PrISM

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CHAPTER 1

Introduction

1.1 Goal

The Goal of Product Innovation and Social Mapping (PrISM) is to empower designers to support a circular economy, create life-friendly chemistry, restore natural capital, and support a just and inclusive society.

1.2 Why is PrISM important?

Chemicals enable our lives as we know them, from personal care products to cell phones. However, the use of toxic chemicals create public health problems including cancers, heart disease, stroke, asthma, reduced fertility, birth defects, and intellectual disabilities. Poor health outcomes from exposure to chemicals disproportionately impact vulnerable populations and economically disadvantaged communities. Chemicals have benefits and hazards, which must both be considered together (1).

Many of the chemicals on the US market have never been fully tested for safety. Toxic chemicals not only influence human health but have detrimental effects on animals, plants, and ecosystems. Harmful chemicals cost the US more than $737 billion (4.4% of GDP) in healthcare costs and lost earnings (2a, 2b).

There are also significant negative impacts from waste: costs for wastewater treatment, reduced property value, harm to wildlife, and many more. Millions of people around the world face increased risk of disease from toxic waste sites, particularly in low- and middle-income regions (3, 4, 5).

Chemical and product designers have the power to change this trajectory of hazardous chemical use and waste generation through sustainable new product development. Using life cycle thinking, considering material sourcing, health and safety exposures, end-of-life possibilities, and eliminating toxic chemicals, you can design more economical, more sustainable, more desirable products. You can use existing design tools and efficiency metrics in concert to create products that are safe from their beginnings as raw materials to the end of their useful life and back into new materials. This can be done with design principles for sustainable green chemistry and engineering as a consistent backdrop.

The impacts of a product over the course of its lifetime are incredibly complex. While a product might excel in one aspect of the life cycle, it may create negative impacts in another. The tradeoffs we make throughout the design process are often nuanced and complicated. This makes it challenging to effectively compare the sustainability of different products that all have different strengths and weaknesses. It also underscores the importance of clearly articulating the boundaries you are able ot address in your design process. But it is possible to increase one's awareness of the impacts and to make more informed decisions in product design and development. Product design is not a static activity, design decisions made early in the process may be revisited at later stages to continue to drive innovation and continual improvement.

To compare chemicals, materials and products for Product Assessment, Safety, and Sustainability (PASS) principles requires that one defines the life cycle stages, identifies all of the the chemicals used and produced and identifies the main impacts and exposures on stakeholders at each life cycle stage.

1.3 Using PrISM

PrISM walks chemical and product designers through a series of modules, applying life cycle thinking and alternative assessment concepts to allow the user to make informed decisions about their design. PrISM builds on alternatives assessment in combination with Design Principles to empower designers to make more informed decisions.

PrISM is applicable for designers at all levels who are interested in applying a holistic framework: * Product designers * Chemical designers * Entrepreneurs * Someone with their first great product idea * Students of chemistry, designer, and related disciplines

PrISM should be used early in the design process, before significant time and resources have been invested. And then it should be used again and again as the design evolves. In some cases, the user will complete step 7 and then cycle through PrISM again with new ideas. In other cases, the user will move forward with product or chemical design before returning to PrISM. Early use of PrISM encourages innovative and disruptive design changes that often discounted later in the process due to the resources already invested in the existing design. Iterative application of PrISM helps product and chemical designers continuously improve the design.

1.4 Additional Resources

Embedded in PrISM are additional resources and tools that will aid designers in evaluating and optimizing product design. These can be accessed at any time, and will help the user progress further in the process.

1. Chemical Inventory
2. Chemical Hazard Assessment
3. Exposure Assessment
4. Stakeholder Considerations
5. Social & Environmental Justice
6. Life Cycle Considerations
7. Decision Analysis

1.5 Product Assessment, Safety, and Sustainability (PASS) principles

The concepts and methods described in this workbook stem from established design principles and tools. Designing products that embody sustainable design principles helps to ensure that products are sustainable and safe. While these design principles do not translate directly into metrics, they do provide a directional compass for the criteria, tools and metrics that allow for measurement. PrISM is founded on Product Assessment, Safety, and Sustainability (PASS) principles, which provide a vision that any sustainable product: * Supports a circular economy * Creates life-friendly chemistry * Restores natural capital * Supports a just and inclusive society

Fig. 1: PASS Principles

PASS principles are founded on existing designed principles, including The American Chemical Society Green Chemistry Institute's Sustainable Design Principles which are derived from the Principles of Green Chemistry and Engineering (6a), and the OECD's Broad Policy Principles for Sustainable Materials Management (6b). PASS principles were developed in collaboration with Interface.

Supports a circular economy. This is a broad and overarching principle that applies to the design of sustainable chemicals materials and products. A chemical, material or product is not sustainable inherently. Rather, sustainability is tied to the dynamic context in which materials flow in environmental and economic systems.

The circular economy concept is simple but difficult to implement. In a linear economy, as chemicals, materials, and products move through their life cycle stages and come to the end of life, they are disposed of as waste. In a circular economy, instead of disposing of products as waste, they become raw material for new iterations of products. To do so requires innovative ways of making products from which materials can be recovered and reused, or the molecular design of chemicals and materials that degrade completely and harmlessly.

A big challenge to a circular economy is the presence of toxic and persistent chemicals in products. Toxic and persistent chemicals in products can spoil opportunities for reuse, recycling and other aspects of a healthy circular economy. Products that support a circular economy avoid hazardous components and include plans for maximizing value recovery at end of life.

Learn more about Circular Design

Creates life-friendly chemistry. Life-friendly chemistry is compatible with life and inherently low hazard. Risk is a function of hazard and exposure. Reducing the inherent hazards of chemicals can help to reduce risk from chemicals, materials and products. Hazards may also be physical. For example, litter is a form of unmanaged waste that can cause physical entrapment and may be mistaken as food by wildlife when it leaks into the environment.

Restores natural capital. Resource efficiency is not just about being efficient and doing more with less. It also includes the imperative to preserve natural capital. Resources that are renewable should not be used faster than they can be regenerated. And resources that are depleting, should not be dissipated and lost to recovery, reuse and recycling. Waste is a sign of inefficiency in a system.

Supports a just and inclusive society. Historically underserved populations are more frequently exposed to environmental hazards and chemicals of concern than those in affluent communities. This contributes to disproportionate health impacts, higher healthcare costs, and a continuing cycle of needless barriers to the best quality of life. This ultimately hinders the diversity of professionals in the field, limiting our collective perspective and ability to solve problems. Sustainable design improvements require that the negative impacts of products are not merely shifted from one population to another.

A number of useful tools already exist to measure various aspects of sustainability. These will help you quantify how products fulfill the vision set forth by these design principles. They include life cycle assessment (LCA), chemical hazard assessment (CHA), exposure assessment (EA), and others. Information about these tools is linked to throughout this workbook.

However, each of these tools only evaluates one sustainability attribute. In reality sustainability attributes are heavily interrelated. Improvement in one area may result in changes in performance in another.

For example, a material such as a plastic may be made only from chemicals with low inherent hazard. If it ends up in a product that is likely to end up as litter and degrades into microplastics, then it is not sustainable. Likewise, extremely toxic chemicals can be made from rapidly renewable feedstock and very efficient processes.

PrISM uses the tools and methods of alternatives assessment and adapts them for use in product design and development. "The objective of an alternatives assessment is to replace chemicals of concern in products or processes with inherently safer alternatives, thereby protecting and enhancing human health and the environment" (8). Inherently safer alternatives may be alternative chemicals, materials, or very different product designs that provide the same product service. Step 6 - Whole Product Assessment - includes examples of disruptive innovations versus safer substitutes.

1.6 Alternatives Assessment

Alternatives assessment (AA) is a structured method to evaluate alternatives to chemicals of concern in products and processes. Alternatives may include chemical substitutes, alternative materials or product and business model designs that eliminate the need for the chemical of concern altogether.

AA helps to ensure that designers make changes with their eyes wide open. The intent is to avoid negative 'unintended consequences'. That is, to make sure that one does not move away from a chemical of concern in a product to an alternative that is unknown or potentially more problematic from the health and sustainability perspective. AA supports informed decision making. A number of AA guides are listed below. They provide resources for assessing alternatives for chemical hazard, exposure, economic impacts, performance, life cycle impacts, materials management, social impacts and more.

The tools and decision frameworks in AA can also support product design. Product assessment and product design are closely related. In the design process, the designer considers his or her options for chemicals, materials, business models, manufacturing options and more. Each of these options can be evaluated from a holistic perspective to inform decisions along the way. That is why this workbook builds on alternatives assessment in combination with PASS Principles to empower designers to make more informed decisions. Alternatives assessment, like all assessment tools is limited by the availability of good data. Despite that drawback, approaching design from a life cycle perspective and using the tools of alternatives assessment to assess various options can help stimulate ideas for product innovation.

- Visit the IC2 website to access the complete IC2 Alternatives Assessment Guide
- A Framework to Guide Selection of Chemical Alternatives (National Research Council)
- Washington State Alternatives Assessment Guide for Small and Medium Businesses
- California Safer Consumer Products Alternatives Assessment Guide v1.0

1.7 Introduction to Life Cycle Stages

Every chemical, material and product has a different life cycle. Depending on the supply chain associated with a chemical, material or product, it may be necessary to separate out production and manufacturing into multiple stages.

As you work through PrISM, think through each step of the supply chain and the individual 'unit processes' that bring the product from conception to production and manufacture to delivery to the user to the end of its useful life and hopefully into future materials and products. Where possible, map out the life cycle stages. This information will also support better understanding of the chemical ingredients used throughout the life cycle and potential stakeholder impacts including exposures.

Consider including some (screening) or all (advanced) of the unit processes in the life cycle stages as illustrated in the graphic below (9). The life cycle of an ideal product is circular.

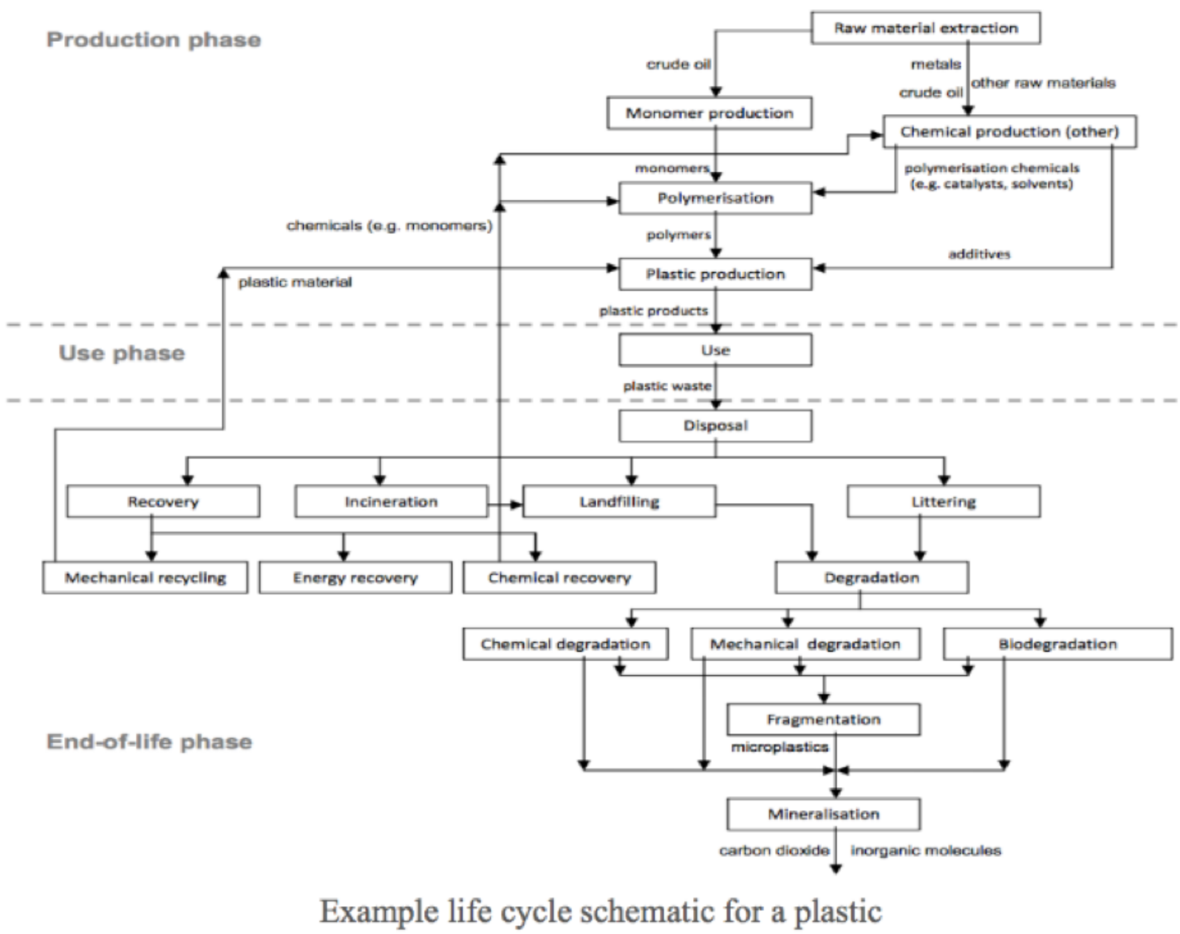

Fig. 2: image

1.8 Acknowledgements

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CHAPTER 2

Step 1 Scoping and goals

2.1 Goal:

To help clarify your sustainable product design objectives. You will consider:

1. Your product sustainability goals and priorities
2. The various life cycle stages of your product

2.2 Introduction

The first step is to clarify the product concept and design specifications and what your goals are for the product. Initial design specifications determine which sustainability criteria are most relevant to assess.

2.3 Example: Floral Soil

A product concept with exceptional ambitions for sustainable product design is Floral Soil. Floral Soil is designed to replace conventional floral foam used by florists to hold flowers in place in an arrangement and to keep them moist. The designer set out to create a product that was 'safe enough to eat' in addition to being biobased, biodegradable in home gardens or compost, reusable and high performing with respect to holding water to replace current floral foams.

Floral Soil design goals includes: 1) Non-toxic 2) Bio-based 3) Biodegradable 4) Grow seeds 5) Hold water

Learn more about Floral Soil Solutions.

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Fig. 1: Floral Soil design goals

CHAPTER 3

Step 2 Feedstock

3.1 Goal:

To use base feedstock that preserves ./or restores natural capital while providing performance and other sustainability benefits.

3.2 Introduction to Feedstock Concerns

According to the World Forum on Natural Capital, natural capital is defined as the world's stocks of natural assets that include geology, soil, air, water and all living things. Humans depend on natural capital for a wide range of ecosystem services. Poorly managed natural capital can destroy productivity and resilience, making it more difficult for humans and other species to sustain themselves (6). To meet the design principle of Maximizing Resource Efficiency, it is necessary to preserve natural capital. The choice of feedstock can have significant impacts on natural capital.

Best practices strive to decouple feedstock selection from negative impacts on natural capital such as natural resource depletion and negative impacts on communities from raw material extraction. Some feedstock is not renewable but it may be abundant.

Other feedstock such as certain metals may be rare and metals are of course not renewable. The use of renewable feedstock will not be sustainable if degradation or consumption of it occurs at a rate that is faster than the resource can regenerate. If a depleting feedstock is used, then care should be taken to ensure that the materials will be recycled once no longer needed.

Products based on depleting natural resources or renewable resources that degrade land or compete with food production do not preserve natural capital and do not support sustainable product design. Feedstock derived from easily recycled materials, readily available wastes such as agricultural wastes or rapidly renewable and abundant biomass like algae or seaweed may help to preserve natural capital. For some renewable raw materi./feedstock, certification programs are available to ensure that the resources are responsibly managed for environmental, social and economic benefits.

At a minimum, define the primary feedstock used to generate the chemical, material or product. In general, rapidly renewable or waste derived feedstock results in supply chain benefits. Evaluations can be enhanced by 'designing with the end in mind'. Think about whether or not there is a relationship between feedstock and waste management options. Can they be linked to create both supply and demand for materials that cycle in a sustainably managed material economy.

3.3 Example

3.3.1 Examples of renewable feedstocks

Image source: Department of Energy

3.3.2 TidalVision USA uses waste from sustainable fisheries

TidalVision USA is an early stage company based in Bellingham, WA that uses fishery wastes to make high value products. They refer to this as 'upcycling' because a low value waste material is used to make a high value product. Their goal is to add value to the sustainable fishing and crabbing industries by generating value from the waste. The company treats salmon skins to make salmon leather using benign chemical process and makes wallets, purses, and other high value products. They also process crab waste to make a variety of useful products based on chitosan that is derived from the chitin in the shell wastes. The founder of the company is an Alaskan fisherman who was disturbed by the scale of fisheries byproduct wastes and became a social and environmental entrepreneur. He uses wastes from sustainable fisheries to add value to an industry that strives to operate sustainably.

Fig. 1: two billion pounds Alaskan fisheries byproducts wasted annually

Fig. 2: wallets made from salmon skin

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CHAPTER 4

Step 3 Production manufacturing

4.1 Goal

To produce and manufacture products in a way that restores natural capital and utilizes life-friendly chemistry in order to protect workers and those who live around the production or manufacturing facility who may be exposed to chemicals and other emissions from production and manufacturing.

