water solubility of DMA create a concern about the chemical's toxicity to aquatic organisms. It has been shown to have a 96-hour lethal dose (LD50) of 18-24 mg/l for fathead minnows.[26]

c. Acetone

Acetone is a common alternative to methylene chloride. It is a highly flammable and volatile solvent. Acetone is readily absorbed into the bloodstream from the lungs and is also absorbed directly from the skin, making inhalation and dermal exposure a concern.[27] Because acetone occurs naturally in the human body, the liver is capable of breaking it down to non-harmful substances that leave the body.[27] The effects of high exposure to acetone are not fully understood and its human carcinogenicity is not currently classifiable.[27] Presently, the greatest concern regarding acetone in chemical paint strippers is its flammability risk.[27] Acetone was considered for the group's economic assessment because information was available in relevant databases, but was not considered for the development of the framework or visualization approach due to its flammability.

3. Process Substitute

Manual & Mechanical Sanding

Sanding, which includes hand sanding and mechanical sanding, is a physical method to remove paint from the substrate, and is usually considered as an alternative to chemical paint strippers such as methylene chloride.

Sandpaper comes in a number of different shapes and sizes such as sandpaper sheets, sand belts, or sand disks. Typical sandpaper consists of an abrasive mineral, backing, and adhesives. Backings for sandpaper are generally made of paper, cotton, polyester, or rayon. Aluminum oxide and resin bonds are the most commonly used components in a wide variety of sandpaper grits and adhesives, respectively. The grit sizes determine the finish of the work, with larger grit sizes resulting in rougher finishes.[28]

Hand sanding is both time-consuming and physically demanding but can be very effective for smaller, more delicate surfaces. Mechanical sanding involves the collective use of a variety of power tools in order to brush off the old layers of paint. Circular sanders, belt sanders, and orbital sanders are often used due to their capabilities to remove paint layers quickly and easily. A great deal of sanding dust is generated during the process. Thus, the EPA has suggested performing sanding tasks in a ventilated area, using vacuum sanders, and operating sanders with the use of personal protective equipment including a mask, gloves and goggles to reduce the potential exposure to harmful matter and dust.[29] It has been reported that hand-sanding results in a 90% reduction in concentrations of airborne dust generated compared with mechanical sanding and 99% of the exposure to dust can be reduced in a ventilated area.[30] Sanding dust may contain airborne particles such as wood dust, which may cause respiratory symptoms and health problems. It also may be hazardous if it contains heavy metals such as copper or nickel, which can result from the sanding process on a metal substrate.[31]

Methods & Data

Framework Development

Methods

Alternatives Assessment, Life Cycle Assessment and hotspot analysis methodologies were reviewed to inform the framework development. Key aspects and factors were identified to develop a life cycle screening framework, which allowed for modification of existing methodologies to suit the needs of the SCP Regulations. A case study was used to develop, test, and refine the framework. Current literature related to industry, state, and international case studies was reviewed to form a basis for the group's case study of paint stripper containing methylene chloride.

Data

Visualization of data was modeled after heat map approaches developed by the Clean Production Action's GreenScreen® method and the Department of Defense Sustainability Analysis Guidance Draft. The incorporation of uncertainty (high, medium, low) evaluation was modeled after the GreenScreen® method.

Impact level evaluation criteria were borrowed and modified from the Toxics Use Reduction Institute (TURI) guidance. The EPA's Design for Environment Alternatives Assessment Criteria for Hazard Evaluation is also consistent with these criteria, demonstrating the validity of the utilized evaluation criteria.

Case Study

Methods

To develop a case study of life cycle screening and to test potential methods for completing this aspect of the First Stage Alternatives Analysis, a Chemical of Concern (methylene chloride) and alternatives (benzyl alcohol, dimethyl adipate and sanding) were identified and assessed for life cycle impacts. To identify alternatives, existing alternatives in the marketplace were researched. Additional potential alternatives were provided by W.M. Barr & Company (W.M. Barr). However, W.M. Barr did not contribute to the group's framework document; the company only provided a list of potential alternatives.

Because an Alternatives Analysis incorporates life cycle thinking into a traditional Alternatives Assessment, three alternatives were ultimately considered: (1) benzyl alcohol; (2) dimethyl adipate; and (3) sanding. These three in particular were selected to represent one chemical alternative (benzyl alcohol), one "green" chemical alternative (dimethyl adipate), and one process alternative (sanding). Rather than limiting the alternatives to only chemical alternatives that would achieve the same function as methylene chloride, the scope was expanded to include any alternative that achieved the same function as the process (e.g. sanding) to test the applicability of the developed framework to both formulated and composite products.

Manufacturers' answers to a REACH questionnaire asking them to state their methylene chloride-free formulations listed many of the chemical alternatives identified here (e.g. Dibasic Ester (DBE)-based products, benzyl alcohol-based products). However, other alternatives were not considered in this project due to the need to create a manageable scope of alternatives for an effective example. REACH also listed mechanical sanding in its report.

The SCP Regulations provided life cycle phases and impact categories to consider and research. Before beginning any research on methylene chloride and its alternatives, the actions included in each life cycle phase and the boundaries of each life cycle phase were identified. The DTSC SCP Regulations presents examples of factors to consider (e.g. duration, route, and concentration of exposure for human health impact). During this process, questions that would help to focus and guide research were formed and compiled into a Generalized Worksheet (Appendix B in results). Additionally, at this point in the research process, the functional unit—one m^2 of painted hard wood that has been 95% stripped of its acrylic paint in less than three hours—was defined to serve as a reference point for comparison.

Data

Research and reports from governmental (e.g. EPA, NIOSH, OSHA, ATSDR) and some non-governmental sources (e.g. Material Safety Data Sheets, UseTox) provide reliable information for initial analysis of each alternative. These sources provided qualitative information about the severity of impacts as well as some quantitative data on animal testing studies (e.g. LC50, ED50) and environmental impacts (e.g. Comparative Toxic Units (CTUe) in air, water, and soil). Each source of information was cited to easily keep track of research and uncertainty.

Data was recorded in a table with life cycle phases in columns and impact categories in rows. The information found was filled into the intersections of columns and rows, called segments (Table 1).

Table 1. Example table for displaying results of a life cycle screening analysis.

Chemical Name	Raw material extraction	Resource inputs and consumption	Intermediate material processes	Manufacture	Packaging	Transportation	Distribution	Use	Operation and maintenance	Waste generation and management	Reuse and recycling	EOL disposal
Public health impact												
Air quality												
Soil quality												
Water quality												
Ecological Impacts												
Waste and EOL												

Based on the quantitative and qualitative information found, the severity of impact ("minimal to no," "low," "medium," "high") was designated according to the most severe data point within each life cycle segment to take the most conservative approach. Colors were assigned to each level of severity:

- "minimal to no" = green;
- "low" = yellow;
- "medium" = orange; and
- "high" = red.

When there was a lack of data on which to evaluate impacts, or when the life cycle phase either did not apply or could be reallocated to other phases, more colors were added to the heat map (black and grey, respectively). Furthermore, life cycle phases that were not expected to change between alternatives (Packaging, Transportation, Distribution, Resource Inputs and Consumption) were designated with a blue color.

A level of uncertainty ("high," "medium," "low") was also given based on the reliability and robustness of the data, and the likelihood of the impact.

The resulting heat maps allowed for an easy visual comparison of life cycle impacts across products and across impact categories. Throughout the life cycle screening process, the steps involved have been documented and assessed in the Framework (see "Results" section).

Economic Considerations

A benefit-cost comparison as well as comparison of net present value (NPV) for methylene chloride and two chemical alternatives (benzyl alcohol and acetone) was conducted. These alternatives were selected based on available information in the databases used for comparison (TRACI 2.1 and USETox). Material costs were calculated using available online resources. The dollar values for environmental costs are based on emissions factors from Tool for the Reduction and Assessment of Chemical Impacts (TRACI) 2.1 and the Material Environmental Benefits Calculator (MEBCalc). TRACI 2.1 was developed by the US EPA and contains emissions data for the assessed alternatives. Emissions data were grouped across nine impact categories such as non-cancer human health impacts, eutrophication, and acidification. The MEBCalc tool was developed by Sound Resource Management Group to estimate the costs to society for various environmental emission impact categories.

Methods

The benefit and cost values obtained for each chemical were forecasted for a ten-year time horizon. A time horizon of ten years was selected to reflect the relatively short time considerations a company will give to a particular product. No sensitivity analysis was performed for the time horizon because our study includes no upfront costs. The lack of upfront costs reflects that a supplier will not pay the fees associated with switching manufacturing. An end distributor (e.g. Home Depot) may be responsible for conducting an Alternatives Analysis if no supplier conducts the analysis and the end distributor continues to offer the identified product. Scaling the time horizon does not affect the results of a cost benefit analysis and only changes the magnitude of a net present value assessment. A private firm discount rate of 7% was used because the company pays the direct costs and is required to consider the indirect costs. This discount rate represents a reasonable value for private entities.

Net Present Value was calculated by subtracting the forecasted costs from forecasted benefits and discounting future values to get an estimated present value.

$$NPV = \sum_{t=10}^{T} \frac{forecasted\ benefits_t - forecasted\ costs_t}{(1 - discount\ rate)^t}$$

Similarly, the cost and benefit values for the cost benefit analysis (CBA) were discounted to obtain NPV. For the CBA, the NPV of costs was divided by the NPV of benefits to obtain a ratio of costs over benefits, which demonstrates the extent to which costs outweigh benefits without consideration of total NPV.

$$Cost\ Benefit\ Ratio = \frac{NPV_{benefits}}{NPV_{costs}}$$

Material Data

The shelf price of the paint stripper products was used in conjunction with the gross profit margin of a typical hardware store to account for the amount that a hardware store would gain in revenue from each paint stripper. This benefit estimation method was chosen because data regarding the amount of money that Home Depot pays and earns for a given product was not readily available due to its confidentiality. Gross profit margin, while less applicable than specific product margins, was selected because the information available for gross profit margins is more current and consistent than the publicly available, product-specific data.

In-store shelf prices were available through Home Depot for all alternatives: methylene chloride; benzyl alcohol; and acetone. While the prices were taken from online sources, they reflect in-store values and any sale or discount pricing was ignored. The gross profit margin values are the most recent quarterly values available at the time of the economic assessment (Fall 2014) and were obtained through Y-Charts, which are Yahoo's financial charts. The methylene chloride product selected as a baseline was Klean-Strip KS-3 Premium Stripper, which retails for $22.98 per gallon at Home Depot.[32] Pure acetone was also available under the Klean-Strip brand at a cost of $4.97 per liter ($18.81 per gallon).[33] Ready Strip, which uses benzyl alcohol as the primary solvent, was sold for $39.97 per gallon.[34] The gross profit margin for Home Depot was 35.02% as of October 31, 2014.[35]

To obtain annual profit for each alternative, it was assumed that the volume of sales would be consistent for all scenarios. The underlying assumption for consistent sales is that demand for paint stripper is relatively inelastic (i.e. customers are not price-sensitive). Home Depot had 27.2% of the home improvement product sales for the United States in 2013.[36] This market share was assumed to be representative of paint stripper sales throughout the United States. Revenue was calculated assuming Home Depot as the responsible entity. Volume of sales was extrapolated from the annual demand for methylene chloride as a solvent in paint stripper in the US that came from the US EPA's Chemical Data Access Tool. The density of the paint strippers was calculated using the volume and weight provided on supplier websites. Average loading level of methylene chloride (i.e. percent of the chemical in the overall product) came from Material Safety Data Sheets (MDSDs) from suppliers. These values, combined with the portion of the paint stripper market held by Home Depot, were used to estimate volume of paint stripper sales. Additionally, it was assumed that Home Depot would run the assessment based on total US sales, despite only being required to consider sales within California, because it would be simpler to consider a nationwide replacement scheme. Furthermore, it is not completely unlikely that other states may establish similar regulations (e.g. the "California Effect" on automobile emissions standards).

Environmental & Human Health Data
TRACI 2.1 provides environmental and human health impacts across nine impact categories identified in Table 2.

