SYNAPSE

SUSTAINABLE PRODUCT DESIGN

DO BETTER

SPRING 2021

HOW TO INCORPORATE SUSTAINABILITY INTO YOUR PRODUCT DEVELOPMENT PROCESS

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EDITOR'S LETTER

Sustainability in product development is no longer an option, it is a business essential. At Synapse, we know that the more closely sustainability is integrated into the design process, the bigger the impact. With that goal in mind, we've assembled a sustainable design process that closes the loop between environmental impact analysis and the product development process, ensuring innovative opportunities are explored, data driven decisions are made, and best practices are implemented. In short, converting good intentions into positive environmental results.

As a product development consulting company, we are in a unique position to drive sustainable design across industries—and we don't intend to stop there. Instead, we are sharing our work to help others design more sustainable products and systems. Collaboration is key to all of us learning and moving forward on our respective sustainability journeys.

This ebook abstracts our sustainable design process into easy-to-use tools, which can be applied to any hardware product development. The first section of the ebook explains the sustainable design approach, and some of the methods to use in sustainable innovation. The ***Apply*** section provides more detailed and specific strategies to use later in the product development process. Everyone's sustainable design efforts will be at different levels of maturity and some of the content of this ebook may be familiar to you, but we believe there will be something of value for everyone here.

We're pleased to offer this Second Edition of our Sustainable Product Development Process. This is a quickly evolving field, and we've been iterating on our approach and refining the included tools to provide the best insights. This is a continuous body of work, and we invite feedback and discussion over the methods presented here. Reach out to sustainability@synapse.com if you would like to discuss the challenges of incorporating these principles into product development, or if you have suggestions for improving this process. We seek to learn together, in pursuit of a more sustainable future.

Sincerely,

Martine Stillman, Vice President of Engineering

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DEFINITIONS

Sustainability Goals refer to targets that are set by a business or industry and extend beyond a single program, for example a business' goal to reduce their carbon emissions by 50% by 2030. Sustainable design of a product or system will contribute to meeting these goals, and these goals should guide the selection of program objectives.

Metrics are a quantifiable way to measure performance towards goals or critical program parameters. Could include: system energy use, CO2 emissions during manufacturing, or water use throughout the product life cycle.

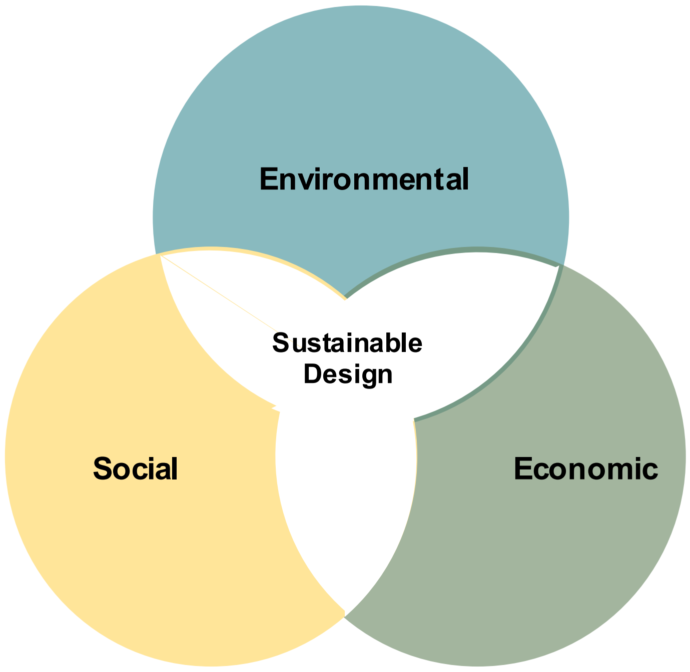
Program Objectives are specific targets for a program, influenced by company goals and priorities. Could include: zero single-use plastic, reduce waste to landfill, or use of local supply chain and manufacturing.

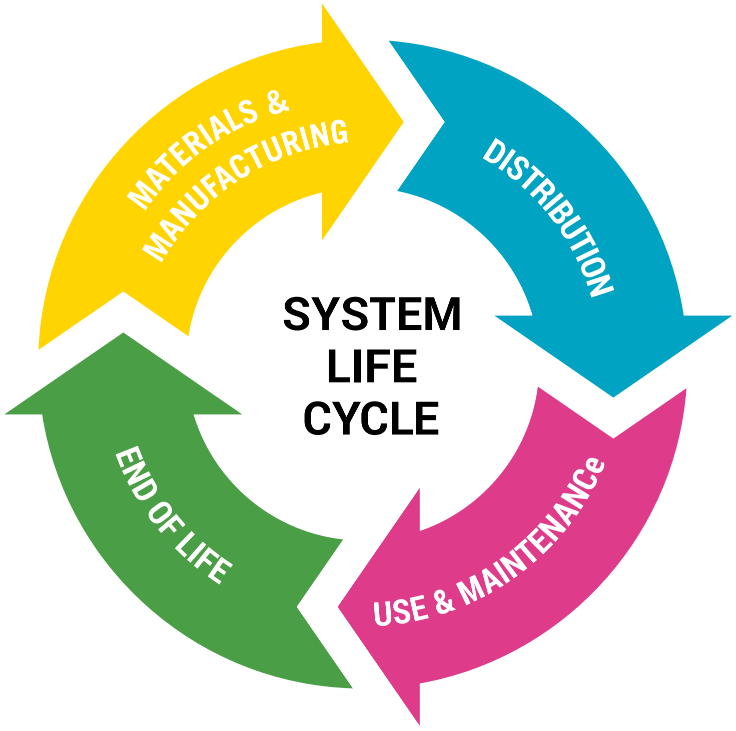
Program Requirements are driven by program objectives, and are measurable and verifiable during product development and testing. Program requirements can be used to generate requirements and specifications for sub-systems as the system design is refined.

WHAT IS SUSTAINABLE DESIGN?

At Synapse, we define Sustainable Design as "maximizing environmental, social, and economic benefits over a system's life cycle, while minimizing associated social and environmental costs".

This definition reflects the "triple bottom line" accounting framework, where the performance of a system is measured by its impact on people, the planet, and the profit it generates. Sustainable design strives to have a positive impact in all three areas. In other words, sustainable design is not only good for the environment, but benefits people and the economy too. Effective sustainable design addresses future business risks, fosters innovative solutions, and appeals to today's evolving consumer. It advances differentiation from competitors and the development of new opportunities for long-term success.