4.2 Introduction

All chemicals used in production and manufacturing have the potential for exposure to workers, neighboring communities, and the environment. Even chemicals not intentially added to a product, such as mold release agents or cleaning agents, may still end up in the product as residuals.

Strategies for meeting the goal require knowing the chemicals used and produced and understanding their inherent hazards and potential exposure pathways. Exposure levels do not need to be quantitatively measured in most cases. Rather, qualitative exposure assessment may be based on the presence of a chemical in a form that can be inhaled, ingested or absorbed through the skin.

Building a chemical inventory is an important step for knowing all of the chemicals involved in making your product. See Resource 1 - Chemical Inventory for guidance and suggestions. The chemical inventory will help you answer guiding questions in the next few steps as well. While identifying all of the chemicals involved can feel like a daunting task, even small amounts of hazardous chemical ingredient additives can greatly impact the sustainability attributes of a product. Additives to plastics and residual chemicals from manufacturing can: * Affect recycling, incineration, and value-recovery options * Be hazardous to workers, the environment, and users * Leak into the environment after disposal * Affect the quality of recycled materials and how they can be used in future products The more you know about what is in the material and what was used to create the material, the better you can identify areas for improvement. Gather as much information as possible now, and identify your data gaps where you are unsure of the chemicals used. Researching and filling in those data gaps is potentially an important action item, as is substituting out known hazardous chemicals.

Once you have built your chemical inventory, you can determine which chemicals are hazardous and may need to be substituted out. See Resource 2 - Chemical Hazard Assessment for guidance and suggestions on learning about the hazards of the chemicals in your inventory.

Restoring natural capital requires measuring the use of energy, water, materials used and the generation of waste in order to benchmark a product against other products or to guide efficiency improvements. Many of these are measured in a Life Cycle Assessment. See Resource 6 - Life Cycle Assessment for guidance and suggestions.

For a comprehensive sustainability assessment, manufacturing must consider economic, social, and environmental impacts. PrISM is founded on Product Assessment, Safety, and Sustainability (PASS) principles, which provide a vision that any sustainable product: * Supports a circular economy * Creates life-friendly chemistry * Restores natural capital * Supports a just and inclusive society

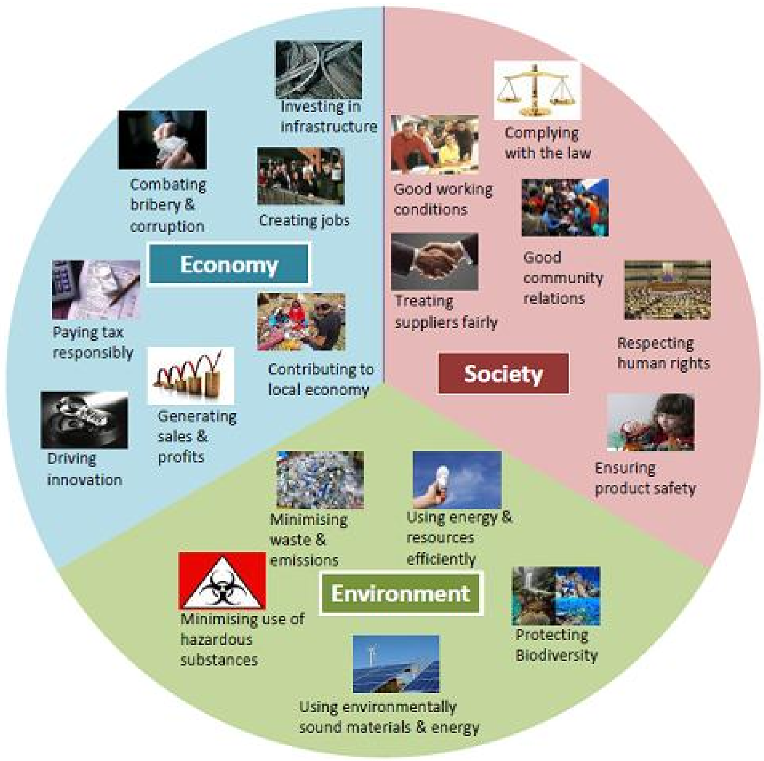

Fig. 1: Consider Econony Society and Environment

Image Source: OECD Sustainable Manufacturing Toolkit

See Resource 4 - Stakeholder Considerations and Resource 5 - Social and Environmental Justic for guidance and suggestions on assessing economic, social, and environmental impact.

4.3 Examples

Grow Plastics developed a way to produce food packaging such as meat trays made from corn-based polylactic acid (PLA). These trays do not require any chemical additives, a big concern for some plastics and other packaging materials where the chemical additives can leach into food. Their PLA trays are made with a unique sandwich panel construction that achieves the desired performance properties but uses less material. Grow Plastics has found that their products produce only./4 the CO2 from materials manufacture compared to conventional plastics. Their lighter-weight biobased products are designed to reduce consumption of materials to preserve natural capital while providing a product with improved performance.



Learn more about Grow Plastics

Image Source: Grow Plastics

Image Source: NatureWorks

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CHAPTER 5

Step 4 Use

5.1 Goal

To minimize or eliminate hazards in products and pollution and increase the use of life-friendly chemistry during the use stage of the product's life cycle. To restore and preserve natural capital by preventing the generation of waste.

5.2 Strategies

- Use low hazard chemicals in materials and products
- Use especially low hazard chemicals in applications where high exposure is likely to occur
- Make products that are intended to last
- Make products from materials that are readily recovered and recycled after use
- Make sure that the user knows what to do with the product after use

Building a chemical inventory is an important step for knowing all of the chemicals in your product. This is the first step to understanding if the chemicals used support life-friendly chemistry, or if they are hazardous. See Resource 1 - Chemical Inventory for guidance and suggestions. The chemical inventory will help you answer guiding questions in multiple PrISM steps as well. While identifying all of the chemicals involved can feel like a daunting task, even small amounts of hazardous chemical ingredient additives or residuals from processing aids can impact the sustainability of the product. The more you know about what is in the material and what was used to create the material, the better you can identify areas for improvement. Gather as much information as possible now, and identify your data gaps where you are unsure of the chemicals used. Researching and filling in those data gaps is potentially an important action item, as is substituting out known hazardous chemicals.

Once you have built your chemical inventory, you can determine which chemicals are hazardous and may need to be substituted out. See Resource 2 - Chemical Hazard Assessment for guidance and suggestions on learning about the hazards of the chemicals in your inventory.

5.3 Examples

5.3.1 3D printing

3D printing or additive manufacturing is a technology that continues to advance rapidly. It is used in schools, a diversity of industries, and homes. One aspect of 3D printing that is unique at this time is that it moves elements of manufacturing from the factory to the home or shop. Decentralizing manufacturing makes it harder to oversee the use and generation of hazardous chemicals and makes the use of materials that are safe and benign even more imperative. When filament made from the plastic ABS is heated, melted and extruded in a 3D printer, it can create volatile compounds and nanoparticles that are harmful to human health. Corn based PLA filament is much safer than ABS when used as filament in additive manufacturing, but PLA can also produce harmful emissions if heated at a high enough temperature.

Fig. 1: Image of 3D printers and printing materials

Image source: NASA

5.3.2 Food take-out containers

Some fiber-based food take-out containers contain highly fluorinated organic chemical additives to prevent wet or oily food from leaking through the container. However, it's nearly impossible to tell just by looking at a product, like the ones pictured below, whether or not they contain such chemicals. In the case of food packaging materials, toxic, extremely persistent, environmentally-harmful chemicals are of particular concern because they come in contact with our food. This is why it's so critical to design products from the outset to be functional during use without the need for hazardous additives.

Different kinds of food packaging, including a pizza box, an egg carton, hot and cold take-away cups, plasticware, and a food take-out clamshell.

Image Source: City of Plymouth Minnesota

Which of these compostable items probably contains fluorinated additives? A chemical inventory must be completed in order to know. See Resource 1 - Chemistry Inventory for guidance and suggestions.

With regards to single-use food contact materials, the Center for Environmental Health tested plates, bowls, clamshells, and multi-compartment food trays for total fluorine content, which would indicate the use of highly fluorinated additives, and the resulting report is available on-line.

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CHAPTER 6

Step 5 End of life

6.1 Goal

To restore natural capital and support life-friendly chemistry by eliminating waste, hazards and pollution associated with the fate of chemicals, materials and products after use. Waste may be mitigated by designing a product for longevity and durability or for reuse and recycling.

6.2 Introduction

End of life hazards include chemical hazards but also physical hazards from litter. A viable waste management pathway for a product once it is no longer needed should be part of the initial product design. In addition, consumers should have clear information on how to best ensure proper management and value recovery.

'Cradle to Cradle' thinking calls for deciding up front whether the materials in the product are intended to be 'biological nutrients' within a 'biological cycle' or 'technical nutrients' within a 'technical cycle' (or both). If a chemical or material is intended to be a biological nutrient, its fate should result in complete and benign biodegradation in its likely waste pathway, whether that is wastewater treatment, compost, etc. If it is intended to be a technical nutrient, it should be reused or recycled in either a widely available recycling system or in a system managed by the product manufacturer to ensure recovery and proper management. Green Blue Institute has developed the How2Recycle Labeling program to assist with optimizing proper end of life management of packaging materials.

The chemicals and materials in a product can enhance or diminish the value of recycled materials. They can also cause problems with different waste management pathways. For example, if a toxic and persistent chemical is included in a commercially compostable plastic, the plastic may biodegrade, but the additive will not. It will stick around and contaminate the compost and make it less valuable. By building a chemical inventory, you identify what chemicals are likely present in the product.

See Resource 1 - Chemical Inventory for guidance and suggestions. This will help you determine which are likely persistent and resistant to degradation, as well as which are likely to break down and what they may break down into, and whether or not these chemical ingredients are toxic as well.

See Resource 2 - Chemical Hazard Assessment for guidance and suggestions on learning about the hazards of the chemicals in your inventory.

Learn more about Cradle to Cradle design.

Consider how your product will have the least impact on human health and the environment after use by striving to be near the top of the waste hierarchy. While there are exceptions to the waste hierarchy, the idea of first preventing waste, then recovering the most material value with the least negative life cycle impacts still holds.

Plastic straws are an example of an exception. When used on beaches, they are frequently littered as opposed to properly disposed of, so it is unlikely that a recyclable straw would actually be recycled. A biodegradable straw is a better fit considering the likely end of life pathways. Another preferrable alternative could be re-usable straws paired with programs to ensure their return, minimizing litter.

6.3 Possible End of Life Pathways for Products After Use

Waste mismanagement and littering are forms of what is called 'leakage' to the environment. It is an all too frequent and very undesirable waste pathway. Estimate how likely it is that leakage to the environment will occur. Using global statistics based on types of waste found in the environment is recommended. Estimates based on regional differences are relevant. For example, some of the more frequently found litter includes cigarette butts and plastic bags.

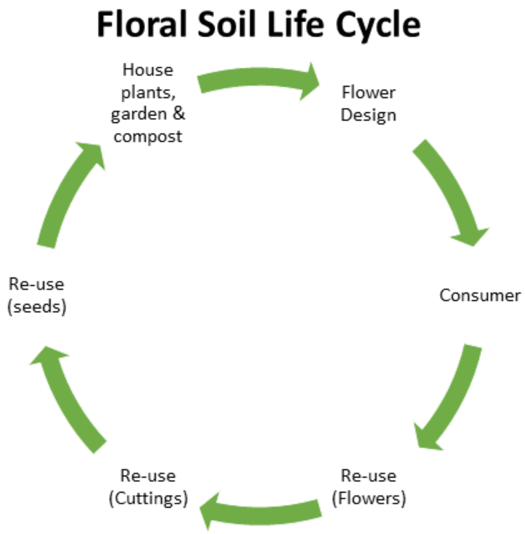
- Leakage (improper management, litter)
- Landfill
- Incineration with no energy recovery
- Incineration with energy recovery
- Recycling (primary, secondary, tertiary or quaternary)
- Compost (commercial)
- Compost (backyard)
- Other biodegradation (aquatic (fresh, marine), aerobic, anaerobic)

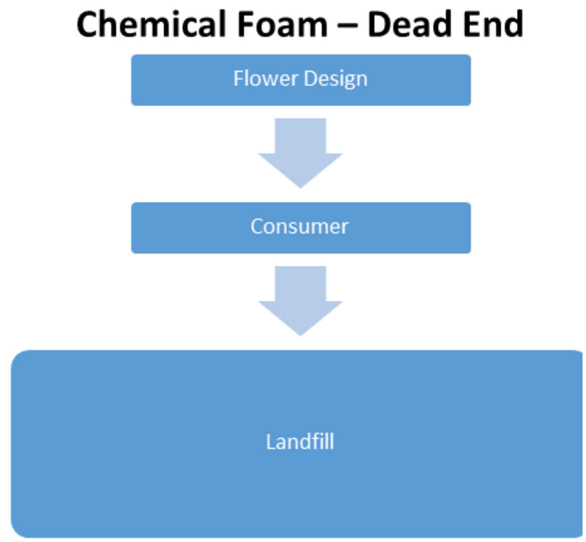
Be sure to include only pathways that are actually available in the area your product is used. While food packaging made from PLA may be potentially compostable in industrial facilities, this is not relevant if the area does not have industrial composting facilities, or if those facilities have chosen to not accept plastic products.

6.4 Examples

6.4.1 Example 1: Design for Multiple EOL Pathways

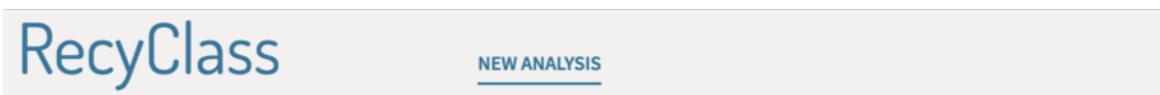
Floral Soil Solutions designed the Floral Soil product for multiple end of life pathways. First of all, the product is designed for reuse multiple times for holding cut flowers. It can also be used to grow plant plants starting with cuttings and even seeds. After multiple uses, if the product is truly spent, it can be added to enhance soil in houseplants, in a garden or in compost.

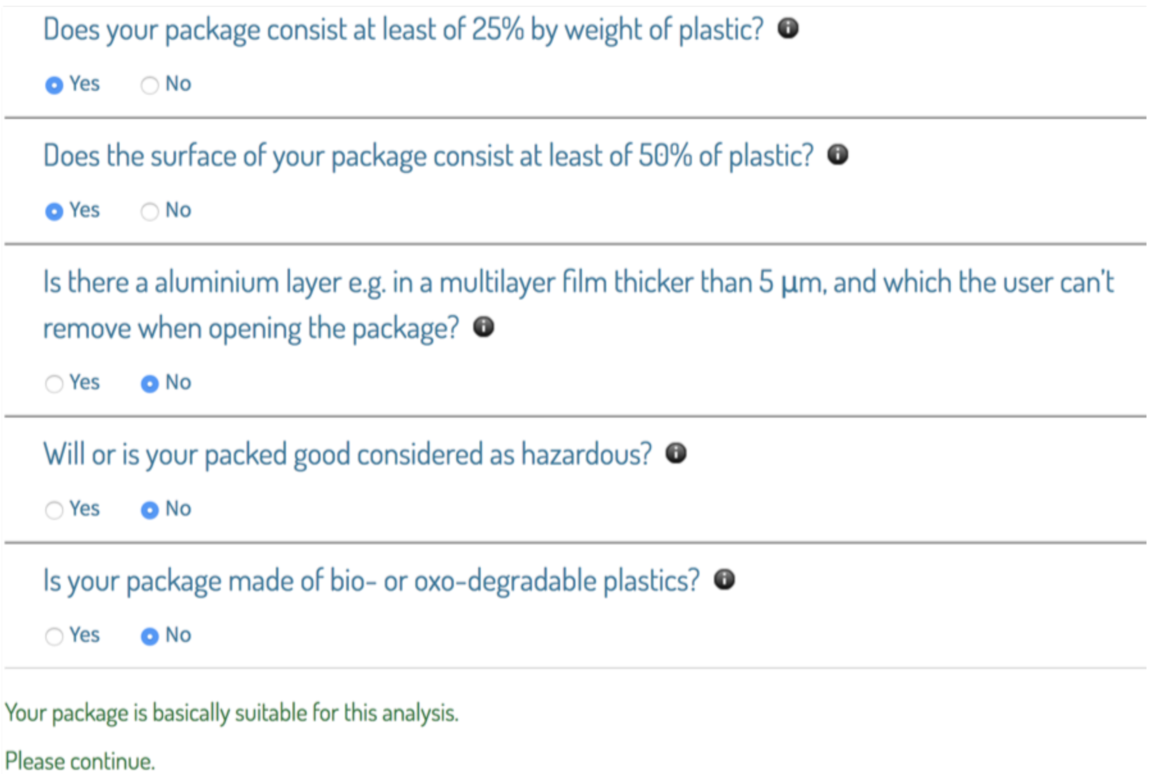




6.4.2 Example 2: Design for Value Recovery

A good model for integrating product design with material recovery is the RecyClass Tool developed by Plastics Recyclers Europe. RecyClass guides the choice of plastic used in packaging and promotes recycling. It addresses the presence of incompatibilities that affect the efficiency of recycling. Plastics that are easy to identify and to separate from the rest of the product, and for which there is an established Plastics Recyclers Europe (PRE) recycling stream score better. RecyClass is limited to a small variety of plastics such as PET-bottles, PE-LD and HD, polyolefin tubs and trays, PVC from the building sector and some technical plastics. While limited in scope, the tool is a good model for how product design considerations can be linked to material selection and to material recycling options.