Table 2. Human health and environmental impact categories for which TRACI 2.1 provides emissions data.

TRACI 2.1 Impact Categories
Global Warming Potential
Acidification
Particulate Matter (PM 2.5)
Eutrophication
Ozone Depletion
Smog Air
Ecotoxicity emitted*
Human Health Non-Cancer*
Human Health Cancer*

*Emissions are calculated to six environmental compartments

This database contains the solvent chemicals being assessed: methylene chloride (baseline), benzyl alcohol, and acetone. Due to the variety of formulations and loading levels that exist for each alternative, it was assumed that only the primary solvents generated enough impact to warrant measurement for comparison to simplify the study.

Emission factors were converted to dollars per kilogram using the Measuring Environmental Benefits Calculator (MEBCalc) tool developed by Sound Resource Management Group. Dollar values were available for all impact categories except smog and ozone and have incorporated information from as recently as 2013. Impact category values for the tool were estimated from existing literature.[37] It was assumed that the human toxicity and human cancer dollar values used in MEBCalc that were estimated based on toluene and benzene emissions, respectively, would be accurate for the scope of our study, given that they were based on chemicals used in the production of the chemicals under consideration. Values for the human toxicity and cancer impact categories may underestimate the true cost because they are based on hospital treatment costs as opposed to using a revealed preference method to determine willingness to pay (WTP) for the avoidance of risk, which tends to yield higher values of statistical life (VSL). MEBCalc was also chosen because it takes into account environmental costs across the life cycle of a product (e.g. production, use, disposal), which reflects the requirements of the SCP Regulations.

The dollar values based on emissions factors from TRACI 2.1 and MEBCalc were multiplied by the annual use of each chemical to obtain environmental and human health costs for one year. It was assumed that annual use of chemical paint strippers would remain consistent over the ten-year time horizon based on market data for methylene chloride sales. To address loading levels, low, medium, and high loading levels for each product were used to test the sensitivity of the results. The low and high loading levels were based on the extremes of the range provided in each chemical's Material Safety Data Sheet (MSDS) and the middle loading level was an average of the high and low values.

Results

Framework/Approach for Initial Life Cycle Screening in Alternatives Analysis

The following document outlines an approach for incorporating life cycle thinking into a First Stage Alternatives Analysis, as set forth in the California Safer Consumer Products (SCP) Regulations. Established Alternatives Assessments focus on use-phase hazards and incorporating life cycle thinking captures aspects of the production, use and disposal of the product to reduce the occurrence of regrettable substitutions.

A full life cycle assessment is time- and data-intensive and is not required by the SCP Regulations. This framework was developed to aid small businesses unfamiliar with life cycle concepts to take into consideration impacts that occur throughout a product's life cycle, and to do so within the time constraints of the SCP Regulations. This framework draws from established Alternatives Assessment and Life Cycle Assessment methodologies, but focuses on hotspotting as a technique to reduce the time and data necessary for decision-making.

This document serves as a screening framework that aims to help identify relevant factors and alternatives to be assessed in a Second Stage Alternatives Analysis. A Second Stage Alternatives Analysis involves a thorough investigation of relevant factors identified in the First Stage, a final comparison of alternatives, and making a decision.

The framework outlined in this document includes six primary steps that are explored below in Figure A.

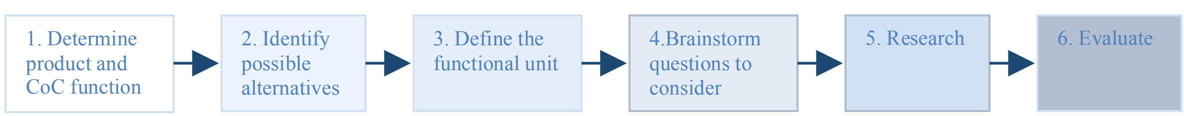

Figure A. Primary steps for incorporating life cycle screening into a First Stage Alternatives Analysis

A case study of methylene chloride-based paint strippers was used to test this framework for its applicability to both formulated and composite products. Methylene chloride is a solvent that causes paint to separate from the substrate, allowing for easier removal using a paint scraper. Examples from this case study are provided in this document to improve understanding of how to implement the framework.

Note: For a complete list of definitions and potential factors that must be considered for an Alternatives Analysis, please refer to the SCP Regulations.

1. **Step 1: Determine the function of product and Chemical of Concern**

To begin the alternatives identification and comparison process, it is important to first understand what the function of the product is and to subsequently identify the purpose of the Chemical of Concern (CoC) within that product.

> **Example:**
> Product: Methylene chloride-based paint and varnish removers.
>
> Product Function: To remove paint or varnish from a particular substrate such as wood or metal, to restore the substrate to its original condition, or to prepare it for new paint or varnish.
>
> Chemical Function: Solvent that dissolves paint by bonding to the chemical, causing it to separate from the substrate.
>
> *Alternative products, therefore, should achieve the same function as the Priority Product. In the case of a chemical substitute for paint strippers, the alternative chemical is likely to be another solvent.*

2. **Step 2: Identification of potential alternatives**

To identify potential alternatives, the function of both the product and the Chemical of Concern should be considered. In the paint stripper example, focusing on the function of the product as a whole (i.e. removing a certain type of paint) allows the responsible entity to consider entirely new alternatives (e.g. power sanders) as opposed to only chemical replacements.

Many information sources for identifying alternatives exist. When DTSC lists a Priority Product it generally includes a list of potential alternatives in the Priority Product Profile. Looking at comparable products already on the market that do not contain a Chemical of Concern can be a good place to start. Additionally, contacting chemical suppliers about alternatives can provide useful information. Reading literature from peer-reviewed sources regarding alternatives can provide another avenue for identifying alternatives, provided public concern or existing regulations have pushed for an assessment of potential alternatives for a product or CoC. *For a list of alternatives identified in the methylene chloride paint stripper case study, see Appendix A.*

2.1. Alternatives that already exist on the market

In many cases, alternatives to a Priority Product already exist. Most responsible entities will already know about alternatives on the market. It can still be informative to look at the market to ensure that no existing alternatives are overlooked. For the methylene chloride case study, an Internet search yielded a list of potential alternatives already on the market.

2.2. Alternatives recommended by suppliers

Chemical suppliers can be a valuable resource for identifying alternatives. These companies know the characteristics of the chemical that they currently supply for a given function (e.g. solvent for paint removal) and can identify other chemicals with similar characteristics and functionality.

3. Step 3: Defining a functional unit for comparison

A functional unit is defined as "a quantified performance of a product system for use as a reference unit,"[38] which allows for an evaluation and comparison of the Priority Product and the alternatives in a measurable way. A well-defined functional unit translates the purpose of the product into a useful metric for alternative comparison. When defining a functional unit, it is important to: (1) be specific in clearly defining goal and scope of the life cycle considerations, and (2) capture all relevant features (i.e. market expectations) of the product.

Example:

<u>Functional Unit</u>: One m^2 of painted hard wood that has been 95% stripped of acrylic paint in less than three hours.

$$Functional\ Unit = \frac{1\ m^2\ painted\ wood, 95\%\ stripped}{3\ hours}$$

The functional unit chosen for paint strippers reflects that it is difficult to remove all paint from a substrate (hence the 95% stripped as opposed to 100%), and that most consumers are satisfied without 100% paint removal because they will be refinishing the wood. It additionally takes into account a time span acceptable to most consumers (3 hours) for removing paint. If it is desired that the product have additional features, such as the ability to remove paint from multiple substrates (e.g. wood and metal), then this aspect should be included in the functional unit. A properly defined functional unit ensures that any selected alternative possesses all of the desired qualities of the original product/chemical combination.

4. Step 4: Brainstorming questions to consider

4.1. Setting up a roadmap for life cycle research

It is important to understand life cycle phases and impact categories identified by DTSC and how they apply to the product and alternatives before beginning research. Key questions emerge that will help to focus research efforts with an understanding of the boundaries between different life cycle phases and what sort of information is needed to assess impacts within those phases. A life cycle phase for a product captures some aspect of the production, use or disposal of the product.

For a detailed list of questions to consider, please refer to the "Generalized Life Cycle Considerations Worksheet" in Appendix B. This resource is intended as a guide to begin the assessment process, and may not cover all potentially relevant factors. It is not meant to be comprehensive and complete, and therefore may not cover all potentially relevant factors.

Example:

Life cycle phase: Raw Material Extraction

Considerations: If one of the raw materials used in a product is mined, some potential considerations include:

- Does the mining process release contaminants to water or air?
- Is there significant waste generated from mining?
- Is the waste generated hazardous?

Establishing important questions or considerations for different impacts within each life cycle phase will help guide research.

4.1.1. Life cycle phases

The life cycle of a product is the "consecutive and interlinked stages of a product system", from raw material extractions from natural resources to the end of life.[38] Life cycle assessment (LCA) is a systematic way to evaluate the impacts of a product or service system throughout the phases of its life cycle (Figure B), with a particular focus on human health and environmental impacts.

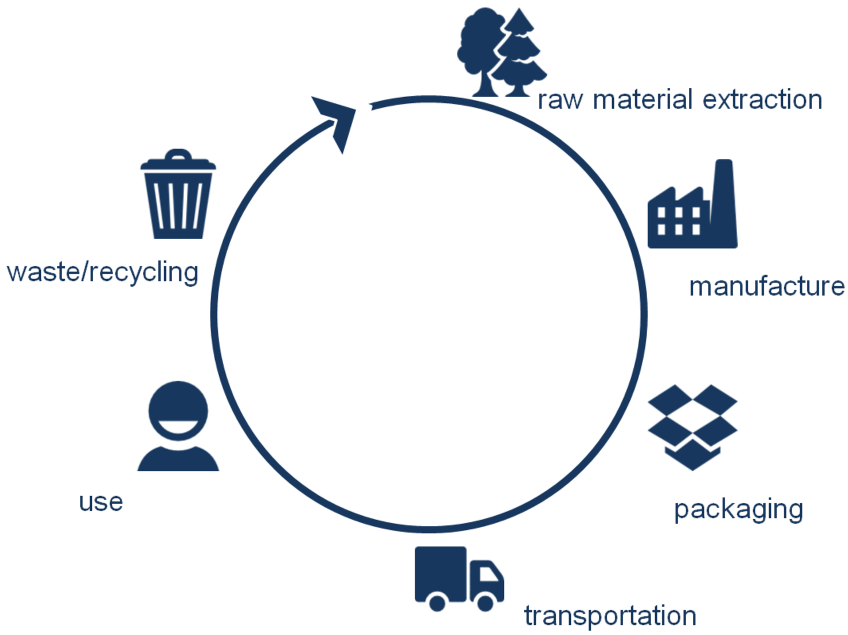

Figure B. Generic life cycle flow diagram indicating phases of a product's life cycle from raw material extraction through manufacturing and use, into disposal.
Icons by Icons8

The typical life cycle includes:

- Raw materials extraction;
- Resource inputs and consumption;
- Intermediate material processes;
- Manufacturing;
- Packaging;
- Transportation;
- Distribution;
- Use;
- Operation and maintenance;
- Waste generation and management;
- Reuse and recycling;
- Waste disposal and end-of-life.

A life cycle approach may reveal significant environmental issues (e.g. adverse ecological impacts and adverse human health impacts) related to the product of concern and its alternatives that may have been missed in a basic, traditional examination of use-phase impacts.

While there are many specific definitions for life cycle phases, the SCP Regulations do not define the boundary between one phase and another. In some cases, the phases may overlap. The phases as listed in the regulations can be considered separately (e.g. transportation, distribution) or may be grouped together (e.g. transportation/distribution). However it is decided to break up the life cycle phases, it is important to clearly define the distinct phases to avoid double counting of impacts.

4.1.2. Impact categories

Impacts resulting from the production, use, or disposal of a product are categorized by the type of impact (e.g. air quality impacts). The objective of this step is to identify the human health, environmental, waste stream, and end-of-life concerns for each life cycle phase. The results should be presented in a format that allows any interested party to have a clear understanding of the study's outcome. See Table A, below, for an example format. In this example, the impact categories are displayed in the rows and the life cycle phases are displayed in the columns. Impacts for a specific impact at a particular life cycle phase can be filled into the intersection of those two factors in the table.