SUSTAINABLE DESIGN PROCESS

To meet this ambitious definition, strategies to produce sustainable products, systems, or services must be incorporated throughout the entire Product Development Process (PDP). At Synapse, we have developed an iterative process that ensures innovation opportunities are explored, data driven decisions are made, and best practices are implemented. This sustainable design process is one that fits within a typical product development process, and provides a formal structure for designing for, and evaluating against, sustainability objectives.

Although following this process can add extra work and cost to the design process, in many cases these upfront costs will more than pay for themselves in the long-term; perhaps through an innovative new business model, reduced product part count, or a lower carbon tax. By staying focused on the positive impact, tough decisions and tradeoffs can be made to generate truly sustainable systems.

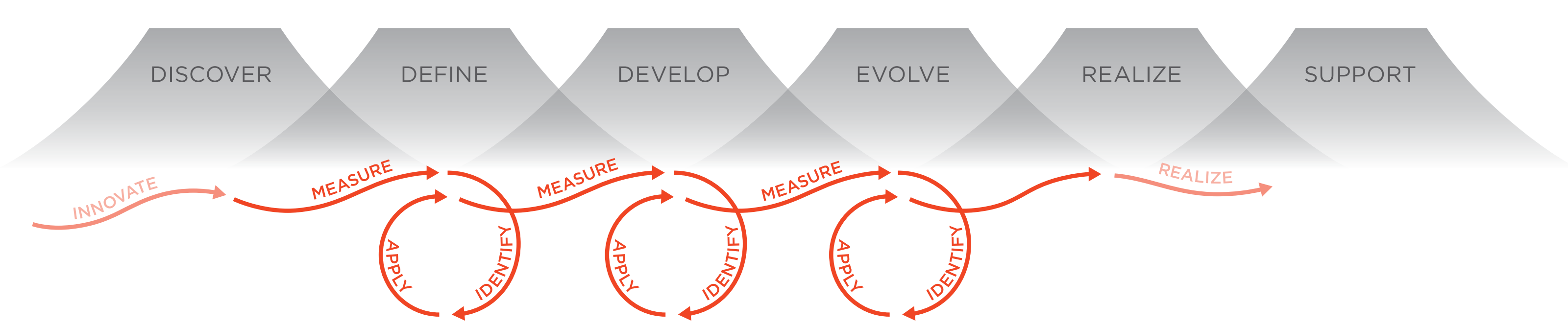
Below is an illustration of the Sustainable Design Process overlaid with the standard Product Development Process. The Sustainable Design Process is intended to be iterative, ideally you would perform the tasks in the ***Innovate*** section at the beginning, and keep those results throughout the process. The ***Measure***, ***Identify***, and ***Apply*** steps should be cycled through in every stage if possible.

Sustainable Design Process (SDP)

repeat

INNOVATE	MEASURE	IDENTIFY	APPLY	REALIZE
Identify strategic and system level opportunities to improve sustainability.	Use LCA to measure environmental performance.	Analyze results to identify opportunities for improvement.	Select and apply strategies: - Manufacturing - Distribution - Use - End of Life	Realize selected design. Document choices and knowledge generated into a case study.