6.4.3 Example 3: GreenBlue's How2Recycle

Green Blue Institute has developed the How2Recycle Program to provide structured guidance for how to communicate information to customers on how to manage a product's packaging once it is ready to become waste.

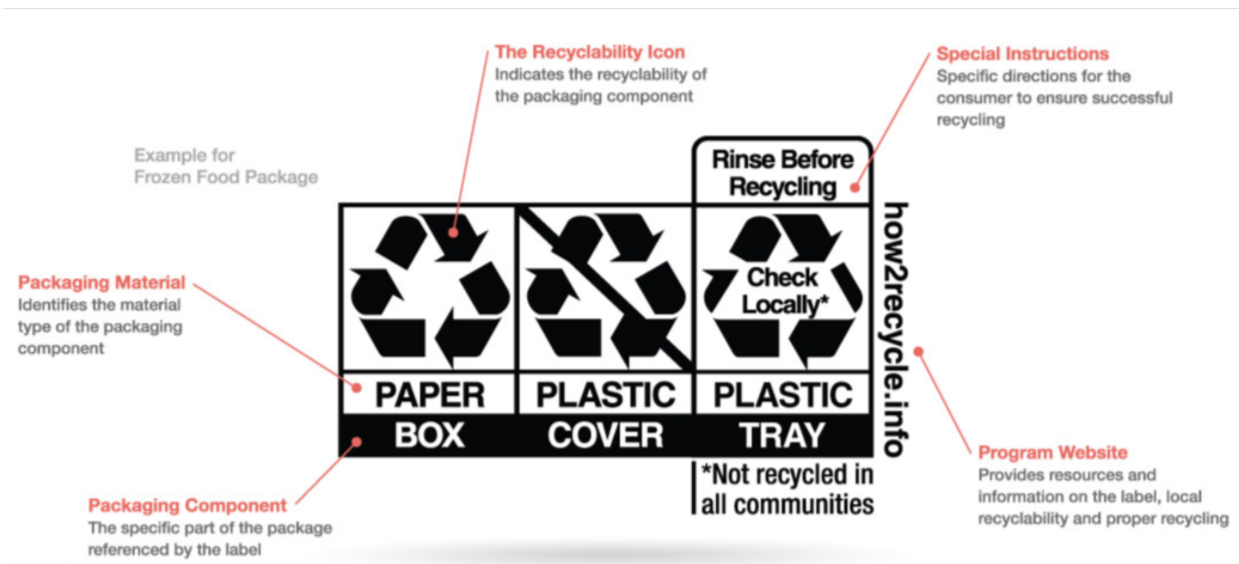


Image Source: GreenBlueLearn more about the Green Blue Institute's How2Recycle Program

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CHAPTER 7

Step 6 Whole product

7.1 Goal

To drive innovation and not just incremental improvements. To restore natural capital and to use life-friendly chemistry over the entire life cycle of the product. To integrate the product into the circular economy.

7.2 Introduction

Remember that there is no one tool or metric that used alone is sufficient for credible and meaningful comparisons. As mentioned previously, it is always useful to check one's assumptions – a product that appears the most sustainable should always be checked against other products and services that perform the same function.

Focusing on materials only may cause a designer to miss truly innovative opportunities. There's an opportunity for designers who wish to create sustainable solutions to develop disruptive innovations. By disruptive innovations we mean new products that provide the same function as old products but in a very different and potentially much improved way. See the examples below on disruptive products. The GO Box turns the need for disposable single use packaging on its head. And the Drive-in Boatwash can eliminate the need for biocidal boat paints altogether.

PrISM can help give you insight into all aspects of your product's life cycle. Critically, it can also help you identify what you **don't** know about your product. Honing in on missing pieces of the puzzle will highlight areas that need additional or deeper evaluation, opportunities for innovation and improvement or where your product really shines.

7.3 Innovative Approaches

In some cases, there may be entirely different pathways to achieving the desired function. What other products or services achieve what your product will? Innovation does not need to occur only at the chemical level. In the examples below, different kinds of innovation that can lead to disruptive new products in the marketplace are described.

Design innovation. Designing new products to integrate circular economy design principles while reducing the use of toxic chemicals to meet performance needs.

Materials innovation. Achieve performance requirements without toxic additives. Examples may include inherently biodegradable materials, especially in the marine environment and materials that fit within the existing materials management infrastructure. Use of biomass that does not compete with food production such as agricultural wastes can support EOL management via feedstock innovation. How do the materials chosen fit in a circular economy?

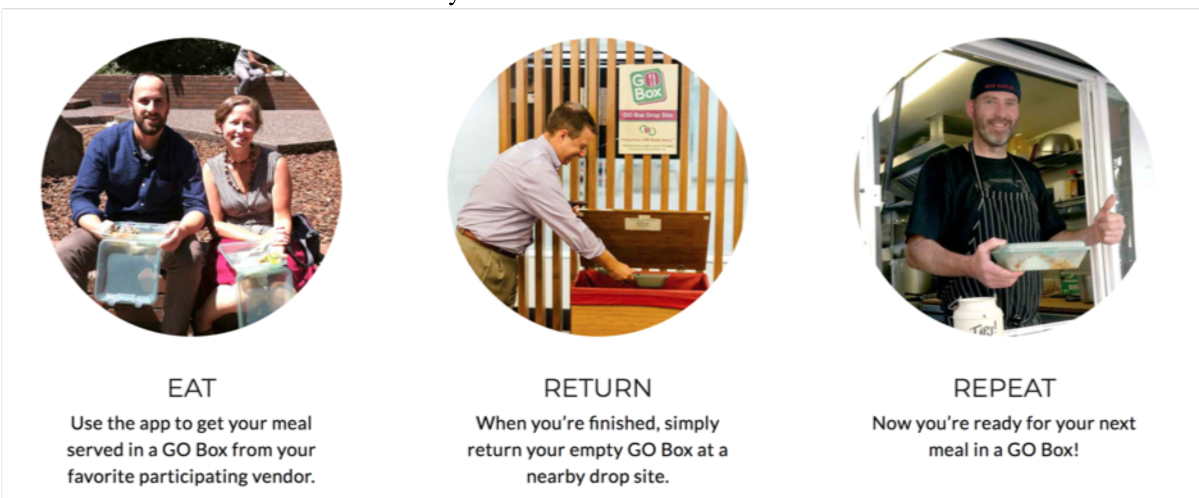
Manufacturing innovation. Optimizing the use of materials through processes such as 3D printing. There is need for innovation in manufacturing for new materials such as injection molding and extrusion of biomass feedstock such as paper pulp and bagasse, and for processes that are scalable and low-cost using locally available materials.

End of life (EOL) innovation. Technologies and business models for collecting, sorting, reusing, and recycling plastics that avoid generating waste or toxics. Waste-to-value innovations are needed to convert plastic waste into high value base materials with sufficient purity that they can displace virgin materials and facilitate high value uses of recycled materials.

7.4 Examples

7.4.1 GO Box

One example of an innovative product that is an alternative to single-use food packaging is GO Box. The start-up created a reusable plastic food container to eliminate waste from take-out food from your favorite food trucks. *Learn more about GO Box.*



7.4.2 Drive-in Boatwash

Drive-In Boatwash is another example of a disruptive innovation. Copper-based antifouling boat paints are common and effective, but they are toxic to aquatic life. The drive-in boatwash is an alternative solution to non-copper-containing boat paints that also reduces the risk to marine life.

Learn more about the Drive-in Boatwash's visit to Washington State. Visit their website.

*

Boats drive in for automate bottom hull cleaning Image Source: Drive-in Boatwash

7.4.3 Bio-inspired innovations

Nature uses life-friendly chemistry to achieve diverse functions. Nature can inspire innovative solutions to today's sustainability problems. One example is photosynthesis-inspired solar power. Plants convert solar energy into chemical energy, fueling growth. Solar cells perform a similar function, ultimately converting solar energy into electrical energy to power homes, factories, and more.

Image source: Aldo C. Zavala, CC BY ND

Explore asknature.org for ideas relating to your product.

7.5 What next?

Your innovative ideas may represent an enormous departure from your current product. It will be important to compare your current product and your innovation(s). Numerous tools can assist with this process, like life cycle assessment (LCA) and chemical hazard assessment (CHA). If you are not sure which resources and tools to start with, use PrISM on the innovative alternative to identify differences. Alternatives Assessment, which is discussed in the introduction, can be a valuable tool for comparing disparate products. The Interstate Chemicals Clearinghouse (IC2) publishes a comprehensive guide to Alternatives Assessment. The Washington State Department of Ecology has published a complimentary guide for small and medium business.

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CHAPTER 8

Step 7 Evaluation and Optimization

8.1 Goal

To encourage transparency, to identify opportunities for improvement and data gaps that need to be researched, to avoid unacceptable tradeoffs and to ensure consideration of all of the PASS principles.

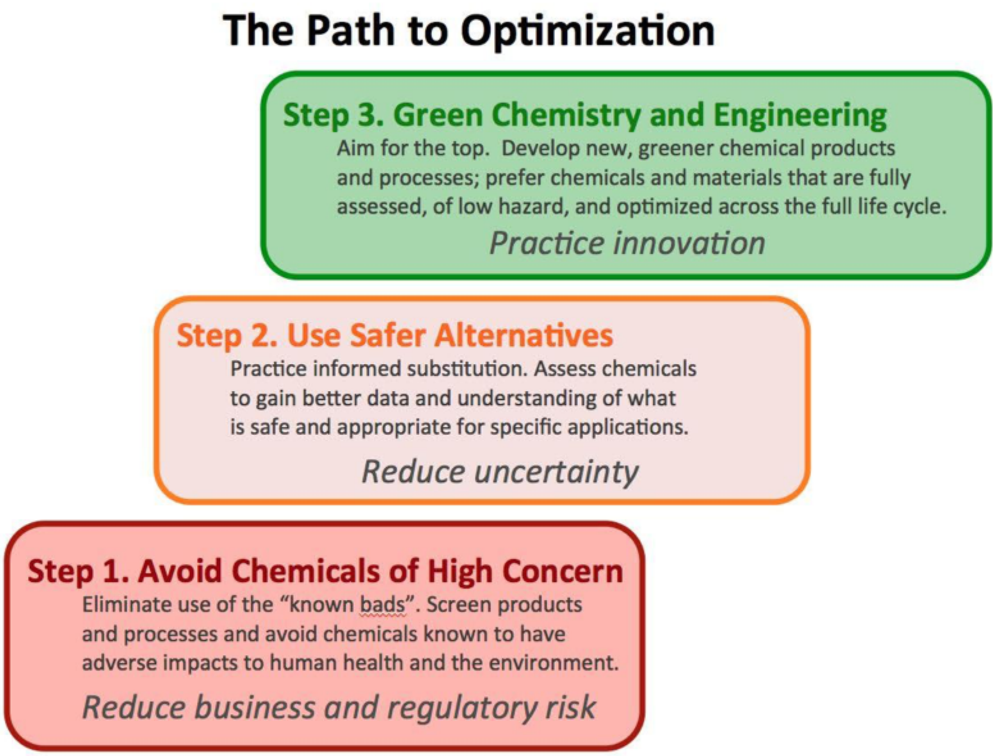
8.2 Introduction

In the introduction at the start of PrISM, we discussed the importance of taking a holistic approach to product design and using PASS Principles to guide holistic design. Product design as a creative endeavor requires tradeoffs. While tradeoffs are inevitable and challenging, there are different ways to manage them.

Wherever there are tradeoffs, *transparency* can support credibility and ensure that decisions are clear and understandable. Tools that are 'black boxes' or that provide results without transparency are not recommended because it will not be clear if the assessment aligns with the stated goals and objectives of the product designer.

Based on the initial problem formulation step, the designer may have established sustainable product design goals. Those goals should be revisited to help the designer identify which aspects are most important. Based on new information and perspectives, the product design goals may be modified in an iterative way.

PrISM can help give you insight into all aspects of your product's life cycle. Critically, it can also help you identify what you **don't** know about your product. Honing in on missing pieces of the puzzle will highlight areas that need additional or deeper evaluation, opportunities for innovation and improvement or where your product really shines.



Optimization is a process of continual improvement. Sometimes the first step is to simply eliminate chemicals or materials of high concern. That can have immediate benefits and it can get the product on the path to Sustainable Green Chemistry and Engineering design.

Data gaps in hazard information are also likely. A tiered approach to hazard screening that begins with hazard list screening and moves to intermediate and then more comprehensive approaches to chemical hazard assessment is appropriate. See Resource 2 - Chemical Hazard Assessment for guidance and suggestions. Using life cycle thinking to narrow the focus of the assessment to those elements that discriminate between options helps to limit data needs. See Resource 6 - Life Cycle Assessment for guidance and suggestions.

Substituting safer chemicals for chemicals of concern in products is a good step. But it is not the end of the road. True innovation happens when designers strive to optimize all of the PASS Principles: * Supports a circular economy * Creates life-friendly chemistry * Restores natural capital * Supports a just and inclusive society Innovative solutions may be found that are not incremental but that are truly disruptive to the marketplace as exemplified in Step 6 - Whole Product Assessment.

8.3 Data Gaps

Filling data gaps can be time- and resource-intensive. All considerations identified in this report are subject to data challenges and subsequent uncertainty. For example, it may not be possible to identify every reagent, auxiliary, additive, and every degradation product formed in a product life cycle. Therefore focusing on those life cycle stages likely to result in the greatest exposure to hazardous chemicals should be prioritized.

Data gaps in hazard information are also likely. A tiered approach to hazard screening that begins with hazard list screening and moves to intermediate and then more comprehensive approaches to chemical hazard assessment is appropriate. Using life cycle thinking to narrow the focus of the assessment to those elements that discriminate between options helps to limit data needs.

Go to Resources: Decision Analysis

Learn more about Chemical Hazard Tools and Methods

8.4 Criteria Weighting

In an ideal universe, an alternative would be optimal for all categories, i.e. low hazard, uses sustainable feedstock, clean production and manufacturing processes, many material reuse cycles, etc. However, this is rarely the case and tradeoffs have to be made. Tradeoffs arise both between and within categories. For example, within hazard assessment, additives may not be Substances of Very High Concern (SVHCs) but they may be moderately hazardous to humans or the environment in different ways.

Fortunately, CHA methods are becoming increasingly standardized to allow for transparent tradeoffs between different hazards within a hazard profile.

Tradeoffs also occur between different impact categories. For example, one option may use more water while another may generate more waste during use. These tradeoffs must be judged against product design goals and using all three Design Principles for Sustainable Green Chemistry and Engineering (below). What is important is that the designer avoids potential perverse outcomes by focusing on only one principle. And that the decisions are made in an informed and transparent way so as to avoid unintended consequences.

Fig. 1: PASS Principles

8.5 Trade Offs

8.5.1 Set baseline requirements

While tradeoffs may be necessary, baseline limits can be set so that gains in one category do not result in unacceptable losses in another. For example, while effective recyclability and available recycling infrastructure are desirable; they are not viable tradeoffs for plastics that violate a design objective to avoid substances of very high concern. Lesser levels of chemical hazard may be acceptable assuming that exposure to those chemicals does not result in unacceptable levels of risk to workers, users or the environment. Identify those trade offs that are ‘show stoppers’.

8.5.2 Apply Decision Analysis

In decision analysis, you will use logic models to evaluate information in way that increases clarity around which options are preferred or less preferred. There are a variety of existing frameworks. You can consider options one at a time in a sequential way or, alternatively, you can consider all the the options simultaneously using a mathematical algorithm. Yet another approach is to use some hybrid of these two frameworks.

Go to Resources: Decision Analysis

8.6 Next Steps

Completing this step will help you identify action items for improving your product or processes. Your next step may involve doing research or testing to fill in data gaps, or you may have already identified a hot spot that needs to be addressed. As you complete these action items, return to PrISM to re-assess your progress and next steps. PrISM is designed to be used iteratively to improve product design.

8.7 Example

Sometimes it makes sense to phase out a problematic product and to start over. Other times it makes sense to improve its next incarnation informed by PASS Principles.