Table A. Example table for displaying results of a life cycle screening analysis.

Chemical Name	Raw material extraction	Resource inputs and consumption	Intermediate material processes	Manufacture	Packaging	Transportation	Distribution	Use	Operation and maintenance	Waste generation and management	Reuse and recycling	EOL disposal
Public health impact												
Air quality												
Soil quality												
Water quality												
Ecological Impacts												
Waste and EOL												

Three elements are included in identifying and assessing relevant impact categories:

1) Conducting a qualitative check on the information of each life cycle phase to ascertain the likely impacts;
2) Applying a systematic approach to quantify identified impacts; and
3) Assessing the results with careful consideration given to conclusions drawn when there is a lack of information or data uncertainty.

These steps are further explained in Sections 5 and 6.

Within each phase of the product's life cycle, adverse effects to public health, the environment, and waste and end-of-life are investigated. Some examples of information to consider are provided below.

4.1.2.1. Adverse Human Health Impacts

The SCP Regulations define adverse public health impacts as:

> Any of the toxicological effects on public health specified in article 2 or article 3 of chapter 54 under Division 4.5, Title 22, California Code of Regulations, or exceedance of an enforceable California or federal regulatory standard relating to the protection of public health.

The health impact assessment should identify all potential population exposures to chemicals or conditions that may cause adverse impacts. Human health data is generally the easiest impact data to find, because government agencies produce reports summarizing such impacts for chemicals used in the United States.

A number of aspects warrant in-depth consideration in the course of the analysis, including:

1) Estimated quantity or concentration of substance and route of exposure (e.g. 14 mg dust/m^3 air inhaled by a worker);
2) The duration of exposure. Analysis is often based on realistic exposure conditions, but occasionally it may be necessary to make conservative assumptions of parameters, such as average time period of exposure, in order to get a quantitative estimate of overall exposure;
3) All potential routes of exposure and the exact exposure pathways involved, both of which must be identified by the end of the Second Stage analysis. The potential routes of exposure include ingestion, inhalation, dermal contact and ocular contact for any product;
4) Estimates of potential health effects caused from risk factors on subgroups of the population. These subpopulations may include: (1) workers involved in the activities in each of the life cycle phases; (2) uninvolved workers (i.e. workers present at the site of the activity, but not involved in the activity); and (3) the general public; and
5) Other factors that may influence the amount of exposure, such as the use of personal protective equipment.

Example:
Scenario: Inhalation of sanding dust as a result of sanding paint from wood surface.

Human Health Impact: Respiratory irritation or damage. Determining the level of expected impact, from no impact to severe impact, will be described in detail in Step 6: Evaluation. Respiratory irritation impacts can be rated on the severity of the impact from:

1) No impact – no respiratory irritation or damage
2) Minimal impact – minor respiratory irritation that fades quickly after exposure
3) Low impact –minor respiratory irritation that is reversible
4) Medium impact – moderate respiratory irritation that may take time to subside
5) High impact – respiratory irritation and some degree of permanent damage

Respiratory irritation is often covered in government reports. When respiratory irritation is a potential concern and data cannot be found, it represents a data gap that should be addressed in the Second Stage Alternatives Analysis.

Factors that may affect exposure: Variations in inhalation rate due to physical activity, the use of Personal Protective Equipment (PPE), and the existence of ventilation or other waste management or air quality equipment.

4.1.2.2. Adverse Environmental Impacts

When conducting an environmental impact assessment, both the physical-chemical environment (i.e. air, water, and soil) and the biological environment (i.e. plants and animal species) need to be considered. This holistic approach is important to evaluate the significance of the primary, secondary, and cumulative impacts of each life cycle phase by studying the fate and transport of the chemicals in each media and the biological effects on living creatures.

4.1.2.2.1. Air Quality

According to the SCP Regulations:

> Adverse air quality impacts" means indoor or outdoor air emissions of any of the air contaminants listed below that have the potential to result in adverse public health, ecological, soil quality, or water quality impacts:
>
> (A) California Toxic Air Contaminants as specified in title 17, California Code of Regulations, sections 93000 through 93001;

(B) Greenhouse gases:

1. Carbon dioxide;
2. Hydrofluorocarbons;
3. Methane;
4. Nitrogen trifluoride;
5. Nitrous oxide;
6. Perfluorocarbons;
7. Sulfur hexafluoride; or
8. Gases that exhibit the global warming potential hazard trait, as specified in section 69405.4;

(C) Nitrogen oxides;

(D) Particulate matter that exhibits the particle size or fiber dimension hazard trait, as specified in section 69405.7;

(E) Chemical substances that exhibit the stratospheric ozone depletion potential hazard trait, as specified in section 69405.8;

(F) Sulfur oxides; or

(G) Tropospheric ozone-forming compounds, including compounds that exhibit the ambient ozone formation hazard trait, as specified in section 69405.1.

A wide variety of industrial or consumer operations could potentially affect air quality. These operations may include any activity that emits pollution into the atmosphere. This impact includes greenhouse gas emissions that occur throughout the product life cycle from factors such as fuel use and electricity production. For a screening level analysis, local air quality impacts are often provided in human health impact reports that indicate the emission levels and effects on human health for a given chemical. For more widespread air quality impacts, a chemical's listing as a volatile organic compound (VOC), greenhouse gas, or other air quality-affecting agent, is a good indicator of air quality impacts.

Be aware of the potential for double counting air quality impacts and human health impacts. When harmful emissions into the air are broad and cannot be tied to individual exposure, they fall under the "air quality" jurisdiction. When emissions are in an indoor or concentrated environment and associated with potential health impacts only for the individuals within the vicinity, they should be counted under "human health". It is possible for an air pollutant to have both immediate human health impacts and air quality impacts.

Air quality impacts for the case study were based primarily on government reports and listings. A few helpful lists that identify major air pollutants include:

- Listings under a California- or United States-wide hazard list:
  - USE EPA Air Pollutant Lists
    - US EPA List of hazardous air pollutants.

- Toxic Air Contaminants identified by the California Air Resources Board

> **Example:**
>
> Scenario: Toluene used in the production of benzyl alcohol.
>
> Air Quality Impact(s): Toluene is highly volatile (i.e. it rapidly evaporates when exposed to air). Toluene can contribute to the formation of photochemical smog when it reacts with other volatile organic compounds (VOCs) in the air. It is on the US EPA List of hazardous air pollutants.
>
> Factors that may affect severity of impact: Filtration systems on the production facility; quantity of toluene used.

4.1.2.2.2. Water Quality

According to the SCP Regulations:

> Adverse water quality impacts means any of the following adverse effects on the beneficial uses of the waters of the State, which include groundwater, fresh water, brackish water, marsh lands, wetlands, or coastal bodies or systems, as specified in Water Code section 13050(f) or adopted in a Water Quality Control Plan under article 3 of chapter 3 and/or article 3 of chapter 4 of division 7 of the Water Code:
>
> (A) Increase in biochemical oxygen demand;
> (B) Increase in chemical oxygen demand;
> (C) Increase in temperature;
> (D) Increase in total dissolved solids; or
> (E) Introduction of, or increase in, any of the following:
>
> 1. Priority pollutants identified for California under section 303(c) of the federal Clean Water Act;
> 2. Pollutants listed by California or the United States Environmental Protection Agency for one or more water bodies in California under section 303(d) of the federal Clean Water Act;
> 3. Chemicals for which primary Maximum Contaminant Levels have been established and adopted under section 64431 or section 64444 of chapter 15 of title 22 of the California Code of Regulations;
> 4. Chemicals for which Notification Levels have been specified under Health and Safety Code section 116455; or
> 5. Chemicals for which public health goals for drinking water have been published under the California Safe Drinking Water

Act (commencing with Health and Safety Code section 116270).

The operation of manufacturing or processing facilities, waste sites and landfills, electricity generation, or other industrial processes potentially affects water quality. It can also be affected by the transportation of pollutants, sewage treatment, and raw material extraction processes such as mining. For a screening analysis, factors such as persistence of a chemical, effect on aquatic life (e.g. lethal dose), and effect on biochemical oxygen demand (BOD—the oxygen needed in water for microorganisms to decompose organic matter) can be used to evaluate water quality. These data points can be found within hazard reports and applied across life cycle phases based on estimated quantities and exposures of a chemical. To start the screening level process, there are many government lists that identify chemicals associated with water quality concerns; a few to focus on include:

- Chemicals identified as Priority Pollutants in the California Water Quality Control Plans
- Chemicals with Maximum Contaminant Levels (MCLs) from the California State Water Resources Control Board.
- Chemicals with a Total Maximum Daily Load (TMDL) identified by the US EPA

Example:

Scenario: Fertilizer used in the raw material extraction for cloth backing of sandpaper.

Water Quality Impact(s): Increase in biochemical oxygen demand, which can be rated by the half-life of the biochemical oxygen demand, because the half-life assesses the persistence of the impact. The following rating scale was adapted from the P2Oasys "Standardized Hazard Score Data Base:"

1) No Impact – no increase in BOD
2) Minimal Impact – 4 day BOD half-life
3) Low Impact – 10 day BOD half-life
4) Moderate impact – 100 day BOD half-life
5) High impact – 500 or more day BOD half-life

Alternatively, the impact rating can be based on water treatment and quantity of fertilizer used, as it was for the instance of fertilizer used in raw material extraction for sandpaper.

Factors that may affect severity of impact: Amount of fertilizer used; waste water pretreatment application.

Potential sources of water quality changes include:
1) Withdrawal of freshwater from surface water or groundwater due to raw material extraction, intermediate processes or manufacturing processes;
2) Discharge of untreated or treated wastewaters from the manufacturing process or waste treatment facilities;
3) Deposition of pollutants from smoke stacks, vehicle emissions, incinerators or landfills;
4) Storm water (e.g. contaminated storm water from incorrect management of sanding dust) and agricultural runoff (e.g. power sanders use a cotton rather than paper backing for the grit, and there may be pesticide or fertilizer use associated with this raw material); and
5) Unexpected accidents such as spills or explosions during chemical operations.

4.1.2.2.3. Soil Quality

According to the SCP Regulations:

> Adverse soil quality impacts means any of the following effects on soil function or properties:
>
> (A) Compaction or other structural changes;
> (B) Erosion;
> (C) Loss of organic matter; or
> (D) Soil sealing, meaning covering surface soil with a layer of impervious material or changing the nature of the soil so that it behaves as an impermeable medium.

Soil quality can be affected by activities related to mining, forestry, agriculture, release of pollutants, and a variety of other factors. These activities include raw material extraction, wet and dry deposition of pollutants and reactants during transportation through air and water media, and incinerators and landfills associated with waste disposal. In addition to the identification of the potential sources that may affect soil quality, the characteristics of the soil, such as the permeability and erodibility, should be considered. However, for the scope of a screening analysis, it is sufficient to take into account information regarding soil quality that is not location-specific (i.e. does not consider specific characteristics of the soil).

Example:

Scenario: Soil erosion and alteration due to natural gas extraction for chemical compounds used to make dimethyl adipate.

Soil Quality Impact(s): Nutrient depletion in the soil – erosion leads to the loss of nitrogen and phosphorus essential for plant life that subsequently supports soil stability. The amount of land affected by erosion and nutrient depletion can be calculated based on production volume of natural gas and the land affected per production volume.

For the case of dimethyl adipate, the volume of natural gas needed to produce the precursor chemicals was "minimal," so the impact was listed as "minimal" with high uncertainty, based on a lack of quantitative information regarding the volume and source of natural gas used to produce dimethyl adipate.

Reference for Measuring Impacts: McBroom, M., Thomas, T., Zhang, Yanli. Soil Erosion and Surface Water Quality Impacts of Natural Gas Development in East Texas, USA. *Water*. 2012. 4: 944-958.

Factors that may affect severity of impact: What the previous uses of the soil were (e.g. forestland versus agricultural land); quantity of gas extracted.

4.1.2.2.4. Ecological Health

Adverse ecological impacts denote all direct or indirect effects on living organisms and/or their environments.