Applying the SDP to the Product Development Process



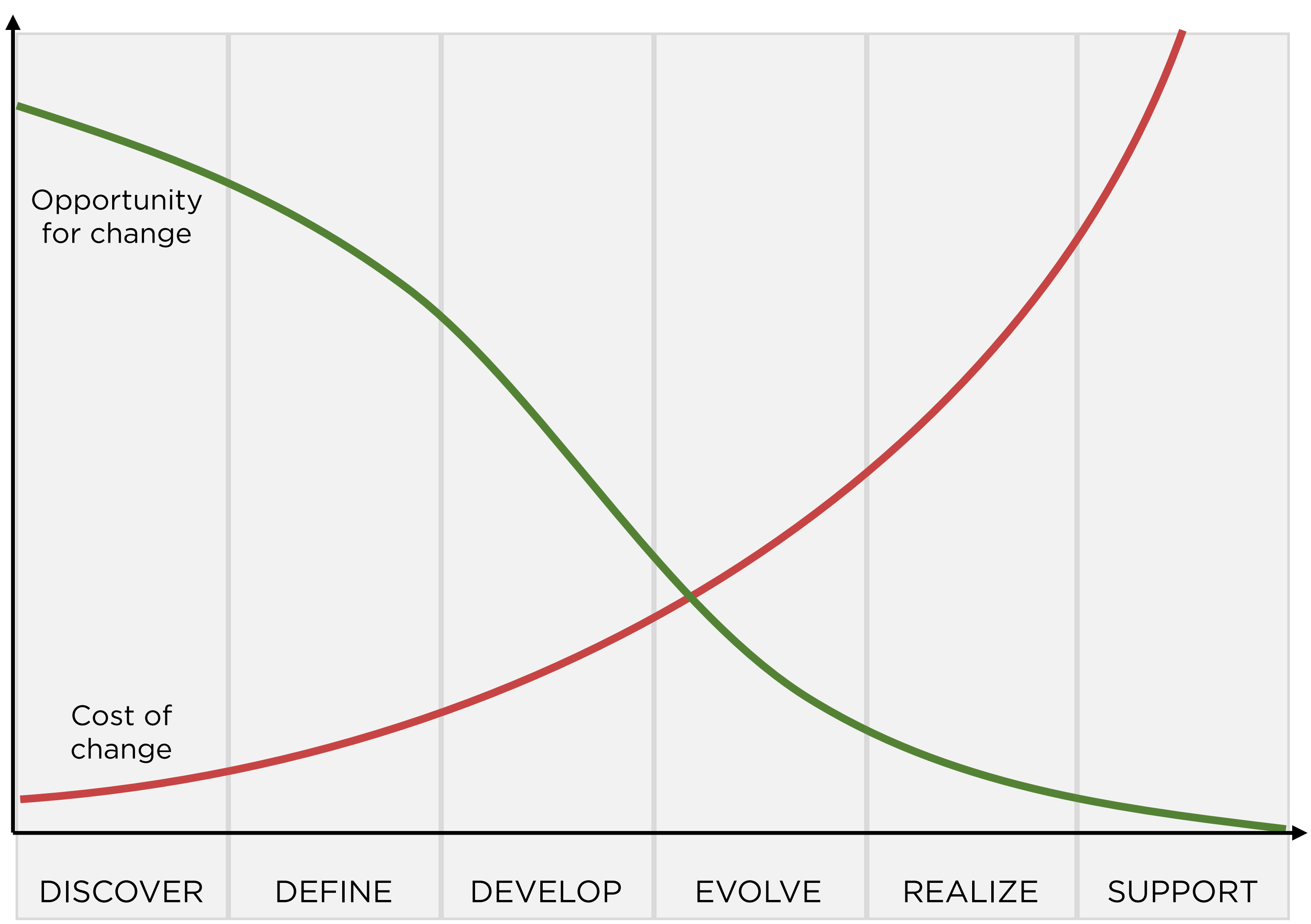
INNOVATE

Radical innovation is needed to develop systems that have positive environmental, social, and economic benefits, moving beyond incremental improvements to existing systems.

Early in the development cycle is the optimal time to do this, when strategic decisions are least constrained, and can have the greatest reach. Critical quantitative insight and whole system analysis are required to ensure that concepts deliver the desired impact throughout the full life cycle.

Using systems engineering principles, we have outlined 3 steps to achieve sustainable innovation at this stage of development:

1. **Identify Business Sustainability Priorities and Goals**
2. **Determine Program Objectives and Requirements**
3. **Utilize Sustainable Design Principles in System Concept Generation**



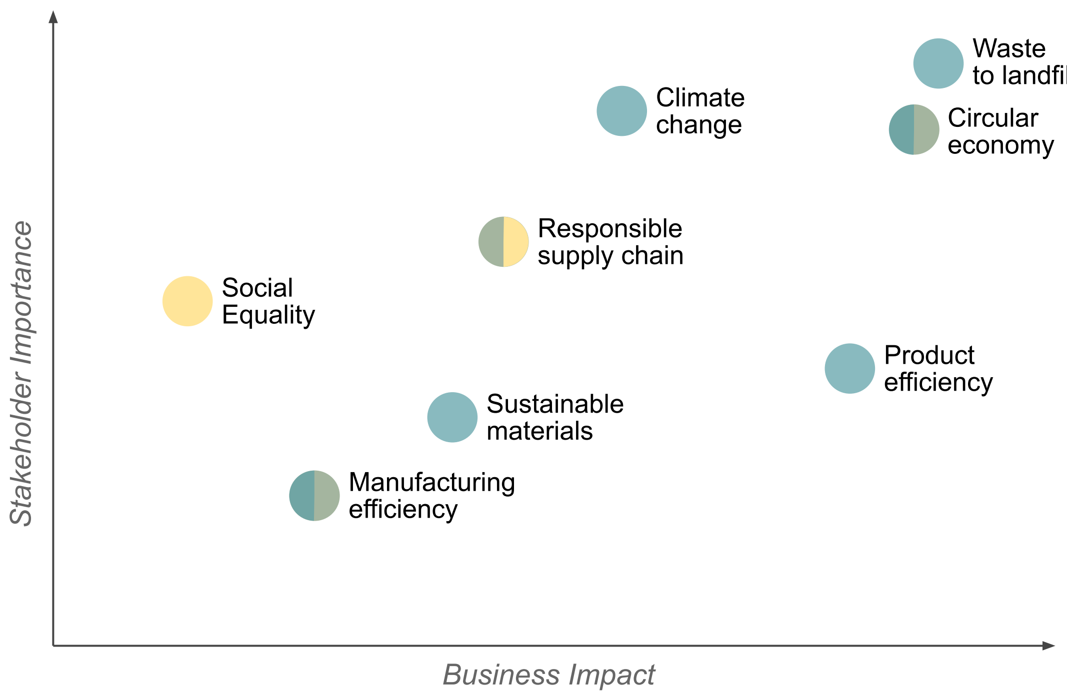
INNOVATE
STEP 1

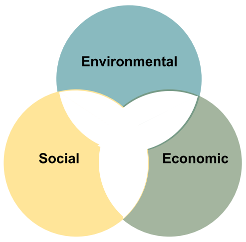
Identify Business Sustainability Priorities and Goals

Setting relevant sustainability priorities and goals informs business planning and system design, ensuring that sustainability is effectively incorporated into product development. Creating these goals should be an iterative process and should involve stakeholders from across the business. This is a critical step, in order to build alignment within the company and to allocate the appropriate time and resources.

Sustainability Priorities

One tool that can be helpful in determining business priorities is a materiality assessment. In this activity sustainability issues are plotted relative to stakeholder importance and business impact. The issues that fall in the top right should become the focus for innovation efforts.





Stakeholder Importance: How the stakeholders rank the topics. Stakeholders include: consumers, manufacturing partners, shareholders, distribution partners, etc.

Business Impact: A combination of the ability for the company to impact the topic and the impact of the topic on the company's business.

MATERIALITY ASSESSMENT KEY QUESTIONS

Find the expanded worksheet at the end of this ebook

1. *What stakeholders exist?*
2. *What aspects of sustainability are most important to these stakeholders?*
3. *Which stakeholders have the biggest impact on system design?*

Completing a materiality assessment (on page 8) will require background research on the market, regulations, and consumer preferences. Furthermore, a lightweight Life Cycle Assessment (LCA) of a previous generation or competitor product can inform the materiality assessment, by identifying the biggest environmental impact areas for the particular market sector. Details on LCA and how to use it as a design tool will be covered in later sections.

Sustainability Goals

Once alignment on sustainability priorities is established, specific goals can be set to address the identified high priority areas. For example, in the materiality assessment above, waste to landfill was most important to stakeholders and had the biggest impact on the business. With that in mind, appropriate goals could be:

+ Reduce product waste to landfill by 50% by 2030
+ Use 100% recyclable or biodegradable materials in packaging by 2040
+ Extend average product life by 2X

It is important that these goals are measurable and trackable, in order to show progress, and to reap the benefits of the high business impact as identified in the materiality assessment.