Figure 5: Decision Logic for Deciding to Phase-out a Product Containing a Chemical of Concern

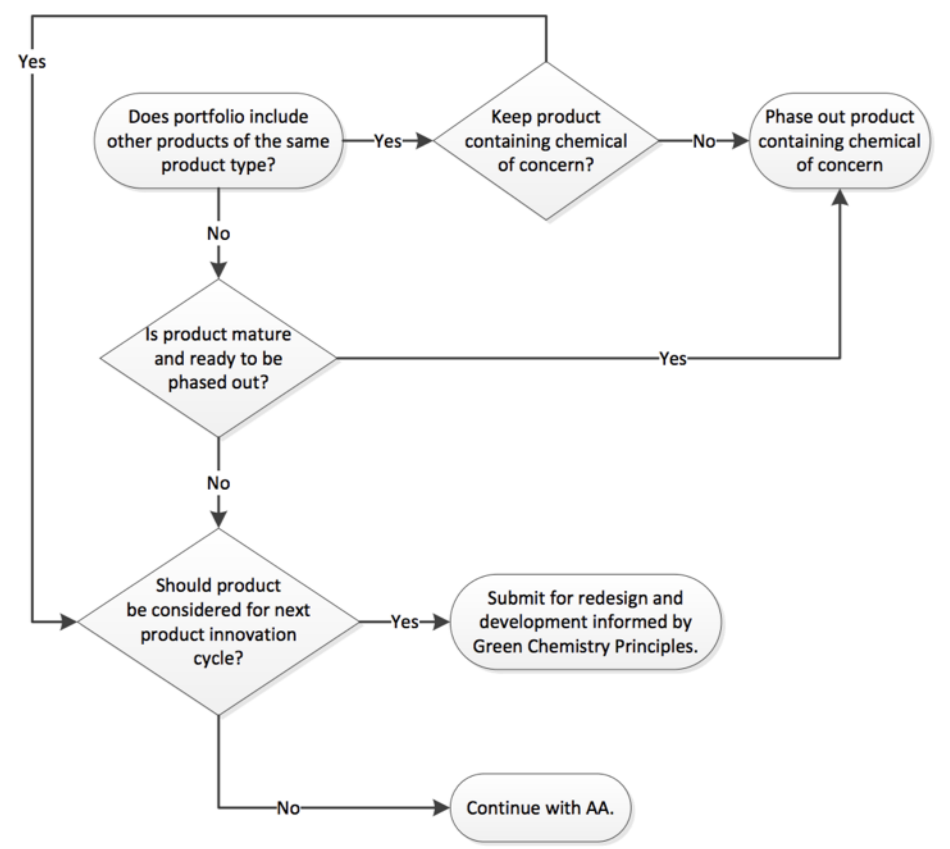


Image source: Page 18 (page 28 pdf) of the IC2 Alternatives Assessment Guide

Learn more about decision analysis in Resource 7 - Decision Analysis

8.8 Reviewing your answers

We recommend generating a pdf report and having it open in another window, or printing it out for easy viewing, while answering these questions. You will be reviewing your previous answers and working to identify data gaps, hot spots, and your next steps for product optimization.

You can generate a pdf report by clicking on the "save and close" button at the bottom of this page, or the "close and return to PrISM" button at the top of this page. Then, on the main dashboard, click on the "generate report PDF" button. You will be prompted to designate a file name and save location. You can then open the pdf in your standard pdf viewer, and either keep the window open side-by-side or print it.

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CHAPTER 9

Resource 1: Chemical Inventory: Identifying Chemicals in Products and Processes

9.1 Goal

To identify the chemicals used to produce and manufacture a product, including those chemicals that remain in the product when used and any chemicals that are produced after use a./or during waste management treatment.

9.2 Introduction

To complete a chemical inventory, you'll have to learn which chemical substances are present in the final product, which are used to make the product, and what breakdown chemical substances are likely. A chemical inventory considers the chemicals used to manufacture a product because they may remain in the product and workers and potentially the local community are exposed to those chemicals. It is also important to think about what the chemical may become when it is released to the environment. Many chemicals degrade into other chemicals or ultimately break down to CO2 and water over time.

Ideally, it would be possible to know all of the reagents, catalysts, auxiliaries, products, by-products, residuals and emissions at each life cycle stage. However, gathering this information is not always a simple task. The more you know about what is in the material, the better you can identify areas for improvement.

Keep in mind that even small amounts of toxic chemical ingredient additives can greatly impact the sustainability attributes of a product. Additives to plastics and residual chemicals from manufacturing can:

- Affect recycling, incineration and value-recovery options
- Be hazardous to workers or the environment
- Leak into the environment after disposal
- Affect the quality of recycled materials and how they can be used in future products

9.2.1 What are the life cycle stages you plan to evaluate?

At a minimum, you will want to know the chemicals that are present in the chemicals, materials or products at the life cycle stage that you control and in the product that you are making to sell to customers. This would include the base material along with known additives. It should also include residuals and impurities above a desired threshold.

9.2.2 What chemical types do you plan to evaluate?

For some products, you may want to focus on certain substance types or functional uses. For example, while there may be many residual substances in a laptop casing, the presence of flame retardants may have sustainability implications. Likewise, there may be concerns about the type of preservative used in a surfactant.

9.2.3 What concentration thresholds will you use?

Commonly used strategies include identifying all chemicals that are intentionally added to the formulations, material or product at any concentration or produced regardless of the concentration. Others will set a reporting threshold such as 0.01% (100 ppm) or 0.1% (1000 ppm) for reporting both intentionally added and residual substances. Others may inventory chemicals at different thresholds depending on the likelihood of concern. For example, safety data sheets require reporting of carcinogens at 10x lower concentrations (0.1%) than other chemical hazards (1%).

Using a chemical inventory template, identify all of the chemicals used at each life cycle stage that you evaluate. Identify the concentrations thresholds or other rules used to decide which chemicals to include in your inventory.

What chemicals are likely to be present in the product based on what you know about production and manufacturing of the product? Identify any concentration thresholds or other rules used to decide which residuals or impurities to include in your inventory.

Which of the above resources have you used to identify chemicals in your product or chemicals that may formed when the product is used or no longer needed?

9.3 Example

Chart template for creating a chemical inventory and mapping chemical use to life cycle stage.

Chemical (CAS RN)	Chemical Name	Function/ Life cycle stage	Production	Manufacture	Use	EOL
Substance 1			x		x	
Substance 2			x			
Substance 3				x	x	
Substance 4				x	x	
Substance 5				x	x	
Substance 6						x

Fig. 1: image

9.4 Tools

Some organizations offer tools for assisting with building, storing, and using your chemical inventory. These are typically focused on the constituents of the product (use phase inventory) and do not necessarily have space by default for inventorying process and byproduct chemicals. Both of these tools will automate list screening hazard assessments, as well. - Pharos Chemical and Material Library - toxnot.com

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CHAPTER 10

Resource 2: Chemical Hazard Assessment

10.1 Introduction to Chemical Hazard Assessment

This module will cover hazard assessment options. You can choose from a screening-level (option 1), intermediate (option 2) or advanced-level assessment (option 3); we also provide guidance at the end for a tiered approach that combines these levels. Information and resources about creating a chemical inventory are available in the Chemical Inventory Resource.

A number of chemical hazard assessment tools exist. Most are based heavily on the Globally Harmonised System of Classification and Labelling (GHS) and on authoritative and screening lists of chemical hazards. GHS provides detailed guidance for how to evaluate a broad set of human health, environmental and physical property hazards. GHS does not currently provide classification criteria for persistence (P), bioaccumulation potential (B) and endocrine disruption (EDC) and therefore criteria for these endpoints are supplemented in other schemes. An even more comprehensive set of hazard endpoints is provided by the California Environmental Protection Agency (CalEPA) in the US in support of their safer products program.

Learn more about GHS.

Foundational work on hazard assessment by McDonough Braungart Design Chemistry and the US Environmental Protection Agency Design for the Environment (DfE) Program as part of their alternatives assessment program helped to establish CHA with tabular hazard classification reporting. The GreenScreen for Safer Chemicals (GS) builds on the GHS, C2C DfE AA Criteria and provides an additional overall chemical benchmark score.

The approaches that follow differ by the number of hazard endpoints evaluated and the depth to which each endpoint is assessed. With increased depth of chemical assessment comes increased understanding of the human health and the environment hazards associated with a chemical and deeper knowledge of data gaps. However, increased depth of assessment requires greater expertise and cost.

10.1.1 Hazard, exposure, and risk

Hazard is something that can potentially cause harm. A shark is an example of something hazardous. Risk is a function of hazard and exposure. Swimming in shark-infested waters is combining hazard - sharks - and exposure to make a very risky activity.

Image source: Genetic Literacy Project

Green Chemistry is based on the premise that risk is a function of hazard and exposure. Once can control risk by controlling exposure or by controlling hazard. Exposure controls are expensive, and can and do fail. It is better to design, make and use chemicals with low inherent hazard. And to avoid swimming in shark infested waters.

10.2 Key Steps in Any Chemical Hazard Assessment (CHA)

10.2.1 Classify Hazards for Individual Chemicals

Each chemical is evaluated against criteria for individual hazard endpoints. For example, GHS uses numbered categories to designate hazard with Category 1 hazards being the most severe. Most of the other chemical hazard assessment methods use GHS as their base but but then provide more intuitive or descriptive ways of packaging the results. For example, a chemical that is a Category 1 Carcinogen would be 'red' in a stoplight communication system such as Cradle to Cradle. It would be High in the US EPA Design for the Environment Criteria for Alternatives Assessment and the GreenScreen that uses a system of Hi./Medium/Low, etc. to designate hazard levels. Hazard classifications can also be linked to the presence of chemicals on hazard lists and to GHS hazard phrases.

For example, a chemical that is listed as a Known Carcinogen according to the US National Institutes of Health would also be High or Red for Carcinogenicity in GS or C2C. The GHS system links Category levels to hazard (H) phrases. For example, a chemical that is a Category 2 Carcinogen is suspected of causing cancer would be labeled H351. And a chemical that is a H400 is very toxic to aquatic life and is Category 1 for Aquatic Toxicity. The hazard phrases associated with a chemical provide a convenient communication method. These hazard phrases can also be integrated into automated list searching schemes and accompanying software.

Table 3. Mutagenicity/Genotoxicity Criteria for Hazard Designations

Mutagenicity/ Genotoxicity	Very High	High	Moderate	Low
Germ cell mutagenicity	GHS Category 1A or 1B: Substances known to induce heritable mutations or to be regarded as if they induce heritable mutations in the germ cells of humans	GHS Category 2: Substances which cause concern for humans owing to the possibility that they may induce heritable mutations in the germ cells of humans OR	Evidence of mutagenicity supported by positive results in *in vitro* OR *in vivo* somatic cells of humans or animals	Negative for chromosomal aberrations and gene mutations, or no structural alerts.
Mutagenicity and genotoxicity in somatic cells		Evidence of mutagenicity supported by positive results in *in vitro* AND *in vivo* somatic cells and/or germ cells of humans or animals		

(Above) Example Criteria for Mutagenici./Genotoxicity from the USEPA Design for the Environment Alternatives Assessment Criteria for Hazard Evaluation

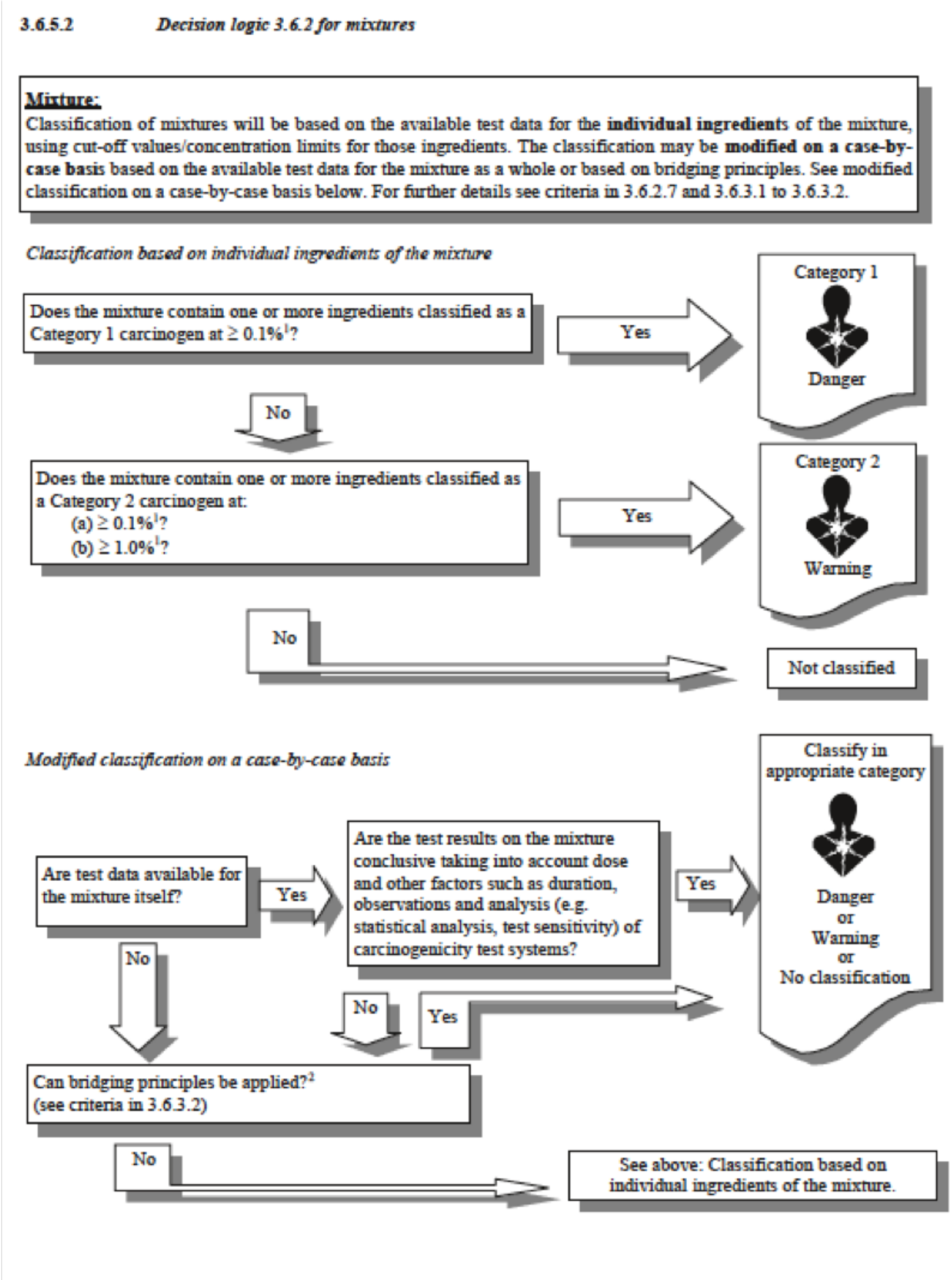
See the full DfE AA Criteria.

10.2.2 Evaluating Mixtures and Polymeric Materials

CHA methods provide insight into the hazards of individual chemicals. But those chemicals and hazards must also be considered in a mixture. Some hazards become diluted out and reduced in a mixture. For example, a strong acid may be very corrosive to the skin and eyes. But when diluted in a formula, it may end up as only slightly acidic and therefore not harmful. Think about vinegar or phosphoric acid in popular carbonated soft drinks.

Other hazards are treated in a more precautionary way because it is very difficult to prove that there is any safe level. For example, chemicals known to cause cancer or elements such as lead are not desirable, especially where there is any feasible opportunity for exposure. In those cases, their presence in the mixture should lead to assuming that the mixture carries the same hazards as the individual chemicals. Based on the CHA method selected and subsequent results, users of the information may choose different strategies to discriminate between product mixtures.

GHS provide a decision logic classifying the hazards of mixtures sometimes referred to as 'mixture rules'. Classification may come from measuring the hazards of the mixture such as measuring the pH of a solution. Or they may be based on the hazard of individual chemicals as described for Carcinogenicity above and illustrated in the image below.



(Above) GHS Mixture Classification Guidance for Carcinogenicity

Image source: Revision 7 of the Globally Harmonised System of Classification and Labelling (GHS)

A product designer may choose to customize an approach to compare mixtures or polymeric materials based on hazards associated with each substance in the product. For example, they may choose to calculate the % composition of each substance in the plastic and whether or not it is a substance of very high concern (SVHC) or a GS Benchmark 1 chemical.

Alternatively they may choose to compare plastics based on the presence of chemicals with specific hazards that are relevant to the product design and how it will be used. For example, skin sensitizing chemicals would not qualify as GreenScreen Benchmark 1 but they may be undesirable for plastics used in wearable devices. Example customized criteria for mixtures and polymeric materials like plastics may include but are not limited to:

1. Products that contain no substances identified as Substances of Very High Concern (SVHCs) or scored as GS Benchmark 1.
2. Products with the lowest weight percent of SVHC or Benchmark 1 substances.
3. Products with no substances with hazard traits that are problematic based on how the product is used. For example, a chemical could be a skin sensitizer or highly toxic to aquatic life and not be a SVHC or Benchmark 1 chemical. Yet if skin sensitizing chemicals were used in a product that is applied to the skin or if aquatically toxic chemicals are in a product that is used liberally around boats, then those chemicals would be prioritized for substitution.
4. Products that do not contain SVH./Benchmark 1 chemicals AND that do not contain chemicals that have specific hazard traits such as skin sensitizers or aquatic toxicants that would negatively impact a product from a life cycle perspective.

10.3 Hazard Assessment Option 1: Hazard List Screening

Screening of chemicals against regulatory and authoritative lists of chemicals with known or suspected hazards can be useful as a first pass and take little time and expertise. For example, the GS List Translator links hazard lists specified in the GreenScreen method to hazard assessment classifications. Several software tools have been created to facilitate structured list screening such as the Pharos Chemical and Material Library and toxnot.com. Some industry sectors such as textile manufacturing and retail have established restricted substance lists (RSLs) for materials and manufacturing processes (MRSLs). Additional screening may be needed for chemicals on RSLs or MRSL.

The US Environmental Protection Agency Safer Choice Program has created a list of inherently lower hazard chemicals for use primarily in cleaning products. This list is called the Safer Chemical Ingredient List (SCIL). There is also a subscription-based online platform called CleanGredients that identifies commercial cleaning chemical ingredients that meet Safer Choice criteria.