According to the SCP Regulations:

> Adverse ecological impacts means any of the following direct or indirect effects on living organisms and/or their environments:
>
> (A) Adverse effects to aquatic, avian, or terrestrial animal or plant organisms or microbes, including:
> 1. Acute or chronic toxicity;
> 2. Changes in population size, reductions in biodiversity, or changes in ecological communities; and
> 3. The ability of an endangered or threatened species to survive or reproduce;
>
> (B) Adverse effects on aquatic and terrestrial ecosystems including:
> 1. Deterioration or loss of environmentally sensitive habitats;
> 2. Impacts that contribute to or cause vegetation contamination or damage; and
> 3. Adverse effects on environments that have been designated as impaired by a California State or federal regulatory agency;

(C) Biological or chemical contamination of soils; or
(D) Any other adverse effect, as defined in section 69401.2(a), for environmental hazard traits and endpoints specified in article 4 of chapter 54.

A complete understanding of the key ecological elements, including the identification of dominant, rare, unique and endangered plant and animal species within the areas of activity, is necessary in the assessment of ecological impacts. Additionally, a study of ecological interrelationships, such as habitat and food chains, may provide a basis to determine the potential impacts on the ecological community at large (e.g. land use change from a forest to agricultural land to produce raw materials, resulting in habitat conversion or loss). For a screening level assessment, it is sufficient to use existing reports about environmental damage or to extrapolate potential damage from animal health studies to assess ecological impacts.

Lists that reference persistence and bioaccumulation characteristics of chemicals can be useful in identifying chemicals with ecological impact concerns. These lists include:

- US EPA Persistent Bioaccumulative and Toxic (PBT) Priority Chemicals.
- State of Washington's list of PBTs
- Canada's chemicals that are identified as Persistent, Bioaccumulative and Inherently Toxic (PBiT)
- European Commission's list of chemicals that are PBT

For the screening level analysis, the components of the products under consideration (e.g. chemical ingredients, paper-backing, grit) should all be checked for impacts. Additionally, the products and chemicals used to produce the final products should be assessed.

Example:

Scenario: The primary release of methylene chloride to surface water and ground water occurs from effluents from industrial processing (i.e. the manufacturing phase).

Ecological Impact(s): Stated in Environmental Protection Agency report:
Methylene chloride has low acute toxicity to aquatic organisms;
Lethal concentrations are generally greater than 100 mg/L;
Ninety-six hour LC50 values for fish are 193 mg/L for *Pimephales promelas*.

Factors that may affect severity of impact: Proximity of aquatic habitat area to the manufacturing facility; water effluent processing at facility; method of disposal and diffusion of effluents from facility.

4.1.2.3. Waste and end-of-life

The characteristics and quantity of generated waste, and the waste management approaches collectively influence the odds of having significant environmental impacts.

According to the SCP Regulations:

> Adverse waste and end-of-life effects means the waste materials and byproducts generated during the life cycle of a product, and the associated adverse effects due to one or more of the following:
>
> > (A) The volume or mass generated;
> > (B) Any special handling needed to mitigate adverse impacts;
> > (C) Effects on solid waste and wastewater disposal and treatment, including operation of solid waste and wastewater handling or treatment facilities, and the ability to reuse or recycle materials resulting from the treatment of solid waste and/or wastewater;
> > (D) Discharge(s) or disposal(s) to storm drains or sewers that adversely affects operation of wastewater or storm water treatment facilities; or
> > (E) Release(s) into the environment, as a result of solid waste handling, treatment, or disposal activities, or the discharge or disposal to storm drains or sewers, of chemicals contained in the product.

Waste sources include industrial processes and manufacture, consumer operations, and disposal of the product. The characteristics of waste materials generally refer to the explosiveness, corrosiveness, flammability, ignitability, or toxicity of the waste as well as its reactivity and biodegradability in the air, water, and soil media. Wastes left over after the use phase can be combined with data regarding the hazards of the chemical and product to estimate end-of-life impacts.

Example:

Scenario: Methylene chloride is considered a hazardous waste by the US EPA and paint stripping applications rarely use the entire volume of paint stripper purchased – the remaining packaged paint stripper must be managed as hazardous waste

Waste and End-of-Life Impact(s): The volume and hazard of methylene chloride waste produced from methylene chloride paint strippers warrants a high hazard rating for waste disposal during the use phase.

Factors that may affect severity of impact: volume of paint stripper leftover after use; consumer willingness to follow hazardous waste guidelines.

5. **Step 5**: **Research**

Research on the product and its alternatives can be organized into two major categories: qualitative and quantitative. Qualitative and quantitative data should be continuously gathered to refine information on which to perform an evaluation of life cycle segments. The amount of information necessary for a First Stage analysis is variable. The more information that is gathered in the screening analysis, the more effectively the scope of alternatives and factors under consideration can be narrowed for the more thorough Second Stage analysis. While there is no solid line of when to stop researching, it is recommended that a company apply as many man-hours as is reasonable in the 180 days allotted for the First Stage analysis to ensure that they Second Stage analysis is manageable. Compiling pieces of data into a **comparative analysis will be covered in section 6**, which discusses evaluation of gathered information.

Less significant life cycle phases (and specific impacts within a life cycle phase) that can be eliminated from further research should be identified. Removing an impact from consideration should be based on an agreed upon set of subjective criteria. The benefit of eliminating life cycle segments less likely to have a significant impact from the screening investigation is that it allows practitioners to focus their efforts on assessing areas of impact that are likely to generate more impact and require a more thorough assessment to compare products. Questions may arise during identification of impacts for each life cycle segment. It is wise to document these questions and compare them across products.

Devise a system for documenting data sources before starting research. References can be documented in a spreadsheet alongside a brief description of the information that they provided for future review. Documenting uncertainty about a given source or study will reduce work down the line when research is evaluated and compiled. There are multiple options available for the degree of research to be completed in the First Stage analysis. This will require devising an uncertainty rating system that is briefly explained in Section 8 of this report.

Note: It is important to differentiate between a lack of data and data that indicates no impact in a given area. When data is lacking, *do not* use it as a reason to eliminate an area from consideration.

Example:

Life cycle phases eliminated from the methylene chloride case study after assessing qualitative information included:

Packaging, transportation, and distribution because they did not vary significantly across products (this is based on similar packaging weights, relatively similar product weights and no change to transportation method or distribution route between alternatives); and
Operation and maintenance for chemical alternatives because they are a one-time use product and do not require maintenance or additional energy for operation. For sandpaper, the operation and maintenance phase was assessed to account for the potential impacts of powering and maintaining a sander. This information was gathered during the assessment of life cycle phases.

5.1. *Qualitative Investigation*

Initial research should follow a *qualitative* approach to the subject. This data should address adverse impacts or effects in each life cycle phase. Use the information gathered during Step 4, the brainstorming stage, to inform what processes and uses need to be assessed for impacts. For example, toluene is used in the production of benzyl alcohol and this warrants considering the human health and environmental impacts of toluene for the manufacturing phase of benzyl alcohol.

Material Safety Data Sheets (MSDSs) are a good place to gather basic information including:

- Exposure effects that can be useful for informing manufacturing, use phase and disposal human health impacts
- Hazard information, such as flammability and corrosivity
- Basic environmental and ecological information, such as whether the chemical is known to contribute to acid rain or greenhouse gas emissions.

MSDSs are available for individual chemicals as well as for complete products, so they are available whether or not the alternatives under consideration are already used as a substitute for the Priority Product.

When first assessing chemical alternatives, check whether they are on DTSC's "Candidate Chemical List" and to note the reason for listing. The authoritative list that warranted a chemical's listing may provide additional information, both quantitative and qualitative, about that chemical's human health or environmental impacts.

Government agency reports provided the bulk of the impact data for the methylene chloride case study. They often contain qualitative data that explains impacts in terms of "low", "moderate" or "severe". These assertions are often backed up with quantitative data, but in instances where the report simply makes a general statement and is the only source providing information for a given impact, it is acceptable to incorporate the information into the screening analysis, provided the qualitative nature of the information is noted. If quantitative information is found during the initial search, it should be thoroughly documented.

Sources that haven't been peer reviewed or come from a questionable origin should not be used in the screening level analysis. Additionally, if a report provides a value cited from a different source, it is best to check and cite the original source.

Example:

Acute inhalation exposure to methylene chloride that may occur during the use phase can affect the Central Nervous System (CNS). Potential affects include: decreased visual, auditory and psychomotor functions.

This information is enough to provide at least a "low impact" rating for human health during the use phase; however, the uncertainty will be high because the severity of the impact is unknown. Further information such as a general descriptor (e.g. moderate) of the impact generated for a given amount of exposure (e.g. one hour) or specific values about the concentration (e.g. 125 ppm for 15 minutes) must be gathered to decrease uncertainty and may increase the severity of the impact rating.

5.2. Quantitative Investigation

Once qualitative information has been gathered, research efforts should focus on quantitative information. Continue to record resources in the same fashion that qualitative data was documented. When quantitative data deepens the understanding of information from a qualitative data point, it can be used in place of that data to inform decisions. Table B, below, highlights sources used in the methylene chloride case study to obtain quantitative data. DTSC is compiling a more in-depth list of resources that can be found in the Guidance Document and through the DTSC's website.

Table B. Potential sources for finding quantitative data.

Resource	Applicability	Comparative Attributes	Data Quality/Sources
USEtox	Chemical fate and transport including some human health and environmental indicators	Ecotoxicity; sensitivity; human toxicity; fate; exposure	Endorsed by UNEP/SETAC Life Cycle Initiative
TRACI	Chemical specific human health and environmental data	Ozone depletion, global warming, acidification, human health cancer, human health non-cancer, eutrophication, smog formation, ecotoxicity, fossil fuel use, land use, water use	Listed in documentation of Excel or selected program for running analysis
EcoInvent	Agriculture; energy supply; transport; biofuels; biomaterials; bulk and specialty chemicals; construction materials; packaging materials; basic and precious metals; metals		"High quality generic LCI datasets based on industrial data and compiled by internationally renowned research institutes and LCA consultants"; compatible with all major LCA and eco-design software tools; data quality standards
National Toxicology Program	Chemical specific toxicology data	Toxicity measures (e.g. LD50)	United States government testing and modeling

Example:

CNS effects can occur following short-term (15 minutes) exposure to methylene chloride when an individual inhales methylene chloride at concentrations of 125 ppm or greater. For longer-term exposure, effects can occur with as low an exposure as 25 ppm over an 8-hour work shift.

For this information to be used in a comparative assessment, it must be determined if these concentrations are being reached during production, use, and/or disposal of methylene chloride paint stripper.

In the case of methylene chloride, it was determined that individuals would be exposed to concentrations of methylene chloride leading to long-term effects on health and warranting a 'high impact' rating from methylene chloride for human health during the use phase (factors such as carcinogenicity also played a role). Many consumers may not wear personal protective equipment (PPE) during the use phase to reduce exposure, so PPE does not reduce the severity of the impact.

6. Step 6: Evaluation

Following multiple iterations of qualitative and quantitative research, data can be standardized and evaluated. This step may culminate in a visualization of results to more easily identify hot spots within each product. A heat map can be useful for displaying results in an easy-to-understand manner. In a heat map for life cycle considerations, life cycle phases and impact categories make up the columns and rows; the intersection of the row and column would have a designated color to indicate the severity of an impact for a given life cycle phase. The heat maps shown below are for methylene chloride and its alternatives: benzyl alcohol, dimethyl adipate, and sanding.

Hot spots indicate where a given life cycle phase may generate significant adverse impacts/effects in a given impact category (e.g. human health effects during the use phase). The criteria for assigning low to high impact should be based on an agreed upon set of subjective/objective criteria and normalization of results.

For the methylene chloride case study, the pre-established standards developed by the Toxics Use Reduction Institute (TURI) to inform its P2OAsys tool for comparison were used as a basis for ranking impacts. The TURI Guidance on L-M-H assessment provides a basis of evaluation criteria for multiple impact categories. With appropriate modifications to add evaluation criteria for impact categories not addressed in the TURI Guidance document, this tool is a useful guide for evaluation, but must be complemented by a normalization or weighting method to determine hot spot impacts.