Examples of how to track these goals (with specific metrics) are shown below:

Metric	Measurement and Calculation Methods
% of packaging mass from recycled sources	Packaging design records, with material source details, and volume of packaged product shipped
Average product life	Ideally user data, but this could be design life, assuming constant use rates per year, if usage data is difficult to obtain
% of product mass that can be recycled at end of life	Product design records, with the materials evaluated for recyclability, and volume of product shipped

Resources

There are existing standards and global sustainability goals to help support companies in making sustainable decisions. These can be used to provide inspiration for appropriate business goals or system level objectives (covered in the next section). Click on the logos below to learn more:

CERTIFIED CARBON NEUTRAL Global Standard | SUSTAINABLE DEVELOPMENT GOALS KNOWLEDGE PLATFORM | SCIENCE BASED TARGETS DRIVING AMBITIOUS CORPORATE CLIMATE ACTION | cradletocradle

INNOVATE
STEP 2

Determine Program Objectives and Requirements

Once business goals are set, it is important to close the loop with design teams by establishing targets for specific programs. This is typically done by translating the goals into program level objectives and requirements, with the program teams involved in the process. Reaching business sustainability goals will require initiatives and feedback from every program.

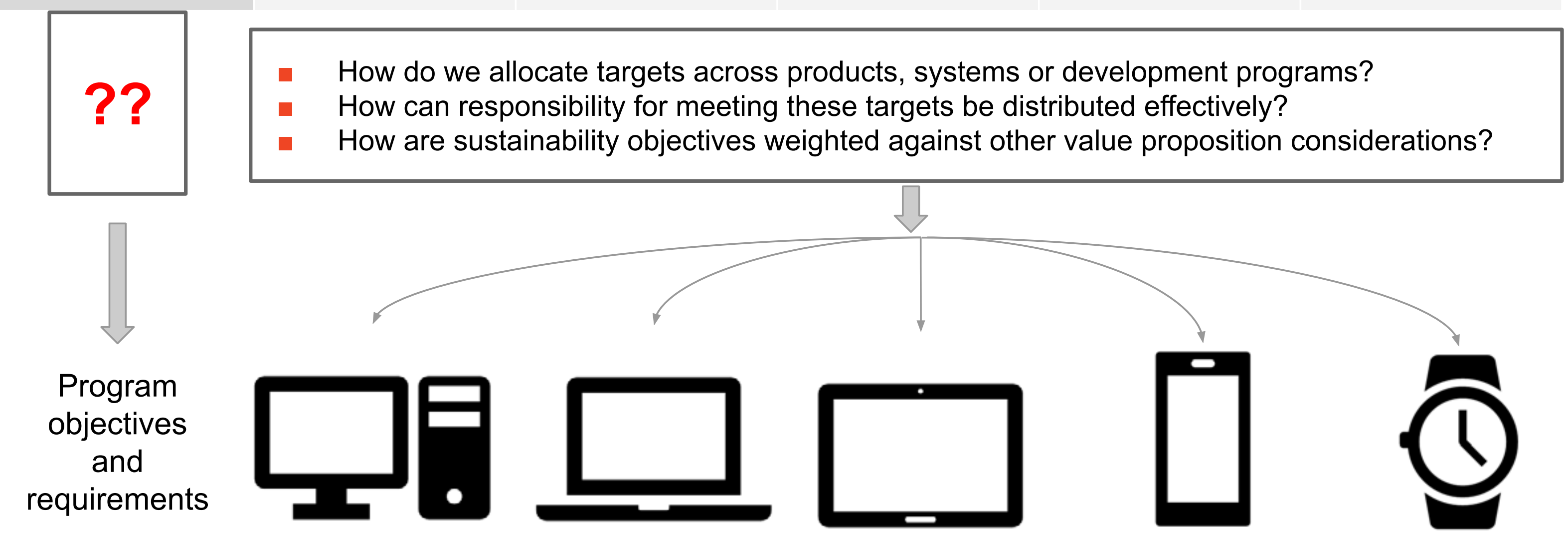
Define Program Objectives

As discussed in the goal setting process, metrics are key to tracking progress and will be critical in enabling program teams to track their own progress and set their own objectives.

The image below illustrates the process of taking business goals, identifying the metrics used to measure progress, and then allocating these across programs. The allocation process across programs should be collaborative. Some programs will contribute more or less to a specific goal.

If a company's goal is to reduce waste to landfill by 50% by 2030, a specific program objective could be to extend the useful life of the product or to design for responsible disposal. As alternative concepts are explored this could trickle down into a product life requirement or a requirement on the % of products reclaimed at end of life for refurbishment or responsible recycling. Because there may be many ways for individual programs to contribute to reaching a business goal, this will be an iterative process–define objectives, establish requirements, explore concepts; refine and repeat. Ultimately, as programs develop, and company roadmapping evolves, program objectives will guide requirements.

Sustainability Goals	Increase product lifetime *by N years*	Reduce environmental impact of packaging *by N%*	Reduce product waste at end of life *by N%*	Increase use of sustainable materials in products *by N%*	Increase product energy efficiency *by N%*
Metrics	Average product lifetime	% packaging material from recycled materials	% mass of products recycled at end of life	% recycled content of materials used in products	Energy use by product over lifetime



Establish Requirements

Incorporating sustainability into the program requirements ensures that the identified sustainability objectives are realized in the system and can be measured in verification testing. This is one of the most critical steps of the process, and can be surprisingly challenging.

Definition of the sustainability-related requirements, as with all requirements, is likely to be an iterative process. Some requirements can be left under-defined early in the design process, to be refined later as concepts are developed, or as testing and analysis informs feasibility of requirements and tradeoffs.

Requirements should reflect the sustainability objectives at the program level, and ideally are able to be derived into subsystem requirements as the design process progresses. Examples of requirements include: total carbon footprint <20 kgCO2e over the entire system life, <2kWh/year system energy consumption, meet a product certification such as Cradle to Cradle (to be accompanied by subsystem requirements). Consideration must be made as to how these requirements can be measured and verified later in the development process.

DEFINE SUSTAINABILITY REQUIREMENTS

Find the expanded worksheet at the end of this ebook

1. *Which system requirements reflect the identified sustainability objectives?*
2. *How will the sustainability-related requirements be verified?*
3. *How can the system-level sustainability requirements be derived into subsystem requirements?*

INNOVATE
STEP 3

Utilize Sustainable Design Principles in System Concept Generation

In this last step of the ***Innovate*** stage, the sustainable business goals and agreed upon program objectives are used to develop **sustainable design concepts**.