Tools and Methods for Completing a Hazard List Screening: - US EPA Safer Chemical Ingredient List (SCIL) - CleanGredients - GS List Translator - ChemHat - Pharos Chemical and Material Library - Pharos Data Commons - toxnot.com

10.4 Hazard Assessment Option 2: Intermediate

Intermediate CHA methods limit the number of hazard endpoints considered and prescribe a limited set of data sources. The Quick Chemical Assessment Tool (QCAT) developed by the Washington State Department of Ecology builds on the DfE and GreenScreen methods and is designed for use by small and medium enterprises with limited toxicological expertise.

QCAT WA Department of Ecology

Tools and Methods for Completing an Intermediate Hazard Assessment: - Quick Chemical Assessment Tool (QCAT)

10.5 Hazard Assessment Option 3: Comprehensive (Advanced)

Full chemical hazard assessments require expert review and interpretation of the scientific literature and results from standard test methods. When data are lacking for the compound of interest, predictive models can also be used. In addition, expert chemists and toxicologists can use a method called 'read-across'. Read-across is a structured method for using available data from a data-rich substance to predict the characteristics of a data-poor substance as long as the substances are similar enough in structure that they can be considered surrogates for each other. Read-across may only be appropriate for a limited set of characteristics.

Computer modeling based on mechanisms of action and structure activity relationships have improved in recent years with the implementation of the REACH program in the European Union which de-emphasizes animal testing. Emerging hazard screening protocols include high throughput screening such as the Tox 21 program at US EPA. In some cases, such as with high throughput screening, the science not yet used for regulatory applications. Here is a list of hazard endpoints typically assessed in a comprehensive CHA:

A List of Recommend Hazard Endpoints for CHA (Derived from GHS, USEPA Safer Choice, and GreenScreen
Human Health Effects
Carcinogenicity
Genotoxicity/Mutagenicity
Reproductive toxicity
Developmental toxicity (explicitly includes neurodevelopmental toxicity)
Endocrine Activity (Disruption)
Acute Mammalian toxicity
Specific Target Organ Toxicity (Systemic toxicity) – single dose
Specific Target Organ Toxicity (Systemic toxicity) – repeated dose
Neurotoxicity
Skin Sensitization
Respiratory Sensitization
Eye Irritation/Corrosion
Dermal Irritation/Corrosion
Ecotoxicity
Acute Aquatic Toxicity
Chronic Aquatic Toxicity
Environmental Fate and Transport
Persistence
Bioaccumulation
Physical Hazards
Flammability (liquids, solids, etc.)
Explosivity and Reactivity (self-reactive, pyrophoric, etc.)
Additional Endpoints
Ecotoxicity: avian (acute oral and dietary) and acute bee toxicity; Terrestrial toxicity (earthworm)

See California Office of Environmental Health and Human Assessment (OEHHA) for an extensive list of Hazard Traits.

Tools and Methods for Completing a Comprehensive Chemical Hazard Assessment: - Globally Harmonised System of Classification and Labelling (GHS) - USEPA Design for the Environment AA Criteria for Hazard Evaluation - GreenScreen for Safer Chemicals (GS) v 1.4 - Cradle to Cradle Material Health Assessment as part of full C2C Certification Standard v3.0

10.6 Obtaining Existing Intermediate and Comprehensive Chemical Hazard Assessments

In some cases, an intermediate or comprehensive chemical hazard assessment has already been completed and is available on-line. While some are available for free, others require payment to view.

Resources for Obtaining Existing Assessments: - Interstate Chemicals Clearinghouse (IC2) Chemical Hazard Assessment Database (CHAD) - free intermediate and comprehensive assessments - GreenScreen Store - mixture of free and paid comprehensive assessments - Chemical Hazard Data Commons - free comprehensive assessments alongside screening assessments - SciVera - commercial tool for screening through comprehensive assessments

10.7 A tiered approach to chemical hazard assessment

Ideally, comprehensive CHA reports would be readily available for every chemical; however, that is rarely the case. A pragmatic approach would entail looking first for existing publicly available comprehensive CHAs such as those in the Interstate Chemicals Clearinghouse (IC2) chemical hazard database. The next step could be list screening. Chemicals with known hazards listed by authoritative bodies can be quickly identified using list-screening tools. Chemicals not on regulatory or hazard lists may be inherently safer or may be less well-studied. In those instances, an intermediate chemical hazard assessment may be informative. If results from intermediate CHA are not definitive, a full CHA may be needed. A full CHA provides information not only on what hazards are known, but also on what is not and includes a data gap analysis.

1. Search for existing comprehensive CHAs
2. Screen using list-screening tools.
3. Eliminate chemicals identified as hazardous.
4. Screen remaining chemicals using an intermediate chemical hazard assessment method.
5. Eliminate chemicals identified as hazardous.
6. Screen remaining chemicals using a comprehensive chemical hazard assessment method.

It is possible that the chemical hazard assessment (either intermediate or comprehensive) will identify data gaps - hazard endpoints for which there simply is insuffucient data available for classification. In these cases, modeling or experiments may be necessary to understand the hazards of the chemical.

Resources for estimating hazard: - USEPA Toxicology Testing in the 21st Century (Tox21) - OECD QSAR Toolbox - USEPA Sustainable Futures Program

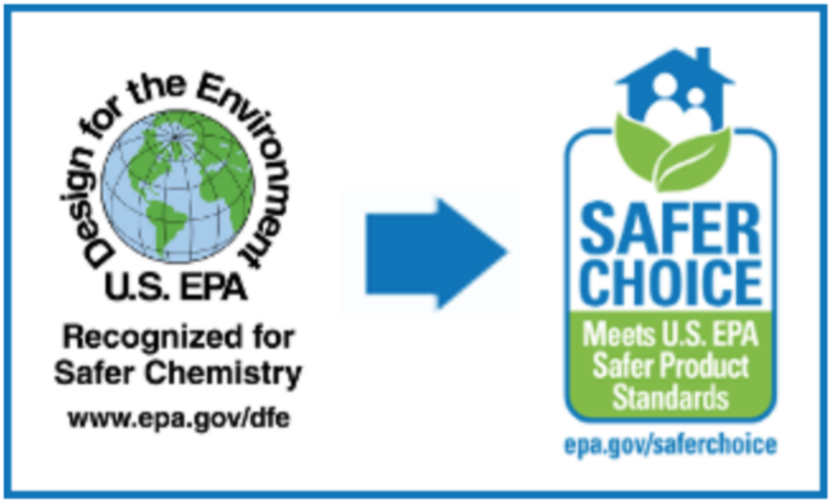
10.8 Using Standards & Certifications in Hazard Evaluation

Several certification programs exist that evaluate materials for hazard and either score them or subject them to pa./fail criteria. Each program uses different concentration thresholds for reporting and scoring that may be more or less protective and precautionary. Examples include:

Cradle to Cradle (C2C) Certification: Products are certified from high to low as platinum, gold, silver, bronze or basic. Each product is evaluated for Material Health based on their toxicity and feasible exposure. The C2C method evaluates products in five categories, i.e. Material Health, Material Reutilization, Renewable Energy & Carbon Management, Water Stewardship and Social Fairness. However, the Material Health category can be used as a standalone method. Learn more about the C2C Certification program.

The DfE Safer Choice Program: The US EPA provides guidance to evaluate chemicals and their degradation products for potential impacts on human health and the environment as part of EPA's Safer Choice

Program. A product that contains ingredients that pass all requirements qualifies for the Safer Choice label. The program was rebranded from Design for the Environment (DfE) to Safer Choice; some resources may still refer to it as DfE. Learn more about the EPA Design for the Environment Program.



GreenScreen for Safer Chemicals v1.4 was recently updated with a mixture assessment procedure. The new procedure assesses the hazard of all ingredients and provides a process to generate an overall mixture Benchmark score. Benchmark scores for mixtures are distinguished from Benchmark scores for individual chemicals. Much of this procedure is based on GHS mixture rules. Learn more about the updated GreenScreen for Safer Chemicals assessment procedure.

The Globally Harmonized System of Classification and Labelling (GHS) provides rules for classifying chemical mixtures using a combination of concentration thresholds and hazard types. Test data for the mixture may be used. Alternatively, individual ingredients may be classified for hazard and an algorithm used to calculate an overall hazard classification. As noted previously, one limitation of GHS is that it does not include classification criteria for endocrine disruption, persistence and bioaccumulation that is needed to identify some SVHCs. Learn more about GHS.

10.9 Example

Senior engineering students at Gonzaga University evaluated four clamshell food takeout containers using alternatives assessment: polypropylene with talc, polystyrene, poly lactic acid (PLA) and waste fiber. The students researched the identities of likely additives and residuals based on literature reviews and discussion with polymer chemists. They obtained information from the manufacturers of the PLA and waste fiber products on the presence (or absence) of additives. The students decided to evaluate the polymeric material at the use stage including residual monomers and any performance additives. They also considered potential combustion products produced at the end of life stage based on the likelihood that in Spokane, the containers would be incinerated.

The table below, taken from the full report, shows how a chemical inventory revealed a number of additives in the four take-out containers. The students used QCAT, GSLT, and publicly available GreenScreen reports to evaluate each ingredient for potential hazards.

Packaging Material	Chemical in Material	Route of Exposure	QCAT	GSLT	GreenScreen
Polystyrene (PS)	Polystyrene				
	Styrene	-	N/A	LT-1	BM-1
	Pentaerythritol tetrakis [3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate]	-	F	LT-UNK	None
Polypropylene (PP)	Polypropylene				
	Propylene	All	B	LT-UNK	BM-U
	Pentaerythritol tetrakis [3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate]	-	F	LT-UNK	None
	Aluminum Benzoate Surrogate: Benzoic Acid	-	F	LT-UNK	None
	Talc	Inhalation	N/A	LT-1	BM-1
		Oral	N/A		BM-3DG
		Dermal	N/A		BM-U
Poly(lactic) Acid (PLA)	PLA				
	Lactic acid	Liquid Form	N/A	LT-UNK	BM-2
	Lactide	All	N/A	None	BM-2
	Surrogate: Talc	Inhalation	N/A	LT-1	BM-1
		Oral	N/A		BM-3DG
		Dermal	N/A		BM-U
Fiber (Cellulose)	Bagasse (Sugarcane)				
	[illegible]	-	Fdg	None	None
	[illegible] or [illegible] Surrogate: Perfluorohexanoic Acid	-	N/A	LT-P1	BM-1

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CHAPTER 11

Resource 3: Exposure Assessment

11.1 Goal

To understand potential exposure scenarios. It is especially important to ensure that hazards are reduced when exposure is likely.

11.2 Introduction

At each step of the product life cycle, who is most likely to be exposed? Consider intended uses of the product and likely unintended uses. Likely unintended use may include children mouthing on a cell phone case, spills of cleaning products, etc.

What are the most likely routes of exposure (dermal, inhalation a./or ingestion)? Develop a template that supports your consideration of alternatives.

What are the relative scale of exposure? How much of the chemical is present? How frequently will exposure occur? And for how long?

11.3 Screening Exposure Assessment: Exposure Mapping

Consider the life cycle stages of the product to map out where potential exposures to hazardous chemicals might occur and who or what will be affected. For example, during production of agricultural feedstock, are workers likely to be exposed to pesticides? When a product is discarded, will it harm fish because aquatic toxicants have leached out? Include the likely routes of exposure (oral, dermal, ingestion, inhalation) in your map.

Consider the amount of the chemical that will be used, the frequency of exposure and the amount of time that exposure will occur.

Chemicals can travel through different environmental media and be taken up by humans primarily through inhalation, ingestion and through the skin.

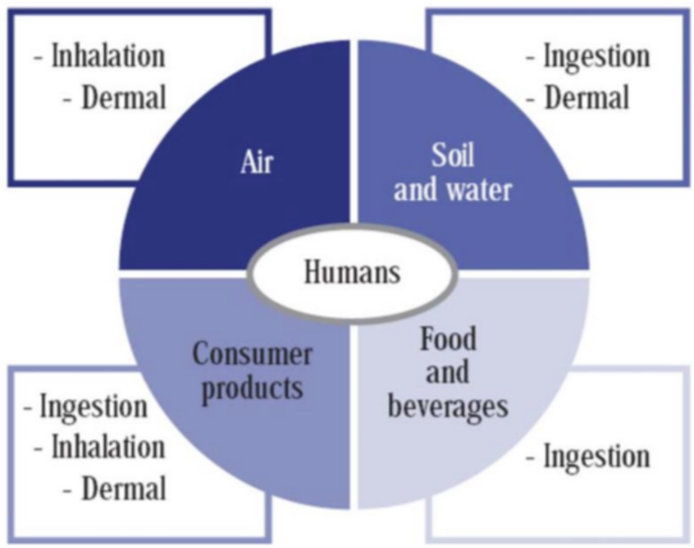

Fig. 1: image

Prepare a conceptual exposure model or map that illustrates the likely exposures that will occur across the life cycle of the product you are making. This is thought exercise that should result in what is sometimes called a 'Measles chart'.

A measles chart such as the one illustrated below, is a structured, prepared form for collecting and analyzing data that provides a visual image of the item being evaluated so that data can be collected visually. It is called a measles chart because of the visual array of spots that may result.

Qualitative approach to comparative exposure in alternatives assessment

11.4 Generalized Environmental Exposure Map

More Exposure Assessment Resources from the U.S. EPA

Considering exposure pathways to humans

Image Source: ASTDR

11.5 Advanced Exposure Assessment

For some products, testing may be required to have verifiable information on the concentrations of chemicals in the product and whether or not the substances leach out of a product. This would be especially true for medical devices and presumably for food contact materials.

Other testing may also be recommended. Testing for impurities in recycled materials ensures that the supply of recycled materials result in the type of quality material that is needed.

Even more exposure assessment would include biomonitoring and environmental monitoring. These assessments measure how much of a chemicals is actually finding its way into bodies and into various parts of the environment.

Life Cycle Stage	Action to Use Product	Expected Receiving Medium	Release Mechanism & Fate and Transport During/After Use	Potential Exposure Medium	Exposure Routes	Populations					
						Human					Pets
						General Population			Workers		
						Adults	Children	Infants	Professional	Industrial	
Use of Toys	Sprayed	Ambient Air	Volatilization	Ambient Air	Inhalation (User)						
	Applied with Tool	Skin Surface - Human or Pets	Aerosolization		Inhalation (Bystander)						
	Applied with Hand	Indoor Surfaces	Evaporation	Skin Surface	Dermal Contact						
	Contacted	Indoor Dust	Migration		Incidental Ingestion						
	Poured Liquids	Outdoor Surfaces	Re-suspension	Indoor Surface	Dermal Contact						
	Poured Solids	Food and/or Drink	Dissolving		Incidental Ingestion						
	Evaporated Liquids or Solids	Drain Water	Contacting	Indoor Dust	Inhalation (Re-Suspended Dust)						
	Mouthed	Surface Water	Washing		Incidental Ingestion						
	Swallowed	Sediment	Waste Water Treatment		Incidental Dermal Contact						
		Soil	Leaching	Outdoor Surface	Dermal Contact						
		Animals	Erosion/Runoff		Incidental Ingestion						
		Plants	Animal Uptake	Food/Drink	Ingestion						
		Human Digestive Tract	Plant Uptake		Incidental Dermal Contact						
			Incineration	Drain Water	Dermal Contact						
			Landfilling		Inhalation (Volatilization)						
				Surface Water/Sediment	Dermal Contact (Swimming)						
					Incidental Ingestion (Swimming)						
				Soil	Dermal Contact						
					Incidental Ingestion						
					Inhalation (Re-Suspended Dust)						
				Digestive Tract	Ingestion						
				Far Field Environment	Inhalation (Far Field)						
					Ingestion (Drinking Water)						
					Dermal Contact (Soil)						
					Incidental Ingestion (Soil)						
					Dermal Contact (Surface Water/Sediment)						
					Incidental Ingestion (Surface Water/Sediment)						
					Ingestion (Produce)						
					Ingestion (Meat, Fish, Eggs, Dairy)						
					Ingestion (Human Milk)						