Normalization means putting usually incomparable factors (e.g. public health impacts compared to ecological impacts) on a percentage scale (100% being the worst impact) to allow for direct comparison. Many tools for normalization exist—among them are the US Environmental Protection Agency's (EPA's) Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) and EPA's Design for Environment (DfE) Alternatives Assessment Criteria for Hazard Evaluation. Table C, below, is a sample from the TURI Guidance document that highlights the ratings incorporation of both qualitative information (e.g. neurotoxicity) and qualitative information (e.g. persistence) into the decision process.

Table C. Sample impact evaluation criteria, borrowed from TURI.

Hazard	Characteristics	Minimal to No Impact	Low Impact	Medium Impact	High Impact
Chronic Human Health Effects	Neurotoxicity	Not classified or known to be neurotoxic	---	Chemical class known to produce neurotoxicity effects; or animal studies and analog data suggest neurotoxicity effects*	Evidence in humans shows potential neurotoxicity effects*
Persistence/ bioaccumulation	Persistence	Not classified as being persistent	Soil, sediment < 30 days; water < 7 days; or ready biodegradability	Soil, sediment 30 to 180 days; or water 7 to 60 days; or potential for long-range environmental transport	Soil, sediment > 180 days; or water > 60 days

The intersection of the life cycle segment and adverse impact/effect should be labeled on a color scale like the one demonstrated in the heat maps on pages 48, 52, and 54. Additional colors/criteria may be added depending on the project. The criteria for each color should differ between products and the scale of impacts should be considered when applying colors and uncertainty.

Heat Map Method:
Classification system for the heat map and examples from the methylene chloride case study:

- Grey indicates 'not enough information'
  - Not having enough information is not a reason to eliminate an alternative from consideration, nor does it assume that the impact or the alternative is benign.
- Black indicates 'non-relevant impact or life cycle phase'
  - The 'operation and maintenance' life cycle phase was not relevant for the chemical alternatives because no operation and maintenance of the product occurred. This life cycle phase was relevant for consideration for mechanical sanding due to the energy to run a power sander as well as the materials needed to clean and maintain a sander. However, it is important to note that only the sanding disc, but not the power sander itself was included in the study. To allow for comparison across all alternatives if one alternative has impacts for a life cycle phase or impact and the others have "black" the "black" can be assumed to be equivalent to "minimal to no impact" for the alternatives where the impact area was not deemed relevant. It is important to note that only the sanding disc but not the power sander itself was included in the study.
- Blue indicates 'impacts not expected to differ between products'
  - Transportation and distribution was assumed to be the same between all chemical alternatives, because the factory distances and weights of products would remain relatively constant. Sand paper or discs used for power sander are usually packed in the box and share the similar transportation and distribution process. Due to the limited access to the information, it was assumed that the factory distance and weights of packed sand paper or disc were similar to those of the chemical alternatives and that any differences in impact would be negligible.
- Green, yellow, orange, and red indicate increasing impacts from 'minimal to no impacts' to 'high impact'
  - An intersection of a life cycle phase and impact category was assigned a color based on the worst-case scenario
  - If respiratory irritation during the use phase was medium (yellow to orange) but dermal irritation was high (red) the intersection of 'Public Health' and 'Use' was designated as a high impact area (red).
- Uncertainty was indicated by an L for 'low uncertainty', M for 'medium uncertainty' and H for 'high uncertainty'
  - Uncertainty is the likelihood of an impact (e.g. whether personal protective equipment is utilized) and the robustness of the data (e.g. whether multiple studies demonstrate the same toxicity effects)

- If data regarding dermal irritation during the use phase was robust, but the likelihood of dermal irritation occurring during the use phase was moderate, the uncertainty would be ranked 'medium uncertainty' (M)

Further description of factors for determining low to high impacts in the methylene chloride case study:

1) Green (minimal to no adverse impact): no inherent impact, potential impact only from very large quantities;
2) Yellow (low adverse impact): some impact but not enough to be significant, some impact depending on improper human behavior;
3) Orange (medium adverse impact): moderate impact, potentially significant, but likely to be reversible
4) Red (high adverse impact): high impact, irreversible effects or significant damage is caused

A sample heat map for methylene chloride based on these subjective criteria and qualitative information gathering is shown in Figure C, on the next page (note: the information represented in this table must be standardized to allow for comparison between alternatives).

	Raw Material Extraction	Resource Inputs and Consumption	Intermediate Material Processes	Manufacture	Packaging	Transportation	Distribution	Use	Operation and Maintenance	Waste Generation & Management	Reuse and Recycle	EOL and Disposal
Public Health	H		M	L				L				L
Air Quality	H		M	M				L				L
Soil Quality	H			H				H				H
Water Quality	M		H	H				H				H
Ecological Impact	H		L	L				L				L
Waste/End-of-Life			L	M				M				M

Methylene Chloride

High Impact	Medium Impact	Low Impact	Minimal to No Impact	No Data	N/A	Not expected to change between products

H	High Uncertainty
M	Medium Uncertainty
L	Low Uncertainty

Figure C. Example heat map. Evaluation of impacts associated with methylene chloride based paint-stripping products. The heat map columns indicate life cycle phases; rows indicate impact category; colors indicate the severity of an impact; and L-M-H indicate the level of uncertainty associated with the evaluation. Life cycle segments colored grey indicate a lack of data upon which to evaluate, life cycle phases colored black do not apply to that product, and life cycle phases colored blue indicate a minimal expected difference among alternatives.

Three examples for how setting hazard criteria & uncertainty was performed in the case study:

1) Use phase ecological impacts for dimethyl adipate

Impact Rating: Orange (medium impact)

Justification: Relatively low lethal doses for aquatic organisms (18-24 mg/L for fathead minnows) and plants (4.35 mg/L for green algae). These doses are likely to be reached because packaging recommends dumping dimethyl adipate directly down drains (regardless of filtration processes) as a method of disposal.

Uncertainty: High

Justification:

- Data source has low uncertainty, because it is a US EPA report.
- Quality of studies has high uncertainty, because the values came from studies with few individuals or from predictive modeling of how a chemical will behave based upon its physical structure (e.g. quantitative structure-activity relationship modeling).
- Likelihood of occurrence has medium uncertainty, because it is unclear if individuals will follow the directions to rinse waste down drains and whether these drains have filtration that will reduce environmental concerns.

Overall rating was high to reflect the conservative nature of our selection process.

2) Manufacturing public health impacts for benzyl alcohol

Impact Rating: Red (high impact)

Justification: Benzyl chloride (used to produce benzyl alcohol) is intensely irritating to skin, eyes and mucous membranes in humans. The acute effects from inhalation consist of severe irritation of the upper respiratory tract, and lung damage and pulmonary edema in humans. **Permanent** eye damage may result from contact with the liquid or the vapor forms of benzyl chloride.

Uncertainty Rating: Moderate

Justification:
- Source uncertainty low: government report (US EPA).
- Study uncertainty low: observed in humans from actual exposure.
- Likelihood of occurrence medium: there are ways to protect workers from exposure, but conditions are not expected to provide consistent protection from exposure and long-term exposure increases severity of effects.

3) End of life disposal ecological impacts for sanding

Impact Rating: Green (minimal to no impact)

Justification: Government research finds that there is No Observed Effect Concentration (NOEC) of titanium dioxide from removed sandpaper grit on aquatic or terrestrial species. The amount of these compounds present in waste sanding paper is minimal and leaching from landfills is likely to also be minimal, so minimal to no impacts are expected to occur.

Uncertainty: Moderate

Justification:
- Source uncertainty low: government report (US EPA).
- Study uncertainty moderate: tested on aquatic and terrestrial organisms and results indicate no impacts, but number of individual organism types studied was low.
- Likelihood of occurrence moderate: waste goes to landfill where leeching can occur.

Interpretation of Heat maps
The two primary goals of the screening level analysis are to: (1) screen out clearly unacceptable alternatives; and (2) identify relevant factors for alternatives comparison. When looking to screen out unacceptable alternatives, the maps can be grouped by product. To identify potentially relevant factors, the maps can be grouped by impact category. These groupings are demonstrated below.

Screening alternatives: visualization by alternative
When comparing across products or impact categories, it is important to be aware of missing data points and the significance of underlying data for a given ranking. These factors complicate direct comparison. While comparison is not as simple as counting the number of segments for each impact level (e.g. high impact) and comparing them, instances where a product appears significantly worse than the status quo option could allow for elimination of the worst seeming alternatives. The worst 'seeming' is used because in some instances, an alternative may be eliminated from consideration that had the potential to be an acceptable alternative. Such an alternative still has the potential for reconsideration if the end of the analysis process is reached and no better alternative than the CoC is found. Eliminating the worst seeming alternatives allows for a deeper dive into the remaining alternatives in the Second Stage analysis. Figure D, on the next page, shows the heat maps for methylene chloride and the three alternatives (benzyl alcohol, dimethyl adipate, and sanding) displayed by product.

Methylene Chloride

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Public Health	H	M	L	L		L
Air Quality	H	M	M	L		L
Soil Quality	H		H	H		H
Water Quality	M	H	H	H		H
Ecological Impact	H	L	L	L		L
Waste/End-of-Life		L	M	M		M

Benzyl Alcohol

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Public Health	M	M	M	L		
Air Quality	L	H	L	L		M
Soil Quality	L		M			L
Water Quality		L	M	L	M	L
Ecological Impact	M			L		
Waste/End-of-Life		M		M	M	L

Dimethyl Adipate

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Public Health	H	H	H	M		H
Air Quality		M	M	L		L
Soil Quality	M		M	H		H
Water Quality	M		M	H	H	H
Ecological Impact	M		H	H	H	
Waste/End-of-Life	M			H	H	H

Sanding

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Public Health	M	M	H	H		H
Air Quality	M	M		M		M
Soil Quality	M	M		M		M
Water Quality	M	M		M		M
Ecological Impact	M	M		M		M
Waste/End-of-Life	M	M		L		M

High Impact	Medium Impact	Low Impact	Minimal to No Impact	No Data	N/A

H	High Uncertainty
M	Medium Uncertainty
L	Low Uncertainty

Figure D. Example heat maps by alternative. Evaluation of impacts associated with four paint-stripping products. The four heat maps are separated by product; columns indicate life cycle phases; rows indicate impact category; colors indicate the severity of an impact; L-M-H indicate the level of uncertainty associated with the evaluation. Life cycle segments colored grey indicate a lack of data upon which to evaluate, and life cycle phases colored black do not apply to that product.

This presentation of the evaluation allows for the identification of alternatives that have an overall similar or worse level of impact than the Priority Product.

For example, in our case study, no alternative is worse than methylene chloride-based paint strippers--all alternatives have lower aggregate impacts than methylene chloride, and therefore all may be carried through to a Second Stage analysis.

Methylene chloride was evaluated to have fifteen (15) life cycle segments with medium or high impacts; benzyl alcohol, dimethyl adipate, and sanding have ten (10) medium or high impacts.

Methylene chloride and benzyl alcohol were evaluated to have thirteen (13) life cycle segments with minimal or low impacts; dimethyl adipate has sixteen (16) minimal or low impacts; and sanding has fifteen (15) minimal or low impacts.

Identifying relevant factors: visualization by impact

Considering relevant factors and comparing the products across impact categories focuses the Second Stage analysis towards areas where impacts or changes between impacts are likely to be greatest. Impact categories that warrant primary focus include: impact categories where the results vary significantly across impacts and where the results indicate consistently moderate to high impacts across the life cycle phases. In an instance where all products have ‘minimal to no impact’ for a given intersection of a life cycle phase and impact category (e.g. soil quality during production), that particular intersection may not necessitate a deeper dive in the Second Stage analysis unless factors such as significant volume or high uncertainty are a concern.

Figure E, on the next page, shows heat maps from the case study displayed by impact category (public health, water quality, air quality, ecological impact, soil quality, and waste/end-of-life).