Concept Generation

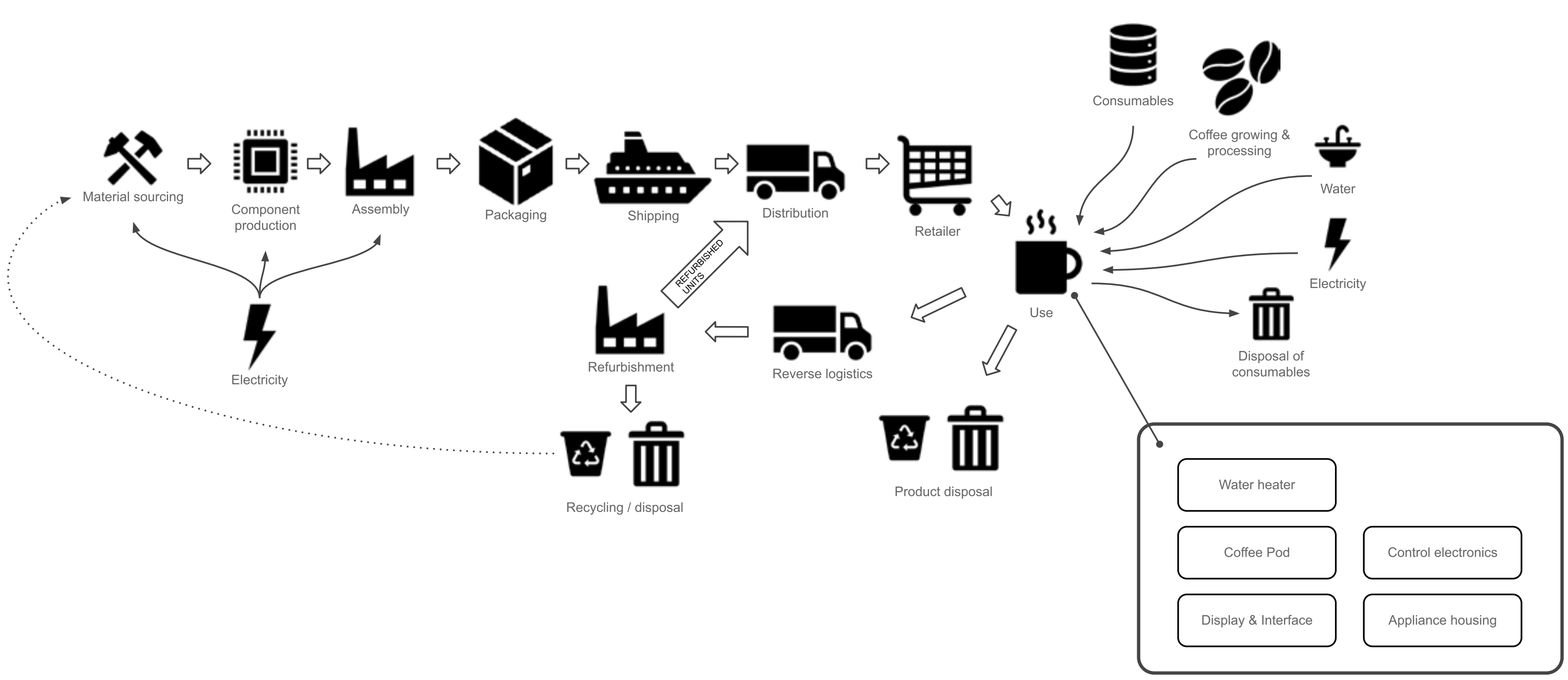
There are many brainstorming techniques for successful concept generation, instead of covering them all here, we've chosen to highlight strategies and principles that allow for innovative solutions in an effort to meet ambitious sustainability goals.

Whole System Mapping

System mapping is a visual process for concept generation that starts with drawing a system map-showing the user stories, interactions, dependencies, stakeholders, and full life cycle of the product, service, or system being developed. Brainstorming is then focused around the map, encompassing the full system by:

+ Generating an idea for every node
+ Considering how nodes can be eliminated
+ Reviewing interactions between stakeholders and the system

The holistic nature of this method exposes the entire product life cycle and can often be more effective for discovering critical or unexpected areas to implement sustainable improvements than standard brainstorming techniques. For further details on this method, refer to the resources available at: venturewell.org