Key
Relevant to Use
Not Relevant to Use
Not Applicable

Fig. 2: image

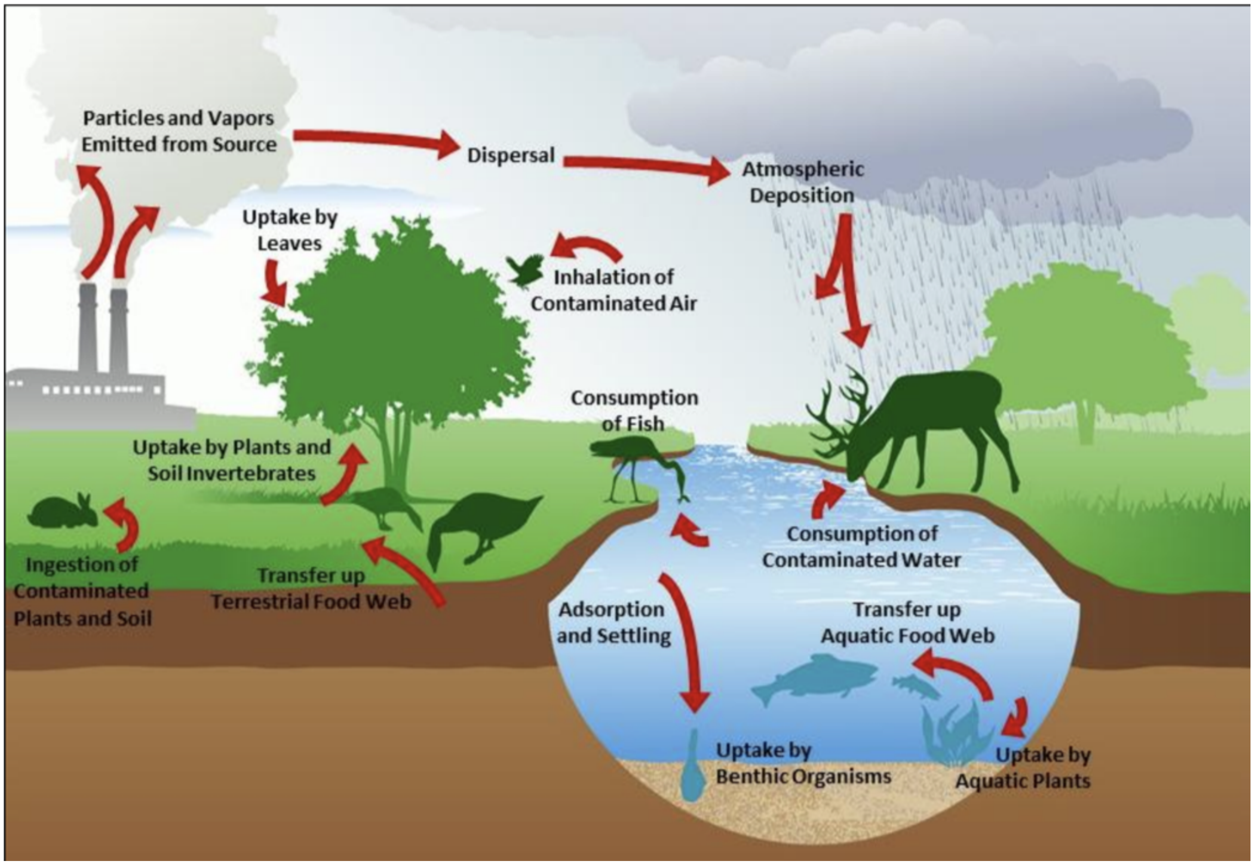

Fig. 3: image

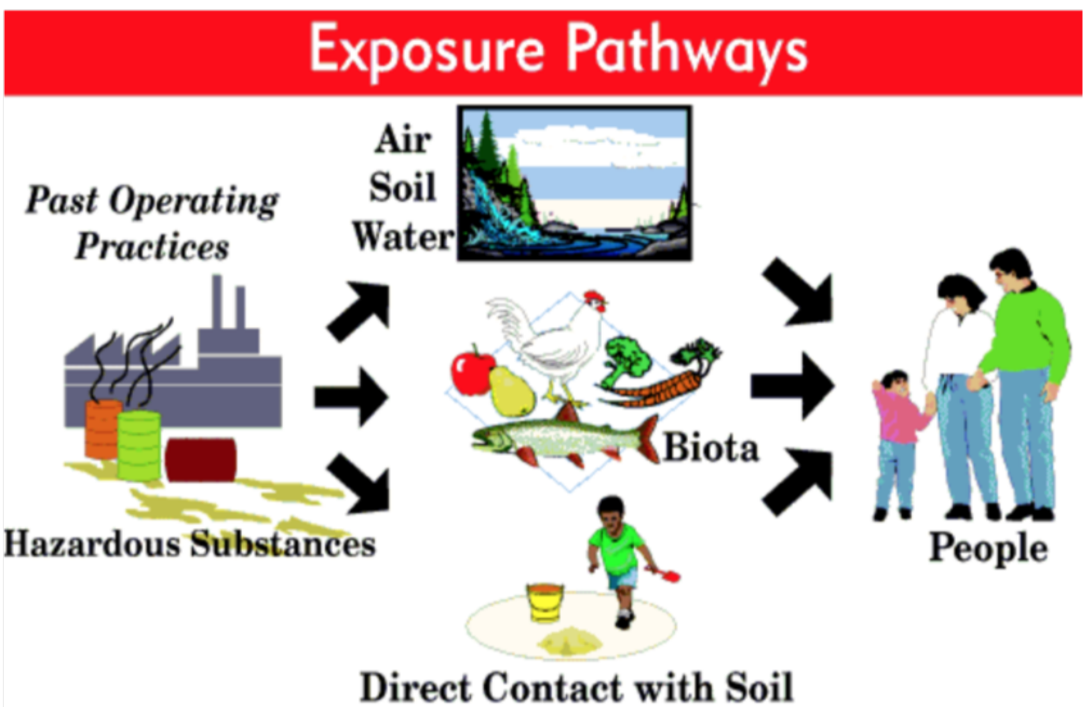

Fig. 4: image

A number of useful exposure models such as the Product Intake Fraction can also support informed decision making about chemicals and materials used in products.

Learn more about Product Intake Fraction

11.6 Control Banding

Control banding is an assessment method that can be used to manage workplace risks. It is a process that matches, for example, a control measure (e.g., ventilation, engineering controls, containment, etc.) to a range or "band" of hazards (e.g., sk./eye irritation, very toxic, carcinogenic, etc.). The control banding method also groups chemicals according to similar physical or chemical characteristics, how the chemical will be handled or processed, and what the anticipated exposure is expected to be. The method then determines a set of controls chosen to help prevent harm to workers.

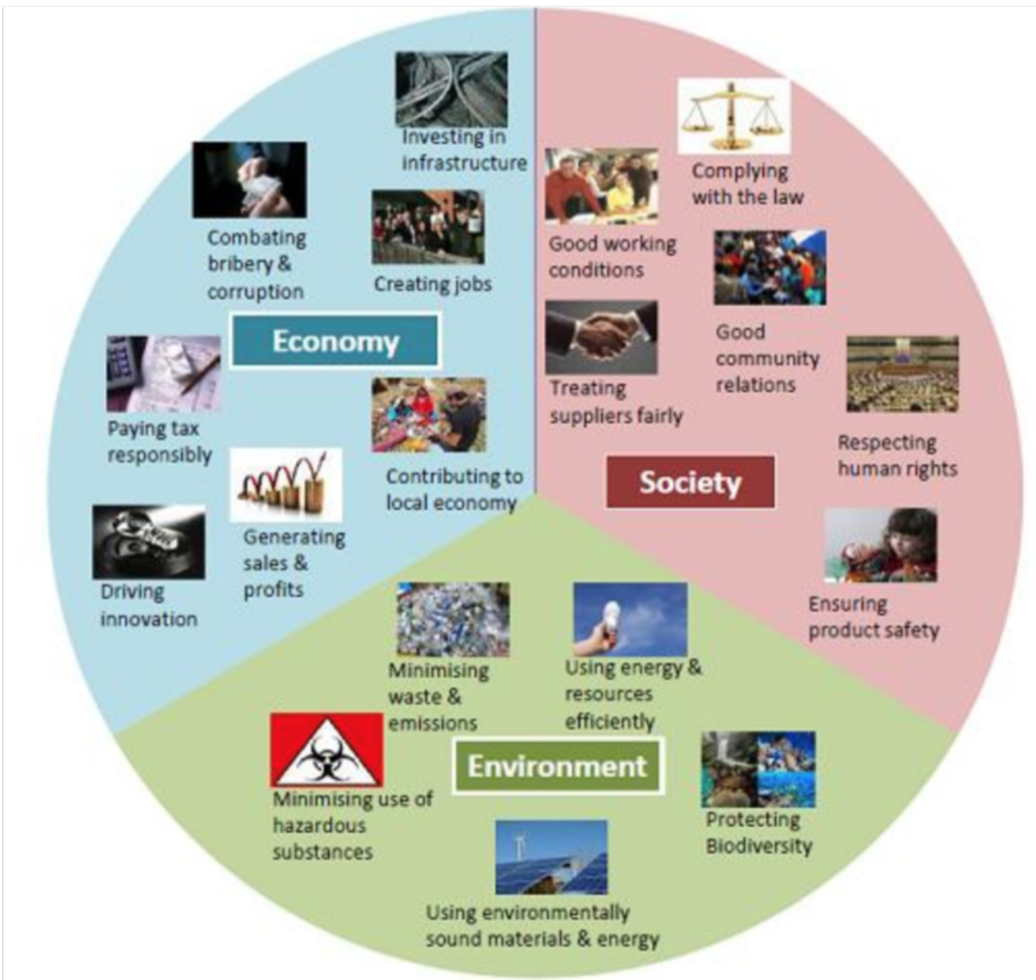

Fig. 5: image

In general, bands represent: - health hazards or risk (e.g., sk./eye irritation, carcinogenic, etc.), - exposure potentials (e.g., quantity used, or characteristics of the products), - control measures that should be taken to protect workers (e.g., types of ventilation, engineering controls, containment, etc.)

A control banding grid like the one below can be created to assess risk level. This helps indicate which hazards require the greatest control measures. The best form of occupational control for a very hazardous chemical is to eliminate it and replace it with a safer chemical or process.

		Extremely unlikely (0-25)	Less likely (26-50)	Likely (50-75)	Probable (76-100)
Severity score	Very high (76-100)	RL 3	RL 3	RL 4	RL 4
	High (51-75)	RL 2	RL 2	RL 3	RL 4
	Medium (26-50)	RL 1	RL 1	RL 2	RL 3
	Low (0-25)	RL 1	RL 1	RL 1	RL 2

Training requirements by risk level:
RL 4 : Expert required on jobsite
RL 3 : Competent person required on jobsite
RL 2 : Hazard awareness expertise required on jobsite
RL 1 : Basic craft skills sufficient on jobsite

Fig. 6: image

11.6.1 Additional Resources on Control Banding

Source: Canadian Center for Occupational Health and SafetyNational Center for Biotechnology InformationImage Source: Center for Disease Control and Prevention (CDC)

PROSCALE is a new method for comparing hazard, exposure and risk from production and manufacturing processes used to make products. It considers chemical hazards associated with each unit process along with exposure routes, amounts, frequency and duration. Results from each unit process can be summed to reflect the entire production and manufacturing process. PROSCALE provides a score that allows for easy comparison between products. It does NOT address the inherent hazards of chemicals in product and exposure to those chemicals. It currently focuses exclusively on production and manufacturing.

11.7 Example

Floral Soil solutions recognized that florists don't wear personal protective equipment, and they are therefore exposed to hazardous chemicals while they work. Floral Soil solutions designed a product that doesn't contain those chemicals of concern, therefore eliminating florist exposure to them.

Learn more about Floral Soil

11.8 Tools for Assessing Exposure

- Learn more about Decision Analysis on p.48
- National Academies: Comparative Exposure Assessment

Fig. 7: image

Contents

CHAPTER 12

Resource 4: Stakeholder Considerations & Social Impacts

12.1 Stakeholder Assessment

12.1.1 Life Cycle Considerations

Stakeholders can be defined as "those groups who can affect or are affected by the achievement of an organization's purpose" Stakeholders can be divided into those who are affected by the material impacts (affected), and those who affect the development of that material (affecters) (8).

This can also be viewed as a 2x2 interest versus power grid such as the one below. Stakeholder considerations range from the most immediate, workers to regional to the global environment. The stakeholder impact map has overlap with the exposure mapping since exposure to chemicals is important to health and safety.

Power versus Interest Grid

12.1.2 Tools & Resources

Use this chart to think through who might be affected and how at each stage of your product's life cycle

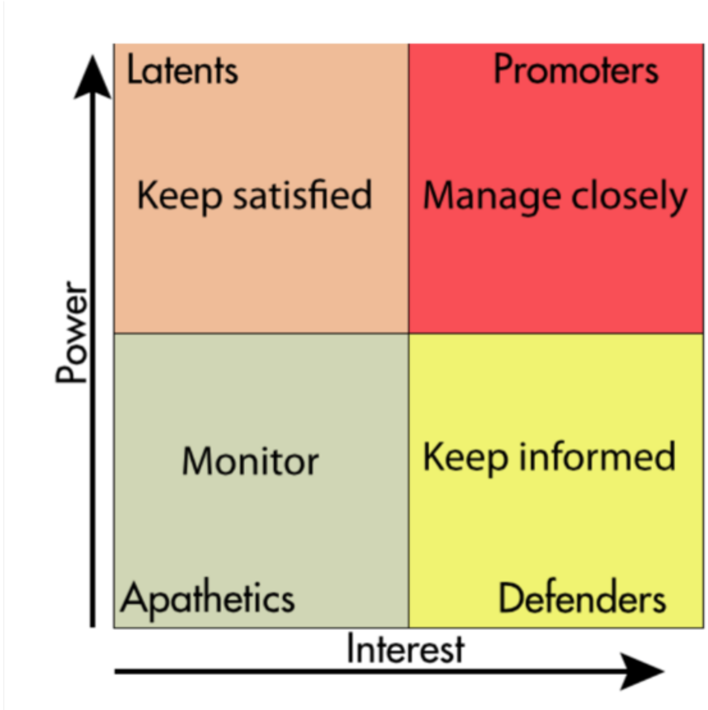

Fig. 1: image

Life Cycle Stage	Key Stakeholders (Affecters)	Key Stakeholders (Affected)	Main Impacts	Exposure Pathways
Overall LCA (Cradle to Gate/ Grave/Cradle)	Materials Developers and Designers, Supply Chain	Affecters, Consumers, Global Health and Environment	Emissions, energy use, resource depletion, other environmental impacts	See Conceptual Exposure Map
Sourcing (Feedstock)	Materials Developers and Designers "Green" Consumers, Supply Chain	Communities Near Extraction Site, Workers	Resource depletion, emissions, energy use, human health impact to workers and communities	See Conceptual Exposure Map
Production and Manufacturing	Materials Developers, "Green" Consumers, Supply Chain	Communities Near Manufacturing Site, Workers	Emissions, energy use, human health impact to workers and communities	See Conceptual Exposure Map
Use	Materials Developers and Designers, Distributors, Consumers	Consumers, Distribution Workers	Toxicity of chemicals	See Conceptual Exposure Map
Product End of Life	Materials Developers, Consumers	Waste management workers, Environment.	Long-term environmental impacts of chemicals	See Conceptual Exposure Map

Example chart developed to consider stakeholder exposures and impacts across the life cycle of a product.

12.1.3 Guiding Questions

- Who can influence the success or failure of your product? Who are your stakeholders? Consider diverse groups: material developers and designers, members of the supply chain, consumers, "green" consumers, parents, teachers, distributors, retailers, trade associations, recyclers, repair organizations, composters, environmental groups, environmental justice groups, social justice groups, community leaders, communities near work sites (e.g. manufacturing plant, extraction site), workers, unions, local politicians, other governmental representatives (federal, state, regional, county, city, international, indigenou./ first nation), and more may be important stakeholders to consider.
- Who should be included in this project to provide input? Reference your answer above. In particular, consider people impacted by the product life cycle who are frequently excluded from decisions, such as communities near extraction sites. See Resource 5 - Environmental and Social Justice for guidance.
- What impacts should be prioritized based on stakeholder analysis? Consider how stakeholders may be impacted (positively and negatively).
- What are the priority impacts based on stakeholder input?
- How are those affected parties impacted, via what exposures?
- Using informaiton you've gathered through life cycle thinking and exposure mapping, what are the most critical product aspects for you to meet the needs of your stakeholders?

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CHAPTER 13

Resource 5: Social & Environmental Justice

Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin or income with respect to development, implementation, and enforcement of environmental laws, regulations, and policies (9). The fundamental tenets of environmental justice involve contesting systems of oppression that privilege one group over another in decision-making, exposure to environmental hazards, and consequences of that exposure (10). Environmental justice includes not only the fair distribution of goods and services but also the flourishing and full function of human life in political, social, economic, and legal spheres (11).

Social impact assessment helps designers evaluate how a product will impact people (workers, users, vulnerable populations and communities broadly) throughout its life cycle. Products should be evaluated for how they impact people in a wide range of demographics.

13.1 Guiding Questions

- Do you need to have an open stakeholder process that directly involves key groups impacted by the product?
- Will the materials and manufacturing related to your product create equal opportunities and fair labor conditions (such as fair sala./wage, safe working conditions, freedom of association and collective bargaining)?
- Have you considered impacts to the community where your product will be made, used a./or disposed?
- What is your plan for transparent communication about your product and materials?
- How will your product contribute to or hinder local economic development in the areas it is produced, used and disposed?

13.2 Social Life Cycle Assessment Resources

While aspects of product design such as social impacts, performance and economic feasibility are important considerations, they are, for the most part, outside the scope of this workbook.

Refer to the Handbook for Product Social Impact Assessment for more detailed information.