Public Health	Methylene Chloride	Benzyl Alcohol	Dimethyl Adipate	Sanding
Raw Material Extraction	H	M	H	M
Intermediate Material Processes	M	M	H	M
Manufacture	L	M	H	H
Use	L	L	M	H
Reuse and Recycle				
EOL and Disposal	L		H	H

Air Quality

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Methylene Chloride	H	M	M	L		L
Benzyl Alcohol	L	H	L	L		M
Dimethyl Adipate		M	M	L		L
Sanding	M	M		M		M

Soil Quality

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Methylene Chloride	H		H	H		H
Benzyl Alcohol	L		M			L
Dimethyl Adipate	M		M	H		H
Sanding	M	M		M		M

Water Quality

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Methylene Chloride	M	H	H	H		H
Benzyl Alcohol		L	M	L	M	L
Dimethyl Adipate	M		M	H	H	H
Sanding	M	M		M		M

Ecological Impact

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Methylene Chloride	H	L	L	L		L
Benzyl Alcohol	M			L		
Dimethyl Adipate	M		H	H	H	
Sanding	M	M		M		M

Waste/End-of-Life

	Raw Material Extraction	Intermediate Material Processes	Manufacture	Use	Reuse and Recycle	EOL and Disposal
Methylene Chloride		L	M	M		M
Benzyl Alcohol		M		M	M	L
Dimethyl Adipate	M			H	H	H
Sanding	M	M		L		M

High Impact	Medium Impact	Low Impact	Minimal to No Impact	No Data	N/A

H	High Uncertainty
M	Medium Uncertainty
L	Low Uncertainty

Figure E. Example heat maps by impact. Evaluation of impacts associated with four paint-stripping products. The six heat maps are separated by impact category; columns indicate life cycle phases; rows indicate products/alternatives; colors indicate the severity of an impact; L-M-H indicate the level of uncertainty associated with the evaluation. Life cycle segments colored grey indicate a lack of data upon which to evaluate, and life cycle phases colored black do not apply to that product.

This format allows for an easier comparison of alternatives for specific impacts to determine whether a more in-depth investigation of a particular impact is warranted.

For example, methylene chloride has a high impact on air quality at the “use” phase, but all three alternatives have minimal or low impact on air quality at the “use” phase. Since all three alternatives have lower impacts than the Priority Product, a further investigation of air quality at this life cycle segment is not necessary. Similarly, since almost all impacts to soil quality are minimal to low, further investigation of soil quality impacts may not be necessary.

The public health impacts are predominantly evaluated as medium or high. To understand more specifically how these alternatives compare to methylene chloride at this life cycle segment, further analysis is warranted and this life cycle segment may be deemed relevant to consider in the Second Stage analysis.

Review of framework steps

Figure F, below, shows the six primary steps of the framework along with secondary details. This framework serves to guide practitioners in incorporating life cycle screening into an Alternatives Analysis as mandated by the SCP Regulations.

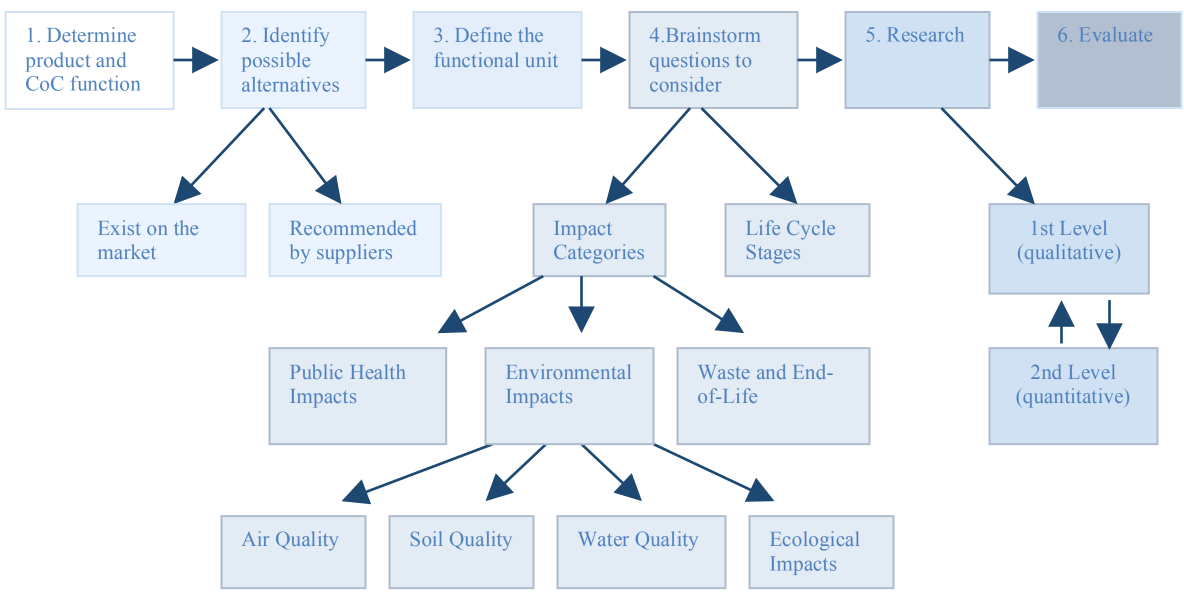

Figure F. Framework primary steps and secondary details.

7. Additional Considerations

7.1 Functional equivalence and normalizing data for direct comparison

It is important to normalize impacts to determine which factors are likely to have the greatest effects. Ideally, this normalization will have a quantitative basis. It is possible to use qualitative information to approximate impacts, though these results will have much greater uncertainty. This process is important to understand the scale of impacts relative to one another to allow for meaningful comparison.

> **Example:**
>
> Often power sanders use grit on cotton backing, which is more durable than a paper backing.
>
> Impact Concerns: During the raw material extraction phase for cotton, pesticides or fertilizers are used to grow the cotton, which generate impacts such as increased biochemical oxygen demand (BOD) in water. This depletes oxygen and can kill flora and fauna.
>
> Consider: The small fraction of cotton that makes up the entire power sander alternative providing the functional unit, indicating that this particular impact is likely relatively small.
>
> Scope: For the case study, fertilizer and pesticide impacts were deemed outside of the scope for a First Stage analysis because the quantity is so small that it will not likely generate a significant impact.

Another important consideration is to account for the functional equivalence if it has not already been considered. For example, to achieve the same performance, one chemical alternative may require three 1-ounce applications, while a methylene chloride-based paint stripper may require a single 1-ounce application. The impacts of the alternative, therefore, should be assessed based upon the amount necessary to achieve the same performance as the methylene chloride product rather than a simple 1-oz.: 1-oz. comparison.

7.2 Further quantification of data

The screening process should inform decisions about which relevant factors and alternatives warrant consideration in the Second Stage analysis. Up to this point it is likely that only readily available data or information has been used. Following the screening process, though, additional data searches should be more focused and may require working with suppliers to obtain necessary data or purchasing relevant data sets. To the extent possible, data should be more quantitative than it may have been in the screening process.

Example:

US EPA reports served as a major resource for the methylene chloride case study.

These reports use terms such as "low" or "moderate" to describe impacts.

For the initial screening it is acceptable to use data containing such terminology as long as sources are consistent for all alternatives. However, for the Second Stage analysis, ***quantitative*** *values would be more ideal for making a comparison across products.*

7.3 Reassessing decision boundaries

The purpose of the life cycle screening process is to identify potentially relevant factors to consider for further analysis and to eliminate unacceptable alternatives from further consideration.

It is possible that after the screening process, too many life cycle phases or alternatives have been eliminated to allow for an informative Second Stage analysis. This situation may require returning to the screening process to determine whether any life cycle phases or alternatives were eliminated from consideration too hastily. If it appears that no alternatives were deemed acceptable with reasonable standards based on relative impacts, it is important to consider alterations to considered alternatives that may lower impact. For example, recycling or reclaiming water for an alternative where water impacts were a significant factor for rejection may make it a more desirable alternative.

8. Data Interpretation and Challenges from the Methylene Chloride Paint Stripper Case Study

Government sources of data such as EPA chemical reports are generally reliable and robust; however, there may still be uncertainty in choosing a color for the heat map. For example, the original TURI guidance document did not cover all of the data points needed for an Alternatives Analysis. The EPA generally classified impacts with words (e.g. acute, moderate, severe) as opposed to the quantified values used in the TURI guidance. Colors were thus based on approximations of a scale. TURI guidance occasionally did not address an impact found in the research; colors were then approximated based on criteria used for similar impacts. The TURI guidance document was amended to suit the case study's needs. Uncertainty was noted in every segment of the heat map.

Uncertainty within the data was further complicated by uncertainty about potential for exposure. For some chemicals, there are multiple production methods, each of which has a unique energy intensity and combination of chemicals for manufacturing. In the case study, it was assumed that the specific production methods used could not be determined and the uncertainty notation was assigned a “high uncertainty” to reflect the lack of certainty regarding exposure. Additionally, for newer, untested products, the use phase handling patterns will not be well known and will likely result in high uncertainty for use phase and disposal impacts.

Data is often limited by constraints such as industry confidentiality. This is especially true of data related to upstream life cycle phases. Inadequate data can restrict the research power and weaken the conclusions of the impact assessment. This lack of information increases the workload for the Second Stage analysis by hindering the depth of information that can be easily gathered in the First Stage analysis. In the methylene chloride paint stripper case study, data was limited by such constraints, and the decision of whether to continue or halt the research for certain life cycle phases was largely determined by professional judgment.

Uncertainty within research in the downstream of life cycle phases mostly comes from two sources: 1) uncertainty of the individual data, such as the toxicity of chemicals, which results from the lack of scientifically substantiated evidence (e.g. animal toxicity experiments); and 2) uncertainty stemming from the circumstantial exposure scenarios.

For example, human exposure to sanding dust varies widely due to the uncertainty surrounding the material of the target substrate, the type of paint (e.g. lead-based paint), and the safety measures taken (e.g. PPE use) during the process of sanding. Thus, even when the toxicity data of chemicals is scientifically conclusive, high uncertainty still exists due to the indeterminacy of exposure scenarios.

Data standardization is critical to be able to compare alternatives. By using a set of standard criteria, such as modifying pre-established standards like the TURI (Toxics Use Reduction Institute) guidelines, it becomes easier to compare products. However, it is likely that the same types of data will not be available across products. For example, air quality during raw material extraction may be based on information about greenhouse gases and particulate matter for one alternative, but data on particulate matter alone may be used to assess air quality impact of a different alternative. For the purposes of screening, it is acceptable to have such uneven comparisons.

In this case study, the most severe individual impact was used to assess the overall public health, environmental, or waste impact at different life cycle phases. This approach seems reasonable given the variation in data. However, it is important to be aware of the data used to make those categorizations to be sure results are not inappropriately skewed. For example, to get an overall high impact categorization, product A may have four data points indicating little to no impact and one data point indicating high impact, while product B may have three data points that indicate high impact. Understanding these limitations will be important, especially in the event of eliminating too few or too many alternatives in the screening process.

Results of Economic Considerations Assessment

Net Present Value

Net Present Value (NPV) for each alternative was calculated by subtracting the calculated NPV of environmental costs from the NPV profit for each ten-year scenario. The results from the assessment are in Table 3, below.

Table 3. Net Present Value of profit benefits and the potential reduction in benefits from environmental costs for three paint stripper chemicals, with green indicating the highest (and best) NPV.

NPV	Methylene chloride	Benzyl alcohol	Acetone
Profit Only (million US $)	192	334	157
Low Loading (million US $)	169	315	157
Medium Loading (million US $)	161	309	157
High Loading (million US $)	154	302	157

Regardless of loading level or consideration of environmental costs, benzyl alcohol is the best option when the alternatives are compared based on NPV. The most expensive product is the best alternative because it indicates the highest revenue, given the assumptions that markup rates are constant and demand for paint stripper is inelastic. This indicates that the environmental costs associated with the various scenarios were not significant enough to change the results of an NPV study of only profits (i.e. a traditional business NPV that does not include costs to society).

Cost Benefit Ratio

Benefits of profit were compared to environmental costs across the ten-year time span. Environmental costs were calculated by applying MEBCalc costs to the emission values from TRACI 2.1. The results of this analysis can be seen in Table 4.