Circular Economy Principles

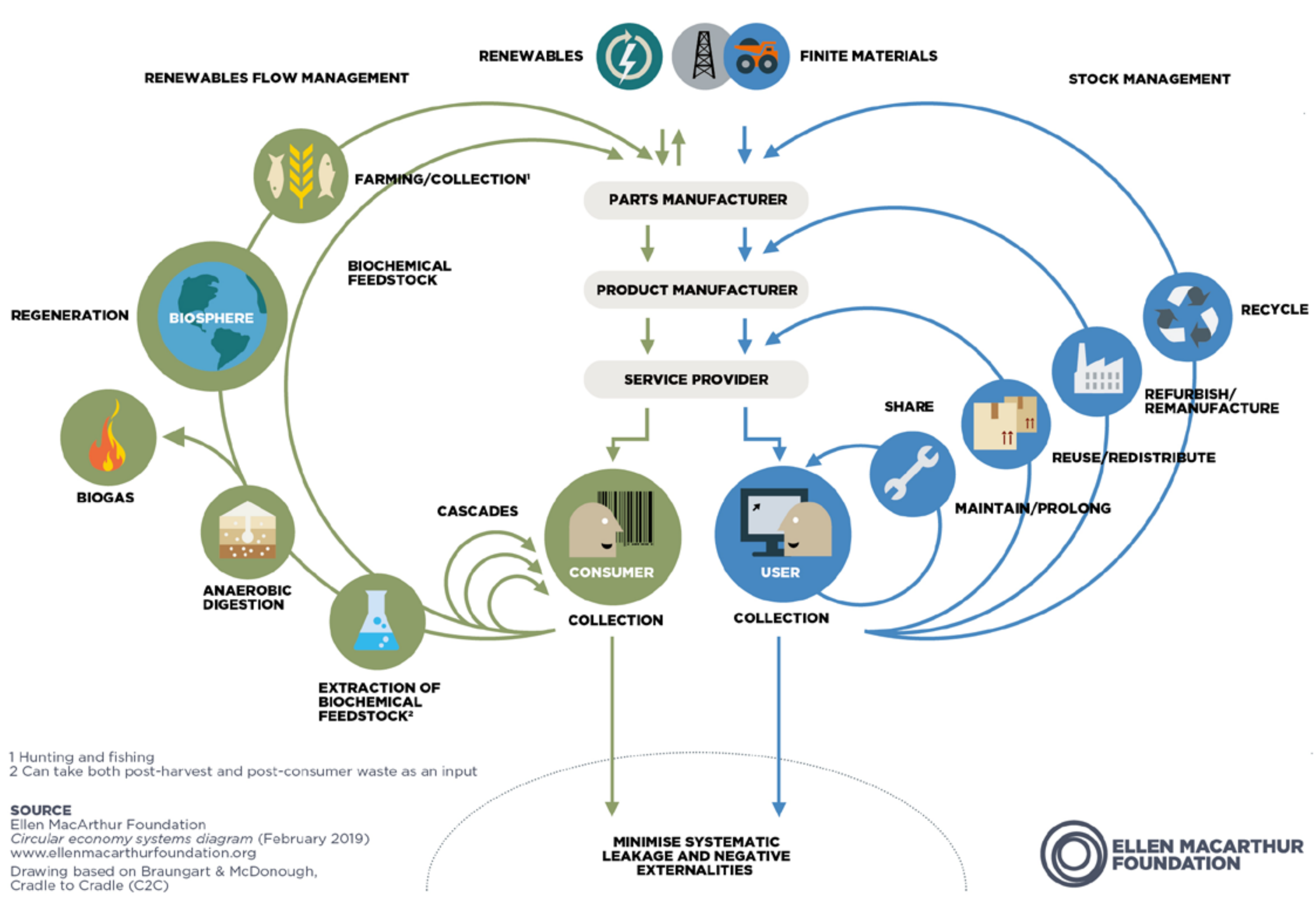
Circular economy principles advocate for the switch from a 'make, use, dispose' business model, to one that is decoupled from the consumption of finite resources. The focus is on keeping goods in circulation and at their highest potential for as long as possible. Using circular economy principles to build more sustainable systems can generate business and economic opportunities, while providing environmental and societal benefits.

There are excellent resources on how to apply these principles at:

+ CircularDesignGuide.com
+ Ellen MacArthur Foundation

To implement circular economy principles in design:

+ Consider all stakeholders and systems that interact with your system. Review and modify material & energy flows between them to maximize value and remove waste
+ Consider opportunities for reuse, repair, refurbish, remanufacture, recycle (prioritized in that order)
+ Design for evolution to avoid product obsolescence
+ Consider how current waste could be used as feedstock
+ Use renewable energy sources to facilitate the manufacture, use, reuse, repair, remanufacture or recycling of products, components and materials without depleting natural resources



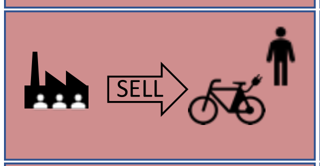
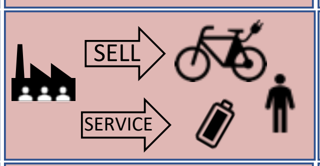
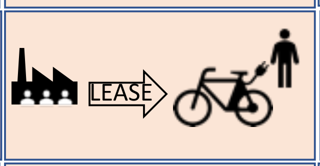
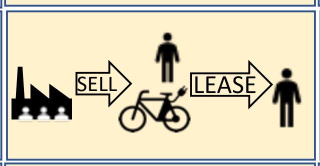
Moving from Product to Service Business Model

Shifting the business model from a pure product model to a combined product service system can facilitate increased sustainability of the ecosystem by increasing the utilization of fewer goods and allowing for more circular material flows. The full spectrum of combined product and service business models is illustrated below.

System Definition

A Product Service System falls on the spectrum from product to service, ownership varies, while value comes from combination of product & service

There are often greater opportunities for sustainable business models the further towards a service the business model can shift

Pure Product	Product Oriented	Use Oriented	Result Oriented	Pure Service
Customer Ownership *Company manufactures, customer buys*	**Product Related Service** *Sell product + related service (software, maintenance, training)*	**Product Lease / Sharing** *Customer either rents use of a product, or shares use of a purchased product with other customers*	**Pay For Service** *End customer pays for a service unit or for outsourcing of a task*	**Service Providing** *Customer pays for service, with no product used by the provider*
				
e.g. purchase of e-bike	e.g. e-bike purchase + battery service	e.g. lease owning of e-bike	e.g. *paying for floating e-bike share use by the mile*	e.g. paying for route planning or bike maintenance training service

Adapted from: https://venturewell.org/wp-content/uploads/PSS-biz-models-table-Faludi-2019.pdf

The business model shift not only provides opportunities for increased sustainability, but also economic benefits for the company. As systems become more service-oriented they typically facilitate increased insight into consumer behaviors through data generated. This increased insight can be used to improve customer satisfaction, and to identify opportunities for increased efficiency. Furthermore, with the shift from product oriented to service oriented, business and consumer needs are better aligned, both parties want durable, efficient, easily repaired goods.

Downselect System Concepts

Downselection of system concepts is done by first screening them against the requirements, and then ranking the remaining concepts against the program objectives and business priorities. There are many tools that can help with downselection, one being a decision matrix as shown below.

Decision Matrix

In a decision matrix, concepts are assessed against a broad range of key criteria, inclusive of, but not limited to those related to sustainability. These criteria reflect key performance metrics of the system, and are weighted based on their relative importance to system success. The concepts are evaluated against each of the criteria, then the total weighted scores are compared. Numerical scores are not intended to be absolute or fully researched, but instead provide a general impression of how well the concepts align with the system criteria.

This tool is best suited to inform stakeholder discussion over concept downselection, and the results should be closely questioned. If the relative scores of concepts do not match your 'gut' feeling, consider re-evaluating the weighting factors and scores. The higher the score the better.