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CHAPTER 14

Resource 6: Life Cycle Considerations

14.1 Introduction to Life Cycle Thinking and Life Cycle Assessment

14.1.1 Life Cycle Thinking (LCT)

Life cycle thinking (LCT) has become an important approach on which businesses increasingly rely to inform decision-making and to identify opportunities to offset negative impacts. LCT is essential because it can help lessen the negative and improve the positive impacts of products and services by informing the design and decision-making process. When you use life cycle thinking, your decisions should "reflect a broad perspective and include consideration of the full life cycle of the product." This includes considering impacts to workers, consumers, and the environment across the life cycle and the supply chain.(IC2) LCT is used to identify life cycle stages where there are significant differences between alternatives. It helps prevent burden shifting, i.e. ensuring that changes at one stage of the life cycle, in one geographic region, or in one impact category do not result in increased impacts elsewhere. LCT can be used to evaluate impacts without the conducting a full LCA. The basic tenets behind LCT are: - To think about a chemic./product/process not as a single, static, entity but as a dynamic continuum that starts with raw materials and ends with an EOL scenario. - To avoid undesirable burden shifting from one stage in a product life cycle to another due to changes in product formulation or design - To look at product impacts from a cradle-to-grave (or "Cradle-to-Cradle") perspective and to identify potential environmental, economic, or social impacts for each life cycle phase, in order to foster choices that support innovation and benefits over the full life cycle.

Life cycle thinking (LCT) and life cycle inventory and life cycle impact assessment (L./A) allow you to consider and measure environmental impacts from materials and products across the life cycle.

14.1.2 Life Cycle Assessment

LCA is a tool that allows quantitative assessment of differences between materials for a set of impact categories. Designers should evaluate options using LCT first to screen materials for obvious differences in sustainability performance. Then, where it is more difficult to distinguish sustainability impacts, materials should be evaluated and compared using LCA. LCA is a standardized methodology (ISO 14040 series) for accounting for aspects and impacts tied to material and energy inputs and emissions associated with a product, process or service. Results vary depending on how the system boundaries are defined. It is often used to find 'hot spots' or areas of greatest impact to identify and target opportunities for improvement. An LCA includes: - Compiling an inventory of relevant energy and material inputs and environmental releases for all life cycle phases evaluated. (Life cycle inventory) - Evaluating the potential environmental and human health impacts associated with identified inputs and releases from processes within phases evaluated. (Life cycle impact assessment) - Interpreting the results to help make an informed decision.

Learn more about ISO Life Cycle Assessment standards.

14.2 Overview of a Typical Product Life Cycle

Life cycle thinking will help you consider the various inputs and outputs your product will require from raw material extraction through end of life.

Common phases in the life cycle of a product include material extraction and processing, manufacturing of product, packaging and distribution, produce use, and end of life. Each of these steps involves using materials a./or energy, and releasing waste and/or pollution.

Image Credit: Design Technology (Western Academy of Beijing)

14.3 Key Steps

We recommend the following approach to using LCT and LCA: - Begin with life cycle thinking (LCT). Identify where life cycle impact differences are likely to be more or less substantive. For example, feedstock choice for a base polymer can result in very different life cycle impacts at the production stage. - Obtain standardized, certified LCAs for chemicals, materials or products with a focus only on those impacts that are likely to be substantively different. - Use information gathered from LCT and LCAs to identify "hot spots" – areas with the most significant sustainability impacts – and leverage this knowledge to identify opportunities for improvement across the life cycle.

Image Source: General Services Administration (GSA)

14.4 Example

You can use a matrix like this to compare alternatives across relevant life cycle stages:

Table compares product and alternatives on various impacts (e.g. human health, air quality, and water quality) for each life cycle phase assessed (e.g. raw material extraction, manufacture, use, and disposal), with each intersection rated as low, moderate, or high.

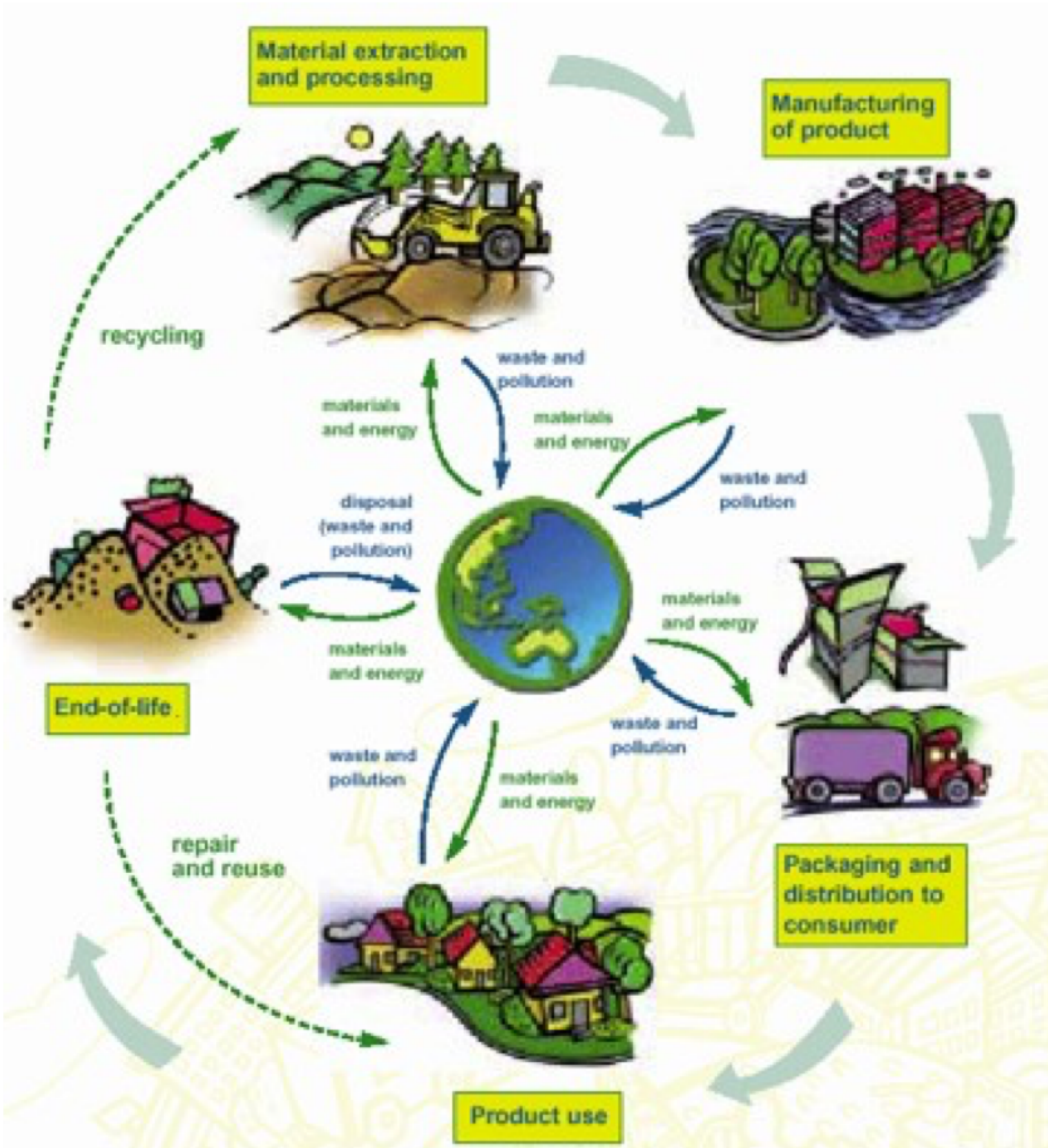

Fig. 1: Common phases in the life cycle

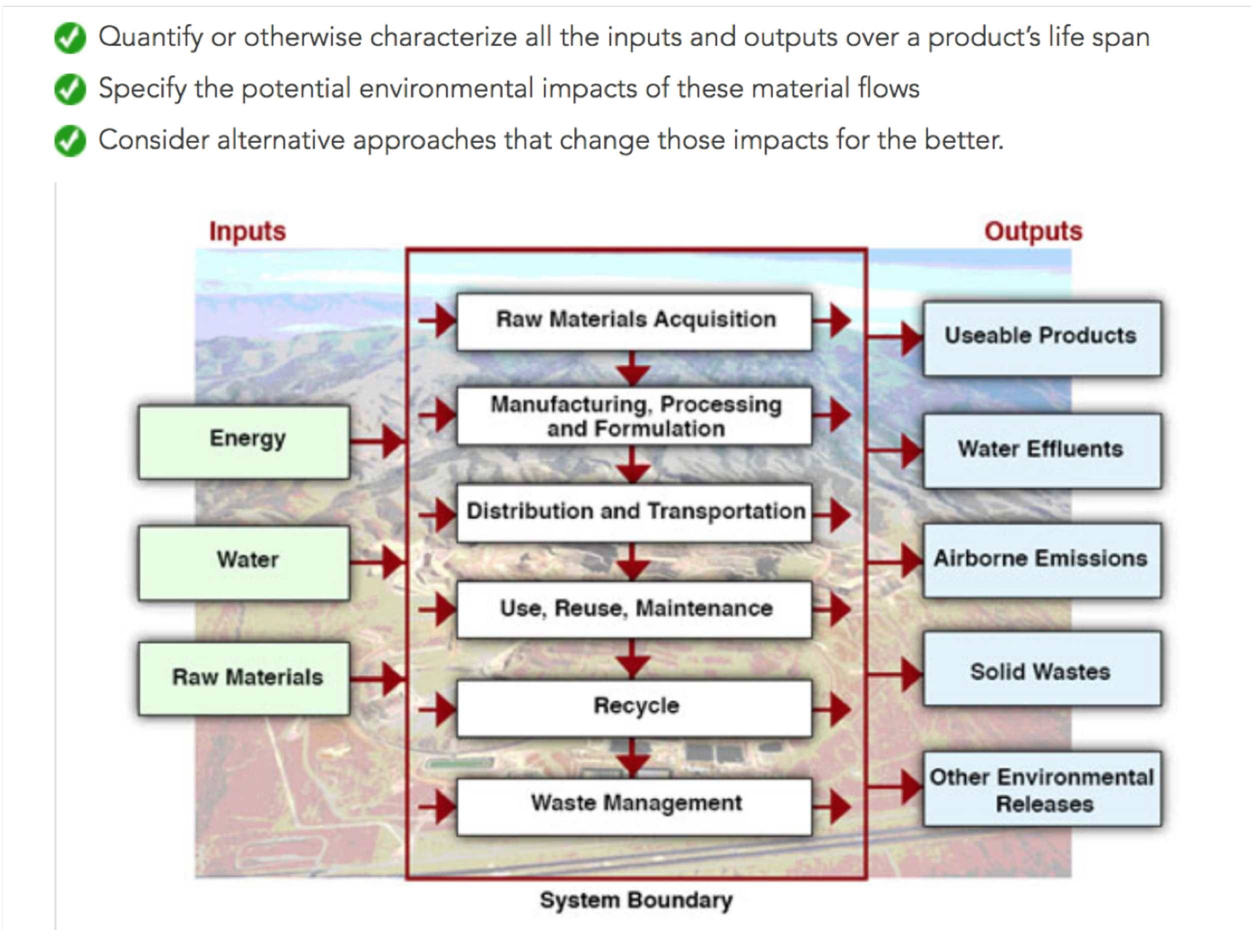
Quantify or otherwise characterize all the inputs and outputs over a product's life span
Specify the potential environmental impacts of these material flows
Consider alternative approaches that change those impacts for the better.
Inputs
Outputs
Energy
Water
Raw Materials
Raw Materials Acquisition
Manufacturing, Processing and Formulation
Distribution and Transportation
Use, Reuse, Maintenance
Recycle
Waste Management
Useable Products
Water Effluents
Airborne Emissions
Solid Wastes
Other Environmental Releases
System Boundary

Fig. 2: image

	Raw material extraction	Intermediate material processes	Manufacture	Packaging	Transportation	Distribution	Use	Operation and Maintenance	Waste generation and management	Reuse and recycling	EOL disposal
Impact: Human Health											
Priority Product	L	H	H				H				H
Alternative A	H	H	M				L				L
Alternative B	L		M				M				M
Alternative C	M	H	H				H				M
Alternative D	L	L	L				M				L
Alternative E	L	L	M				M				M
Impact: Air Quality											
Priority Product	H	M	L				L				L
Alternative A	H	H	M				L				L
Alternative B	H		H				H				H
Alternative C	M	M	M				H				H
Alternative D	L	L	L				L				L
Alternative E	L	L	M				M				M
Impact: Water Quality											
Priority Product	H	M	L				L				H

14.5 Tools for Evaluating Life Cycle Sustainability

LCA can provide a comprehensive picture of the impacts that a chemical, product or process has on aspects of human health and the environment and can help to manage trade offs. It is also an important tool that can be used to check assumptions. Given the scope and depth of a standard LCA, the biggest challenge can be data availability and understanding the most important system inputs. This can be especially challenging when manufacturing processes and chemical ingredients are held as proprietary information. The CalEPA Alternatives Analysis Guide provides an extensive list of LCA tools in its Appendix 7-2 including the following leading examples:

- International Organization for Standardization, 2006. 14040:2003, Environmental Management-Life cycle assessment-Principles and framework
- EIO-LCA: Estimates the materials and energy resources required for and the environmental emissions resulting from, activities in our economy
- GaBi: Life cycle assessment software
- SimaPro: Life cycle assessment software
- ecoinvent: Life cycle inventory data
- UMBERTO: Life cycle assessment software
- DEAM: Data for Environmental Analysis and Management, Life cycle database
- World Resources Institute Greenhouse Gas (GHG) Protocol

14.6 Challenges with LCA

Like all methodologies LCA is limited by available data. Conventional plastics are typically accounted for in well established and standardized LCA databases and software tools. However, newer materials or plastics manufactured in non-conventional ways may need customized data. Standard software packages consider multiple impact categories. In addition, high levels of uncertainty are associated with results and it can be challenging to know if differences are significant or within margins of error.

Given the potential scope of LCA it can be challenging to use LCA in a limited and pragmatic way. One strategy is to limit the scope of the system boundary. Another is to limit the number of aspects and impacts to evaluate. Life cycle thinking (LCT) uses the approach and principles behind LCA to determine whether impacts associated with a given product are likely to be greater, lesser, or similar to those associated with other alternatives.

Contents

CHAPTER 15

Resource 7: Decision Analysis

15.1 Select A Decision Framework

It is helpful to consider how decisions will be made for material selection early on in the evaluation process. A decision method can drive information needs and the criteria to be applied moving forward.

Some decision-making approaches are simpler than others to apply, use fewer resources and therefore cost less to implement. Currently, there are three decision methodologies used in the alternatives assessment (AA) process, i.e. the Sequential, Simultaneous and Hybrid Methodologies. In general, the Sequential Method provides the greatest cost savings because it can help narrow down options early in the assessment process.

The Simultaneous Method is the most expensive to implement and has the greatest data needs. It requires comparison of results for all of the available options and for all considerations and criteria.

15.1.1 Transparency is Key

Wherever there are tradeoffs, transparency can support credibility and ensure that decisions are clear and understandable. Decision support tools that are 'black boxes' or that provide results without transparency are not recommended because it will not be clear if the assessment aligns with the stated goals and objectives of the product designer.

15.2 Sequential Framework

In the Sequential approach, decisions are made at each evaluation point and only those alternatives that meet or exceed the criteria at any point continue on for further evaluation.

The best analogy is a sieve where at each point along the process, the data collected are used to differentiate between acceptable alternatives and those that do not have desired characteristics. At each point, data are collected only on those alternatives that pass through the prior sieve and the reasons for eliminating plastic options are documented.

Documentation along the way is important. It both enables others to understand the process but also could be needed if at the end of the assessment no viable alternatives are identified. The product developer may choose to revisit and alter decisions along the way in order to identify a viable option.

The benefits of the Sequential approach is that it is cost effective. Data gathering is costly with respect to time, expertise and money. At each step in the Sequential approach, the number of viable alternatives decreases, restricting data collection needs to only those that meet or exceed criteria and eliminating the need for further data collection on alternatives that have been screened out. The Sequential approach also has the benefit of facilitating a final recommendation more quickly than the other decision methodologies. For these reasons, it is a commonly used technique in the alternatives assessment process.

One negative aspect of the Sequential Methodology has limited its use by some organizations. At the end of the process, the alternatives identified may not include the optimal alternative(s) when one considers all the data simultaneously. As with most decisions, there are often tradeoffs between criteria. In the Sequential approach, an alternative may be eliminated early on based on one category, but it may be a preferred alternative based on the full set of criteria.