Table 4. Benefit Cost Ratios of revenue received to environmental costs for methylene chloride, benzyl alcohol, and acetone, with green indicating the highest (and best) Benefit Cost ratio.

Scenario	Methylene chloride	Benzyl alcohol	Acetone
Low Loading (BC ratio)	8	18	266
Middle Loading (BC ratio)	6	13	266
High Loading (BC ratio)	5	10	266

The results indicate that every scenario had a desirable Benefit-Cost ratio (B/C ratio), as indicated by all values being greater than one. The benefits of revenue were compared only to the environmental costs. Even when the responsible entity considers the environmental costs to society, the revenue gained makes all options more desirable than not selling any chemical paint stripper. However, some scenarios have higher B/C ratios than others. Acetone consistently has the highest B/C ratio, followed by benzyl alcohol and then methylene chloride.

Discussion & Conclusion

Framework

The developed framework was intended to introduce life cycle concepts to a non-expert audience as a way to achieve the objectives of a First Stage Alternatives Analysis to: (1) identify alternatives; (2) screen alternatives; and (3) identify relevant factors to consider in a Second Stage Alternatives Analysis. This framework successfully addresses these three objectives. The second step of the framework presents a process for identifying alternatives, and the final step introduces a visualization tool to screen alternatives and aid in identifying relevant factors.

This framework is applicable to assessing both formulated and composite products. Consequently, this single framework is general enough to provide guidance to a wide variety of users. It serves as a starting point for the assessment, providing general questions that can generate more specific questions that are targeted to a particular product or process.

This approach was tailored to the SCP Regulations. The life cycle phases and the impacts assessed were those identified by the Regulations. Additionally, this framework addresses the time and data limitations expected under the SCP Regulations. While most LCA methods are time- and data-intensive, this framework allows for a relatively quick assessment of data to highlight and focus additional research on life cycle phases and impacts that are most likely to be relevant.

The framework draws from established methodologies, incorporating critical aspects of Alternatives Assessment and LCA methods into a hotspotting approach. The framework emphasizes the importance of a functional unit to compare product performance and the need for well-defined boundaries to avoid double counting of impacts.

The evaluation criteria suggested in this framework are well-established. The framework suggests the use of criteria developed by TURI, but it is important to note that these criteria are similar to other Alternatives Assessment evaluation criteria, such as those developed by the US EPA’s DfE program. The mixture of qualitative and quantitative criteria lends itself to the combination of qualitative and quantitative data gathered under this approach.

While these evaluation criteria have validity, not all sub-impacts to be considered under the SCP Regulations have established criteria (e.g. Biochemical Oxygen Demand or Chemical Oxygen Demand water quality impacts). Further work is needed to develop sound criteria with which to evaluate these data points.

To assess uncertainty, several criteria were considered: (1) the degree of data available; (2) the robustness or the reliability of individual data; and (3) the likelihood of the impact occurring. There is subjectivity in determining a level of uncertainty for a given impact category, particularly with qualitative data. Factors to consider in determining uncertainty include the source of the data, peer reviewed status, and the size of the study. With more quantitative data, this uncertainty assessment can be more objective.

Though the SCP Regulations call for social and economic impacts in the Alternatives Analysis process, this framework did not address those issues. Rather, the framework focused on introducing the concepts of life cycle thinking and suggesting an approach to incorporate these considerations in a time- and data-limited environment. Currently, additional impacts would require a separate assessment. However, this framework is malleable, and the additional impacts could easily be incorporated into this model to avoid conducting a completely separate assessment.

Case Study

The primary function of the case study was to inform the framework development and to test its applicability. Since the framework was designed to be general enough to be applied to both formulated and composite products, both chemical (e.g. benzyl alcohol) and process (e.g. sanding) substitutions were considered in selecting the alternatives for the paint stripper containing methylene chloride.

Based on the results obtained, no alternative would be eliminated from consideration. This may be because only three alternatives were considered in the case study. However, the limited number of alternatives did not narrow or overlook the breath of factors or aspects that need to be considered in an Alternatives Analysis, since they represented sources of alternatives ranging from a "green" chemical substitution to a process substitution. The unique properties of the three alternatives enabled the group to incorporate diverse information for consideration.

The challenges encountered in the case study largely stem from inadequate data, which restricted the research ability and prevented the group from conducting a more in-depth investigation of each life cycle phase. Not all the information regarding the processes and resources involved, or the type and amount of waste generated during each phase was accessible due to constraints such as industry confidentiality. This was especially true of data related to upstream life cycle phases. However, manufacturers might not face as many limitations due to confidentiality when conducting an Alternatives Analysis on their own product. It is important to note that data limitations might be a challenge that future Alternatives Analysis practitioners could encounter, and thus it is critical for the practitioners to face and treat the issue with caution.

Most of the information and data adopted in the study were gathered from governmental or non-governmental agencies and authentic research institutes, such as Agency for Toxic Substances and Disease Registry (ATSDR), US Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH). These institutions provide relatively reliable information regarding toxic substances and harmful exposures that are substantiated by environmental sampling tests, animal laboratory experiments and human exposure assessments. However, the data reliability does not guarantee the robustness of data used in the study. When the human health data associated with less-studied alternatives was lacking, information from animal studies (e.g. lethal dose for rats) was used to extrapolate human health hazards. Thus, data robustness was weakened.

The likelihood of exposure, including almost all the factors integrated in the exposure assessment, was also considered. Factors relating to the concentration of chemicals to which individuals would be exposed (e.g. the application of personal protective equipment or the installation of ventilation), possible exposure pathways, exposure time, and the different exposure thresholds for the sensitive versus general populations, were all considered in the evaluation step. Although the data limitations were further aggravated by insufficient information about exposure scenarios, the consideration of likelihood of exposure enabled the group to identify and incorporate these critical factors or aspects into the framework, which provided a substantial stepping-stone for future practitioners.

Economic Considerations

The economic considerations assessment provided comparable results that incorporated human health and environmental impacts. However, measurement issues may arise due to potential inaccuracies in the data and models used. The human health costs from MEBCalc were calculated from estimated hospital visits and health care costs, meaning they did not incorporate other indirect health costs, such as missed workdays, and did not use data extrapolated from the value of a statistical life. Moreover, estimates of costs and benefits from health impacts are subject to criticism.

With many regulations, it is useful to also conduct a cost benefit analysis based on non-compliance. However, the SCP Regulations do not impose fees for not phasing out Chemicals of Concern; it only fines companies that do not conduct an Alternatives Analysis and file the appropriate paperwork. Therefore, for the scope of this project, the approach of measuring costs and benefits based on non-compliance fines was not applicable.

A number of assumptions were made to simplify the cost benefit model for the scope of this assessment. While sensitivity analysis was performed to test some of these assumptions (e.g. chemical loading level), further assessment of the results' sensitivity to the various assumptions would prove beneficial. For example, no price elasticity was assumed based on a lack of publicly available information regarding price elasticity of demand for paint stripper products. In reality, there is probably some degree of price elasticity. Determining this value and assessing the impacts of price elasticity of demand would improve the robustness of results.

When working with data regarding business entities, much of the information needed to conduct an assessment is proprietary (i.e. owned by a company and unable to be publicly shared). For this reason, many assumptions were made to fill data gaps that resulted from a lack of access to valuable proprietary information (e.g. profit margins and sales rates specific to paint stripper for Home Depot). Future assessments should work to gain partnership with a business so that more accurate and precise data can be used to inform a cost benefit analysis. A future assessment may also benefit from looking at the costs as an intermediate supplier as opposed to an end-of-the-line supplier. This is because an end-of-the-line supplier, like Home Depot, pays minimal to no costs to switch from one product to another. Conducting the analysis as an intermediate supplier allows the costs of updating machinery and switching chemical suppliers to be accounted for. However, the intermediate supplier is not likely going to consider physical substitutions because the facility to make such a product would be entirely different.

Additionally, this study did not incorporate one of the chemical alternatives and the process substitution due to lack of information. For a complete economic assessment, all alternatives must be brought into consideration. To address these information gaps, one could look for existing literature on the alternatives (e.g. LCA of sanding) and use transferrable information. However, it is important to note that different practitioners may arrive at results using different methods. Thoroughly documenting sources and using only the highest quality information available will reduce the uncertainty and variation in results.

Based on the results of the example cost benefit analysis, acetone is the best alternative to replace methylene chloride as a paint stripper sold at Home Depot. Ultimately, a decision was made to use the benefit cost ratio and not the net present value as the metric to inform this recommendation. Of the three options, the results indicate that benzyl alcohol provides the highest net present value. If only the cost benefit analysis was guiding a business decision, then this would likely be the best option. However, the SCP Regulations require a responsible entity to complete an Alternatives Analysis and make a decision within the monetary constraints required to keep doing business. Since the benefits outweigh the costs for all three chemical products (i.e. it will still be cost-effective for Home Depot to continue selling any of the three products), the benefit cost ratio is a more appropriate metric for evaluation in this example. The paint stripper containing acetone has a higher benefit cost ratio than both the methylene chloride and benzyl alcohol products. The cost benefit analysis used to perform the Alternatives Analysis indicates that Home Depot should replace the methylene chloride paint stripper with the acetone paint stripper in its retail line.

Conclusion

The objective of this group master's thesis project was to determine the best available methods for incorporating life cycle screening into the Alternatives Analysis process required by the SCP Regulations. A new framework was developed and tested using a case study of methylene chloride-based paint strippers and three alternatives. It incorporated critical aspects from LCA methods, Alternatives Assessment and hotspot analysis. The framework aims to introduce life cycle concepts to future Alternatives Analysis practitioners and to present a user-friendly visualization of results in a time- and data-limited environment. This framework is intended to aid future practitioners in achieving the objectives of a First Stage Alternatives Analysis.

There is still a lack of objectivity in determining the level of uncertainty for a given impact category due to inadequate data, especially quantitative data, and this aspect of the framework will be refined and tested in future work.

Appendices

Appendix A. Paint stripper chemical alternatives

Paint Removal Options		Pros	Cons
Chemical or Chemical Class	Methylene Chloride	strong	hazardous
	Benzyl Alcohol	less toxic	expensive; slow
	Acetone	good on some surface	not all applications
	NMP (2-mmethyl-2-pyrrolidone)	can be effective	flammable; prop 65
	Dibasic Esters	low toxicity	minimally effective; not good for all applications
	1,3 Dioxalane	good on some surfaces	toxic; not all applications
	Caustic	effective for 1 purpose	only for white lead based paint
	Methyl Esters	effective on most paints	slow; difficult to package
	3-methoxy-3-methyl-1-butanol (MMB)	effective	Flammable liquid VOC
	3-methoxy-3-methyl-1-butyl acetate (MMB-AC)	effective on most paints	VOC; not effective in removing alkyd paints
	Anisole (methoxybenzene)	effective	Combustible; VOC
	Butyl Carbonate	effective on most paints	expensive
	dibutoxymethane (butylal)	effective	Combustible; VOC; not effective in removing alkyd paints
	diethoxymethane (ethylal)	effective	flammable; VOC
	dimethyl carbonate	effective	flammable
	eastmen omnia (butyl-3-	effective on most	VOC; not effective in removing alkyd paints

	hydroxybutryrate)	paints	
	glyercol formal	effective on most paints	VOC; not effective in removing alkyd paints
	PCBTF/Oxsol 100	effective on most paints	not effective in removing alkyd paints
	propylene carbonate	effective on most paints	not effective in removing alkyd paints
	n-butyl propionate	effective on most paints	flammable; VOC; not effective in removing all paints
	soya methyl ester	effective on most paints	not effective in removing alkyd paints
	Steposol MET-10U	effective on most paints	not effective in removing alkyd paints
	TOC (2,5,7,10 tetraoxaundecane)	effective on most paints	VOC; not effective in removing alkyd paints
	ethylene carbonate	effective	solid at room temperature
	trans-1,2 dichloroethylene	effective	VOC; flammable
	Dimethyl Adipate	effective on most paints	not as effective on alkyd paints
	Dimethyl Sulfoxide	relatively effective	toxic; rapid absorption
Physical	Heat	relatively efficient	volatilizes paint toxins; warps softer surfaces
	Sanding	efficient	particulate matter (inhalation concerns)
	Sand Blasting	strong, effective	particulate concerns; damages wood
	CO2 blasting	effective	difficult for consumer projects
	BiCarb blasting		
	Laser	relatively efficient	volatilizes paint toxins; warps softer surfaces