Input Code:
CRITERIA WEIGHT (0.1 [least important] - 1 [most important])*
CONCEPT OPTION SCORE (1 [low] - 10 [high])

		Sustainability Criteria			Product Criteria			Total:
	Criteria:	Emissions	Consumption	Waste	Cost	Performance	Time to Market	
	Weight:	0.3	0.1	0.5	0.5	0.7	0.1	
Options:	Sell e-bike	3	3	3	3	8	5	**10.3**
	Sell e-bike conversion kit	5	5	5	5	5	7	**11.2**
	E-bike long term lease	9	9	7	5	6	5	**14.3**
	Floating e-bike share program	8	8	7	7	4	3	**13.3**

Find a blank decision matrix at the end of this ebook.

MEASURE

Regular measurement of the environmental performance of the system is core to this sustainable design process. ***Measure*** is the next step after the ***Innovate*** stage. This step is also performed during every design iteration and is the last step before realizing the system.

Whether it is a concept or detailed design, a **Life Cycle Assessment (LCA)** is the recommended, industry-standard method to quantify the environmental impact of the design across the system or product life cycle.

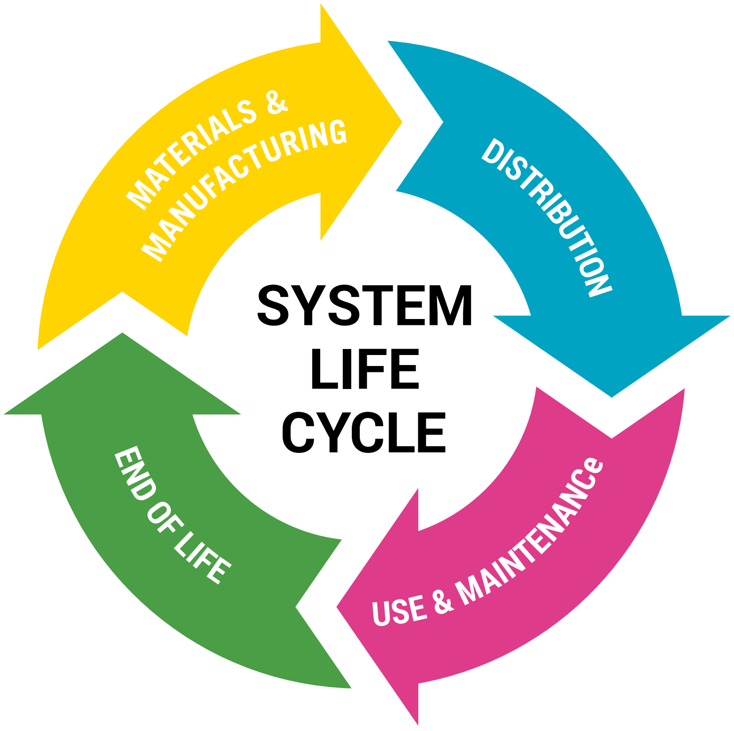
Performing an LCA allows the environmental impacts of the system to be understood, and allows the quantified impact to be evaluated against sustainability objectives and requirements. Some metrics may not be measurable using LCAs, and in that case alternative measurement techniques should be used to monitor progress.

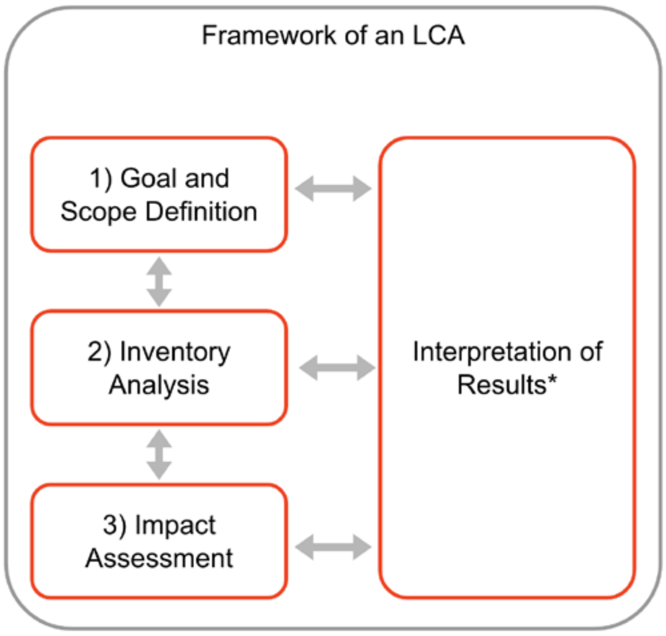
In this sustainable design process, LCAs are used to:

+ Set a benchmark to compare concepts and design iterations
+ Identify 'hot-spots' in a system's design or life cycle that contribute the majority of the environmental impact
+ Quantify the environmental impact of a product over its lifetime

In early phases of the system development, this will likely be a quick estimated LCA or a comparative analysis of a benchmark system or product. As the design matures, the LCA should be refined with each iteration to increase confidence in the results as well as capture the effect of any design changes. During the final analysis, measure the LCA results against the sustainability requirements and objectives.

The LCA process is outlined below, including key considerations specific to product development, to ensure the analysis generates reliable results.





*In this sustainable design process the interpretation of results is performed in the next stage: Identify.

Life Cycle Assessment Steps

Step 1: Goal and Scope Definition

This stage defines why the LCA should be performed and what will be included. System boundaries are set for the analysis, which could exclude areas that are undefined, or that the team has little influence over, to simplify the calculations. For example, packaging details may be left out in early stage consumer product LCAs.

Step 2: Inventory Analysis

Typically, LCA tools require a detailed inventory to produce an accurate impact assessment. Specifics on part properties, product distribution, system use, and end-of-life need to be collected. Early in the design process, there will likely be unknowns in some or all of these areas, so assumptions can be made in the assessment, with the knowledge that the results will have greater uncertainty. These assumptions are then refined in future assessments as the design is developed and uncertainty is reduced.

LCA tools use a detailed database to build the picture of your system impact. The databases contain geographic information, like the impact of electricity generated in different places or the impact of mining materials from various locations. The more detailed you can be about your manufacturing plans, the more accurate your assessment will be. If you don't yet know these details, you can evaluate a few different options to see how the impact is affected.

Step 3: Impact Assessment

Having defined all the system inputs to the LCA, the impact of these inputs can be calculated. During this stage it's important to consider how the LCA results relate to your sustainability objectives—this will drive selection of the impact assessment method and will influence the LCA software you use. See the following page for further information on LCA software tools.