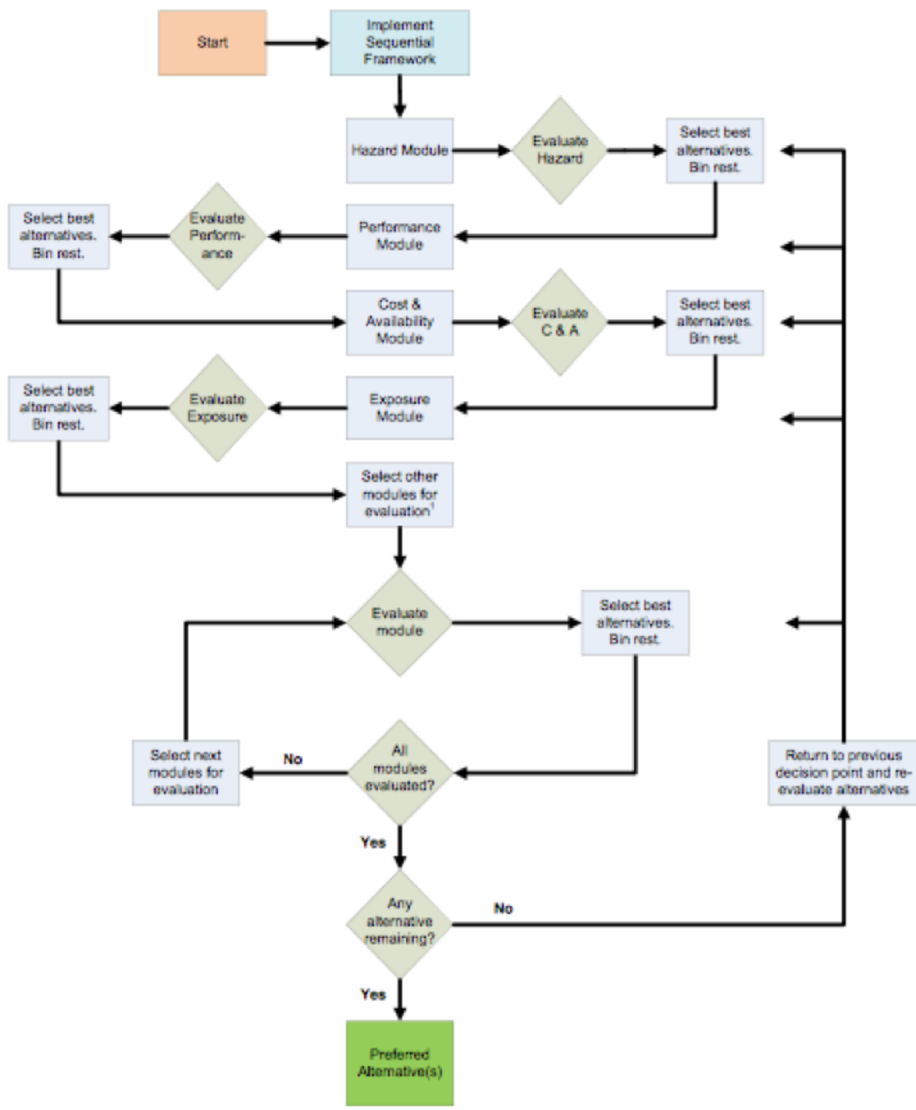

Fig. 1: image

Using the parameters of Hazard, Performance, Cost & Availability and Exposure, the above flow chart illustrates how the Sequential approach to decision support would help to identify preferred alternatives.

15.3 Simultaneous Framework

In the Simultaneous approach, data are collected on all alternatives for all relevant categories and criteria. The product developer then creates a framework and a weighting scheme and documents the decision criteria. Using the data collected, all of the alternatives are compared against the desired criteria simultaneously. When more than one material is found to be viable, additional criteria may be applied to further refine the preferred alternatives.

The benefit of the Simultaneous approach is that it retains more options throughout the decision-making process. The Simultaneous approach identifies materials with the lowest overall impact to human health and the environment. However, while optimized for an overall score, a material may be sub-optimal for any one category.

The negative side of the Simultaneous approach is that it is expensive and labor intensive because data are collected on all possible alternatives. In addition, the product developer must create ranking criteria against which all the alternatives are compared. Data gaps may become more of an issue because more data are needed. For these reasons, some organizations opt not to use the Simultaneous approach.

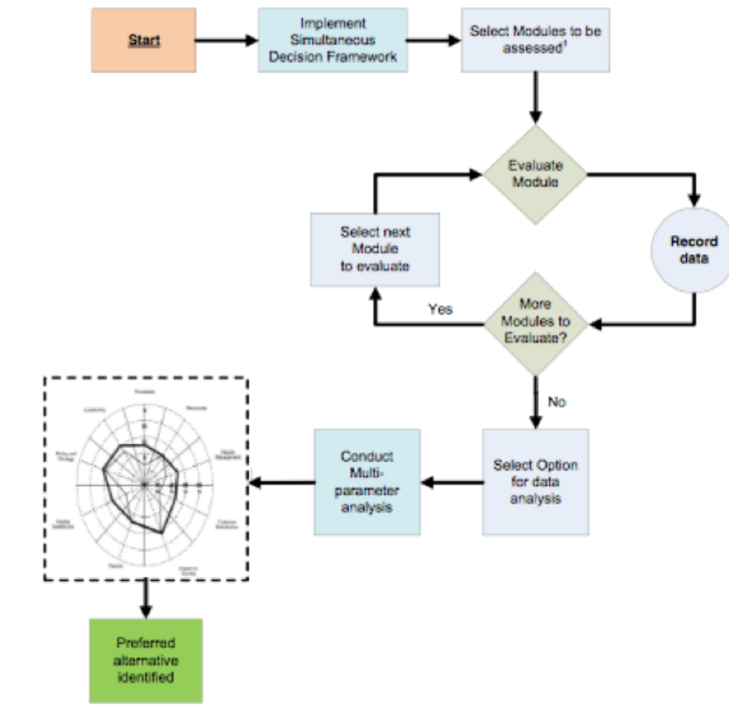

Fig. 2: image

Using the parameters of Hazard, Performance, Cost & Availability and Exposure, the above flow chart illustrates how the Simultaneous approach to decision support would help to identify preferred alternatives.

15.4 Hybrid Framework

The Hybrid approach, as its name indicates, is a mixture of the Sequential and Simultaneous approaches. In the Hybrid approach, the Sequential approach is used for a few criteria and the alternatives that remain at the end of that process are subjected to further evaluation using the Simultaneous approach. For example, an organization may decide to use the Sequential approach for the performance and toxicity evaluations. Only those chemicals or materials that meet or exceed the performance requirements are submitted for a toxicity evaluation. Upon completion of the toxicity evaluation, only those chemicals or materials that meet or exceed toxicity requirements are evaluated using the Simultaneous approach for the remaining decision criteria.

The Hybrid approach has the benefit of addressing to a degree the pros and cons identified for the Sequential and Simultaneous approaches. By using the Sequential approach, cost and resource requirements are reduced by concentrating limited resources on the most viable candidates. By using the Simultaneous approach, evaluation is conducted on a broader pool of alternatives.

Because of its flexibility and its optimized use of resources, the Hybrid approach may be the preferred approach for evaluating alternatives.

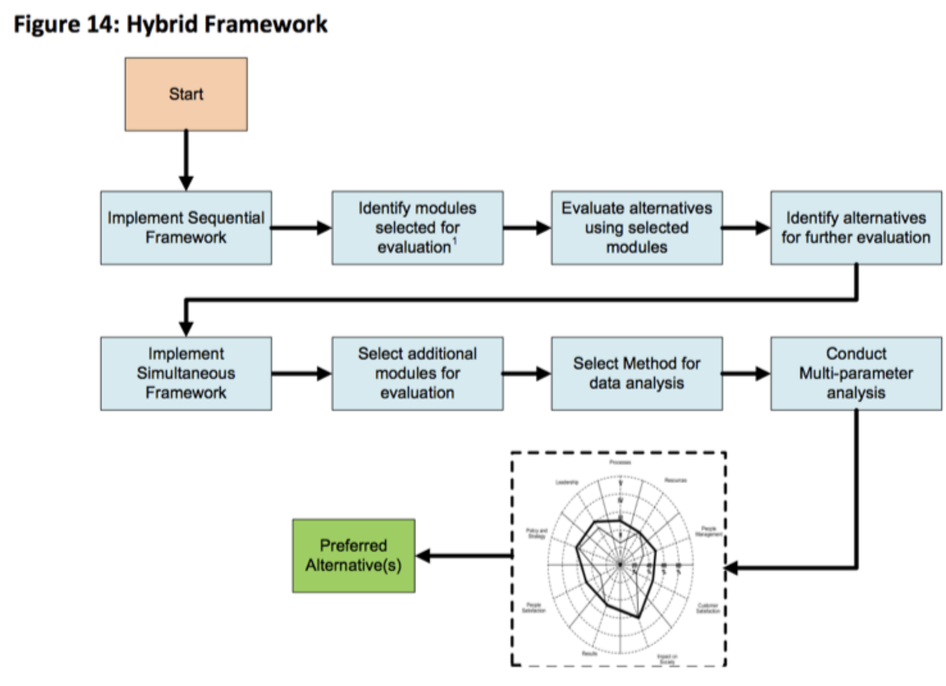

Fig. 3: image

The Hybrid Framework combines elements of the Sequential approach and the Simultaneous approach. First the Sequential approach is used to rule out those options that fail the initial screening criteria. Then the Simultaneous approach is used to compare all of the remaining options for all of the remaining criteria at the same time.

15.5 Example

Using the parameters of Hazard, Performance, Cost & Availability and Exposure, the above flow chart illustrates how the Hybrid approach to decision support would help to identify preferred alternatives.

15.5.1 Tools and Resources

Learn more about Decision Analysis in the IC2 Alternatives Assessment Guide. Images on this page are sourced from the Guide.

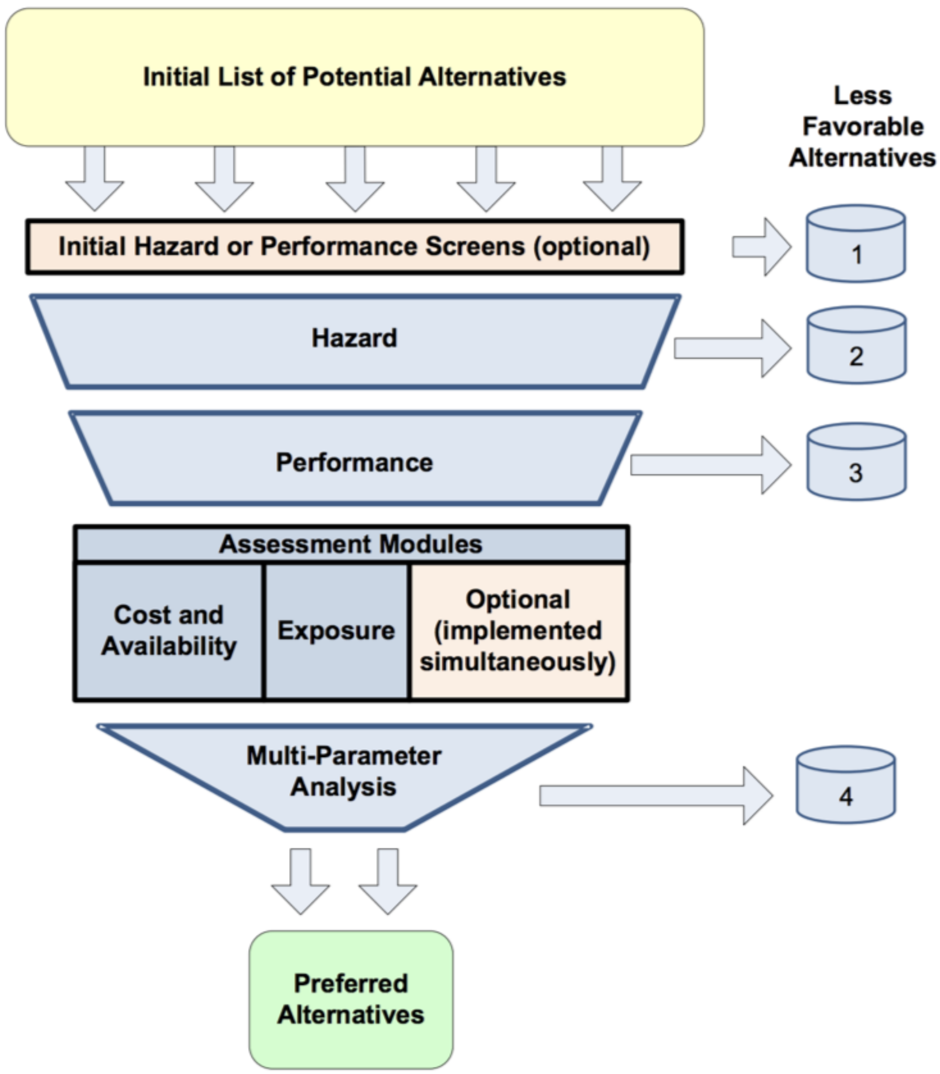
Initial List of Potential Alternatives
Less Favorable Alternatives
Initial Hazard or Performance Screens (optional)
1
Hazard
2
Performance
3
Assessment Modules
Cost and Availability
Exposure
Optional (implemented simultaneously)
Multi-Parameter Analysis
4
Preferred Alternatives

Fig. 4: image

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CHAPTER 16

References

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Contents

CHAPTER 17

Colophon

How this site came to be developed and tested on

`$ uname -a`

`Linux 5.2.17-200.fc30.i686 #1 SMP Mon Sep 23 13:43:18 UTC 2019 i686 i686 i386 GNU/Linux`

17.1 History

Original text content in markdown format was copied from the Prism app content repository develop branch. Images came from PrISM app assets repository develop branch.

The original electron app was developed with the intent of publishing this content inside the app. The app worked great, however required an annual fee for authentication and required end users to install a special app on their computers.

This document is the tutorial content liberated from the app.

17.2 Multi-step process

Converting multiple markdown pages into an organized website.

- `markdown -> Pandoc -> reStructuredText -> Sphinx -> html -> Github -> read-the-docs`

17.3 Pandoc

- Converting from markdown to reStructuredText requires the installation and running of Pandoc.
- Command line syntax generic
  - `pandoc -s -t rst --toc $source -o $target` where:

      * `$source=~/workspace/PrISM-read-the-docs/content`
      * `$target=~/workspace/PrISM-read-the-docs/conversions/source`
      * Pandoc copies from .md `/content` and converts into .rst `/source`

17.4 reStructured Text

- reStructuredText has an .rst suffix.
  - Pandoc outputs the .rst files to:

    `~/workspace/PrISM-read-the-docs/conversions/source`
- Currently the `/conversion/source/*.rst` files are the result of a scripted conversion from the markdown and should not be edited directly.

17.5 Conversion to html

- Conversion to **html** requires the installation and running of Sphinx a python based document generator.
  - Change into the `/conversions` directory, which also has (or will have) the Makefile.

    `$ cd ~/workspace/PrISM-read-the-docs/conversions/`
  - **One time only**, to generate some sphinx defaults

    `$ sphinx-quickstart`
  - Command line syntax generic:

    `$ sphinx-build -b html source build`
  - Command line syntax **specific to this project**:

    `$ sphinx-build -b html \`

    `~/workspace/PrISM-read-the-docs/conversions/source \`

    `~/workspace/PrISM-read-the-docs/conversions/build`
  - Sphinx expects an `index.rst` file that dictates the table of contents. In this project the index did not exist previously, and was therefor created in the `/source` directory, and outlined in a way that seemed to mimic the numbering of the original markdown documents.
- The transformed output *build* documents are served as a web page something like:

  `$ firefox ~/workspace/PrISM-read-the-docs/conversions/build/index.html`

17.6 Workspace customization

1. Install Pandoc. On Fedora linux it might look something like:

   `$ sudo dnf install pandoc`
2. Install python virtual environment something like:

   `$ pip3 install virtualenv`

3. Create a virtual environment for the project

   `$ cd ~/workspace/PrISM-read-the-docs/conversions/`

   `$ virtualenv venv`

4. Enable the python virtual environment

   `$ cd ~/workspace/PrISM-read-the-docs/conversions/`

   `$ source ./venv/bin/activate`

5. Install Sphinx

   `$ cd ~/workspace/PrISM-read-the-docs/conversions/`

   `$ pip3 install -U sphinx`

17.7 Github

- This documentation can be accessed at github.com/NorthwestGreenChemistry/PrISM-read-the-docs something like:

  `$ git clone https://github.com/NorthwestGreenChemistry/PrISM-read-the-docs.git`

  – and once the edits are done push back to the repository

    `$ git remote add origin`

    ```
    `https://github.com/NorthwestGreenChemistry/PrISM-read-the-docs.git `
    ```

  `$ git push -u origin develop`

17.8 Read-the-docs

> "Read the Docs simplifies software documentation by automating building, versioning, and hosting of your docs for you. Think of it as Continuous Documentation."

1. Write the recommended `readthedocs.yml` configuration file into the root directory of the project. For example

   `$ touch ~/workspace/PrISM-read-the-docs/readthedocs.yml`

2. `$ git push` the repository to Github.
3. Sign in to the read-the-docs account to administer the configuration.
4. View the resulting documentation at prism.readthedocs.io

17.9 Misc important stuff

- The original links paths to assets such as images were hard coded in the app where the In this document the hard coding have been deleted and replaced with relative paths. This means the location of the asset directory matters relative to `/source`. The assets directory was manually **copied** once into `/source` to allow Sphinx to easily find the assets.

```
/conversions
          |- /source/
                   assets
                   (content .rst files)
          |- /build
```

- In order for the github repository to accurately render the markdown pages with images the `/assets` directory must be **moved** into the `/content` directory.

```
/content
      |- /assets
/conversions
```

- Markdown is great for simple docs, however reStructuredText meets the challenges of more complex documents, including features like table of contents and indexing. If this Sphinx document format is marketable, it may make sense in a future revision to move away from markdown to only use the reStructuredText.

17.10 Bash script for editing automation

There is a bash script written just for this project to allow the conversion process to be repeated during editing of the markdown files.

script

- location: `$ cd ~/workspace/PrISM-read-the-docs/conversions/`
- filename: `convert-md-to-rst-to-html.sh`

running the script

- Make the script executable
  - `$ chmod 744 convert-md-to-rst-to-html.sh`
- make some edits to the markdown in `/content`
- run the script in `/conversions` like this:
  - `$ ./convert-md-to-rst-to-html.sh`

CHAPTER 18

Indices and tables

- genindex
- modindex
- search