Appendix B. Generalized Worksheet

General questions for Initial Investigation

	Raw Material Extraction	Resource Inputs and Consumption	Intermediate Material Processes	Manufacture	Packaging	Transportation
Initial Investigation (Basic Information Involved in Each Phase)	What raw materials are needed in the final product	What are the major components or active ingredients in the final product	What is the process involved (material inputs, bi-products, etc.)	What is the process involved (material inputs, bi-products, etc.)	What is the size of package	How far is the product transported from the manufacturers to the retailers or consumers themselves
	What processes are used to extract raw materials (naturally or industrially derived)	Are there any additional components or ingredients needed in the products			What type of materials are used for packaging (e.g. paper, glass, plastic)	What type of fuel is used during transportation
						What is the loading size of shipment(s)
						What types of transportation methods are used (e.g. trailer, truck, plane, ship)
	Distribution	**Use**	**Operation and Maintenance**	**Waste Generation and Management**	**Reuse and Recycle**	**EOL and Disposal**
	Is the product sold in a retail store or online	Are there preferential uses of the product (e.g. preference for sandpaper use is on hard wood surface)	What frequency of product use or application	What kind of waste is generated during use	Is it possible to disassemble the product and reuse or recycle a component of the product	Is a permitted waste disposal facility required
	Can the product be rented and returned by multiple users	How large and what type of material is the target product (e.g. the area of the wood surface, is it flat or slope, etc.)	How often is product maintenance required	Are there any collection methods to handle the waste (e.g. dust collection bag in a vacuum sander) - If so, what is it	Are there any special processes involved in recycling and/or reuse of the product or its components	Are wastes landfilled or incinerated
	Can the product be delivered directly from the manufacturer	Is manual labor or electricity required	Are there any additional inputs (e.g. water, energy) required for maintenance			What kind of waste would be generated during incineration and landfilling
		What is the duration of use to achieve a functional unit				

		Is PPE (e.g. goggles, gloves, mask) recommended or required during use				
		Are there approaches to reduce the time or amount of product required to achieve the functional unit (e.g. primer used to make sanding easier)				
		Is the product used indoors or outdoors				

General Questions for Second Level Investigation

	Raw Material Extraction	**Resource Inputs and Consumption**	**Intermediate Material Processes**	**Manufacture**	**Packaging**	**Transportation**
Second Level Investigation (Detailed Information Involved in Each Phase)	Are there any hazardous wastes generated in the process of extraction	Are there any virgin or recycled inputs	Are other inputs (e.g. Energy, Water) required	Are additional materials required	How much material is used in packaging	What kind of machinery is required
	If hazardous wastes are generated, what kind of hazardous waste is it	How much of a particular input (e.g. energy) is required	What kind of waste byproducts would be generated (e.g. paint will result to lead exposure)	Are other inputs (e.g. energy, water.) required	What is the difference in the quantity of the materials used for packaging	What are the sources for different fuels required
	If hazardous wastes are generated, how much	How much would be considered as "Yield Loss"	Would engineered nano-materials be involved in the process (e.g. TiO_2 production is related to nano-materials)			What is the difference between emission factors of the fuels used for different transportation modes
	Are rare materials involved in extraction					
	Distribution	**Use**	**Operation and Maintenance**	**Waste Generation and Management**	**Reuse and Recycle**	**EOL and Disposal**

		How much manual labor, if any, is required to achieve a functional unit	What amount of additional inputs are used for maintenance (e.g. How much electricity is required to maintain the power sander)	How much waste is generated during the use	How often is the product or the components of the product recycled	What amount of waste is generated during the landfill or incineration process
		How much electricity, if any, is required to achieve a functional unit	What components can be replaced or repaired to extend the useful life of the product	Are hazardous waste exposure prevention methods required	How much of the product could be recycled or reused	What amount of the waste is released into the atmosphere
		How much of the product itself is required to achieve a functional unit		Is pretreatment required to reduce waste generation		What amount of the waste is released into water bodies
						What amount of the waste is released into the soil

Generalized Questions for Human Health Impacts

	Raw Material Extraction	Resource Inputs and Consumption	Intermediate Material Processes	Manufacture	Packaging	Transportation
Human Health Specific	Is there an inherent danger to the extraction process (e.g. explosives used in mining)	Are there inherent dangers	Are there inherent dangers (e.g. highly reactive intermediate chemicals used)	Are there inherent dangers (e.g. highly reactive intermediate chemicals used)	Are there inherent dangers (e.g. hazardous chemicals leaking; dangerous machinery)	Are there air quality concerns (e.g. exhaust fumes; greenhouse gas contributions)
	Are volatile organic compounds (VOCs) generated or released	Are VOCs generated or released	Are VOCs generated or released	Are VOCs generated or released		Are there risks of accidents depending on mode of transportation (e.g. chemical explosion)
	Is particulate matter (PM) generated or released	Is PM generated or released	Is PM generated or released	Is PM generated or released		
	Are workers exposed to toxic chemicals?		Are workers exposed to toxic chemicals	Are workers exposed to toxic chemicals		

	Do the physico-chemical properties create routes of exposure for workers		Do the physico-chemical properties create routes of exposure for workers	Do the physico-chemical properties create to routes of exposure for workers		
	Will the distribution of pollutants on a regional or global scale going to affect human environments		Will the distribution of pollutants on a regional or global scale going to affect human environments	Will the distribution of pollutants on a regional or global scale going to affect human environment		
	Distribution	**Use**	**Operation and Maintenance**	**Waste Generation and Management**	**Reuse and Recycle**	**EOL and Disposal**
	Are there concerns of physical harm from labor	What are the short-term and long-term effects on human health (i.e. human toxicity profile of a chemical)	What kind of chemicals and products are necessary for maintenance (e.g. washing clothes)	Is there any potential for human exposure to CoCs	Is there any potential for human exposure to CoC or other hazards	Is there any potential for human exposure to CoC or other hazards
		How is the product used	What kind of fuels are necessary for operation	Are there any special handling requirements (e.g. hazardous waste)	Human labor (e.g. physical strain of moving product)	Are there any special handling requirements (e.g. hazardous waste)
		What are the potential exposure sources for humans (e.g. air, soil, water)				Is manual labor (e.g. physical strain of moving product) involved
		What is the expected exposure concentration in each media?				
		What are the expected exposure routes (e.g. inhalation, ingestion, dermal contact)				

		Does the exposure, including exposure route and concentration vary with or without use of PPE (e.g. mask, gloves, goggles)				
		What is the likelihood of exposure to the CoC for a sensitive population				

Generalized Questions for Environmental Impacts

	Raw Material Extraction	Resource Inputs and Consumption	Intermediate Material Processes	Manufacture	Packaging	Transportation
Environmental considerations including ecological, soil, air, and water quality specific	Does raw materials extraction relate to land-use (e.g. clearing forests for mining)	How much energy is required	What is the fate and transport (downstream pathway) of the waste byproducts	How much energy is required	Are there environment al effects of resource inputs	Are there any GHG emission
	Are fertilizers used to produce a raw material (e.g. cotton, used for sandpaper backing, requires fertilizer)	How much of water would be used	How much of water would be used	How much water is used		Are VOCs released
	Are pesticides used to produce a raw material (e.g. cotton, used for sandpaper backing, is often applied with pesticides)	Are there GHG emissions. If so, will the amount generate adverse environmental impacts (e.g. climate change)	Are there GHG emissions. If so, will the amount generate adverse environmental impacts (e.g. climate change)	Are there GHG emissions. If so, will the amount generate adverse environmental impacts (e.g. climate change)		Is PM generated or released
	Are there GHG emissions. If so, will the amount generate adverse	Are there processes related to land use change	Are there processes related to land use change	Are there processes related to land use change		Are there any other emissions generated from burning fuels

	environmental impacts (e.g. climate change)					
	Will the processes involved in raw materials extraction threaten any species or habitats, especially endangered ones	Are pesticides used	Are pesticides used	Are pesticides used		
	Does the waste generated during raw material extraction adversely impact the water quality (e.g. increasing turbidity, BOD)	Are VOCs released	Are VOCs released	Are VOCs released		
	How is the landscape altered (e.g. compaction, contamination, erosion)	Is PM generated or released	Is PM generated or released	Is PM generated or released		
	What kind of physico-chemical properties are related to the probable phase distribution in the environment (i.e. what are the biodegradation pathways)	Does the waste generated during the process adversely impact the water quality (e.g. increasing turbidity, BOD)	Does the waste generated during the process adversely impact the water quality (e.g. increasing turbidity, BOD)	How are byproducts and wasted materials (e.g. yield loss) managed		
	What parameters would be involved for biodegradation and what kind of meteorologi			Is there any potential for leaks and emissions from facility to the environment		

cal parameters would be considered					
Distribution	**Use**	**Operation and Maintenance**	**Waste Generation and Management**	**Reuse and Recycle**	**EOL and Disposal**
What are the environmental effects of resource inputs	Does the target product generate hazardous waste during use (e.g. lead particles will be generated when using sandpaper to remove lead-based paints)		Is there potential for leaks and emissions into the environment during disposal	Are there hazardous wastes contaminating recyclable materials	Does the target product generate hazardous waste that must be disposed of
Are there any other emissions from fuel (e.g. for forklift)	Are there additional hazard wastes generated due to the use of the product (e.g. dust, noise from a power sander)	Are there GHG emissions. If so, will the amount generate adverse environmental impacts (e.g. climate change)	Are there GHG emissions. If so, will the amount generate adverse environmental impacts (e.g. climate change)	Are there GHG emissions. If so, will the amount generate adverse environmental impacts (e.g. climate change)	Are there GHG emissions. If so, will the amount generate adverse environmental impacts (e.g. climate change)
	Will terrestrial or aquatic plants be directly or indirectly exposed to the hazards generated (e.g. accumulation in terrestrial environments)				
	Will terrestrial, aquatic and/or aerial animals be directly or indirectly exposed to the hazards generated (e.g. accumulation in terrestrial environments)				

		Will any hazardous waste be accumulated in the terrestrial/ aquatic/aerial biosphere through the food chain (e.g. Hg will bioaccumulate in fat tissue)				
		Does the chemical react with other substances to form products that affect air quality (e.g. some VOCs could react with NO_x and form ozone)				

Generalized Questions for Waste and End-of-Life

	Raw Material Extraction	**Resource Inputs and Consumption**	**Intermediate Material Processes**	**Manufacture**	**Packaging**	**Transportation**
Waste and End-of-Life Specific	How much waste is generated	How much of the inputs (e.g. electricity) are lost during transmission & distribution	How much waste is generated	How much waste is generated	How much waste is generated	Transmission & Distribution Losses (i.e. how much of the inputs (e.g. electricity) would be lost during transmission & distribution)
	Is the waste flammable, corrosive or toxic		Is the waste flammable, corrosive or toxic	Is the waste flammable, corrosive or toxic	Is the waste flammable, corrosive or toxic	
	How is waste managed and disposed		What is the typical handling of waste	What is the typical handling of waste	What is the typical handling of waste	
					At what LC phase is waste generated (e.g. transportatio n, use)	
	Distribution	**Use**	**Operation and Maintenance**	**Waste Generation and Management**	**Reuse and Recycle**	**EOL and Disposal**

	Transmission & Distribution Losses (i.e. how much of the inputs (e.g. electricity) would be lost during transmission & distribution)	How much waste is generated	Are wasted generated during operation and maintenance	What kind of waste is generated during the use	What kind of waste is generated from reuse and/or recycling	Does the waste stay in the atmosphere or drop to the soil and surface water with precipitation
		Is the waste flammable, corrosive or toxic		How much of the waste would be managed or collected during the use	How much waste is generated	Does the waste react with other solid, liquid or gas substance to form products that will affect air quality during transportation
		What is the typical handling of waste			Would the waste put human and/or environmental health at risk	

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