One of the most commonly used impact assessment methods reports a measure of CO2 equivalent emissions associated with the system. This is perfect if you have sustainability objectives related to greenhouse gas emissions, but less relevant if you are focused on another area, such as water use.

There are other more holistic assessment methodologies, including ReCiPe and TRACI, which take into account several sustainability indicators encompassing human health, ecosystem quality, and resource depletion. Consideration must be given to the relative weighting of the impact area scores,and how these relate to your sustainability goals and objectives. For simplicity of analysis, it is possible to generate single scores using these assessment methods, but the weighting used to generate these scores should be evaluated and understood when using these results.

LCA WORKSHEET

Find the expanded worksheet at the end of this ebook

1. What is the goal of your LCA?
2. What is the system boundary for the analysis?
3. What is the functional unit for the system?
4. Collect the system inventory (best done as a separate BOM document):
    - What materials and manufacturing methods are used to produce the system?
    - What is the intended distribution plan?
    - What energy is used during the system use?
    - What is the end of life strategy?
5. What level of uncertainty exists in your system inventory?
6. What impact assessment method is most appropriate for the system?.

LCA TOOLS

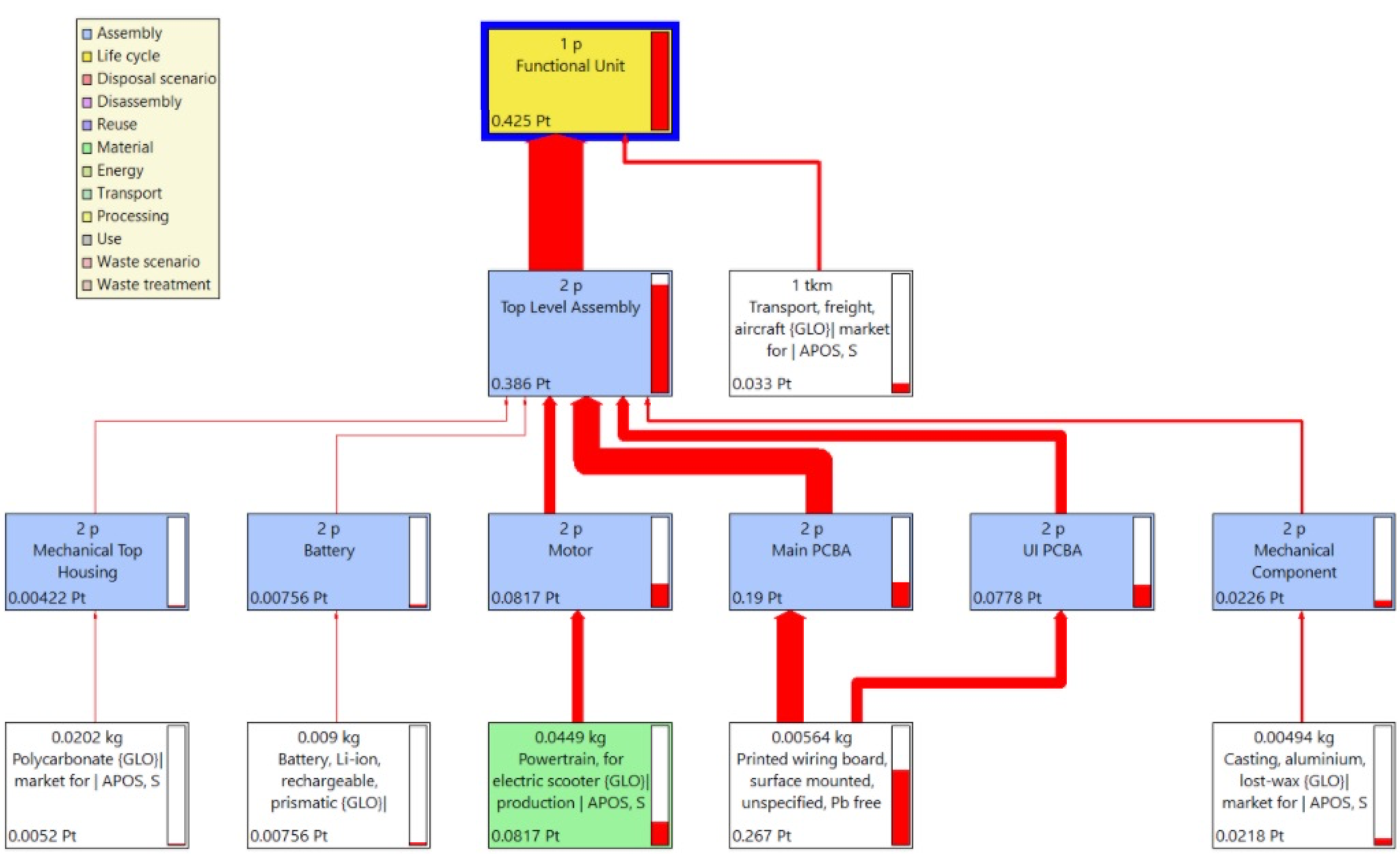
By nature of the iterative process, you may rely on different LCA tools and resources throughout the product development process. For a well defined system late in the development process, SimaPro or GaBi, two of the industry standards, can be used. For less defined systems early in the design process, we lean towards lightweight tools like Sustainable Minds or impact databases like Ecolizer that allow for higher level evaluation of alternative concepts.

The different tools available can use a range of assessment methods. For tools such as SimaPro and GaBi, there are multiple impact assessment methods to choose from, whereas for more lightweight tools, there are often only one or two assessment methods available.

Below is an example output from SimaPro using the Recipe single score assessment method. The thicker the flow line in the network chart, the greater the impact of the specific component or process.

Synapse & Cambridge Consultants have developed a tool to evaluate the carbon emissions of a product at a very high level, introducing the impact of carbon pricing on the overall product cost. This can be helpful in preliminary discussions about hot spots or as a way to demonstrate the value of LCA techniques in a very low-overhead way. This tool is available in Beta at the time of publishing this book at upintheair.cambridgeconsultants.com

Synapse is also collaborating with academic and industry experts to develop user-friendly LCA tools for evaluating concepts at various stages of maturity. This is going to be critical in supporting effective decision-making at the concept stage with quantitative analysis to support best practices. Please follow along on Synapse's social media platforms for updates on these tools.



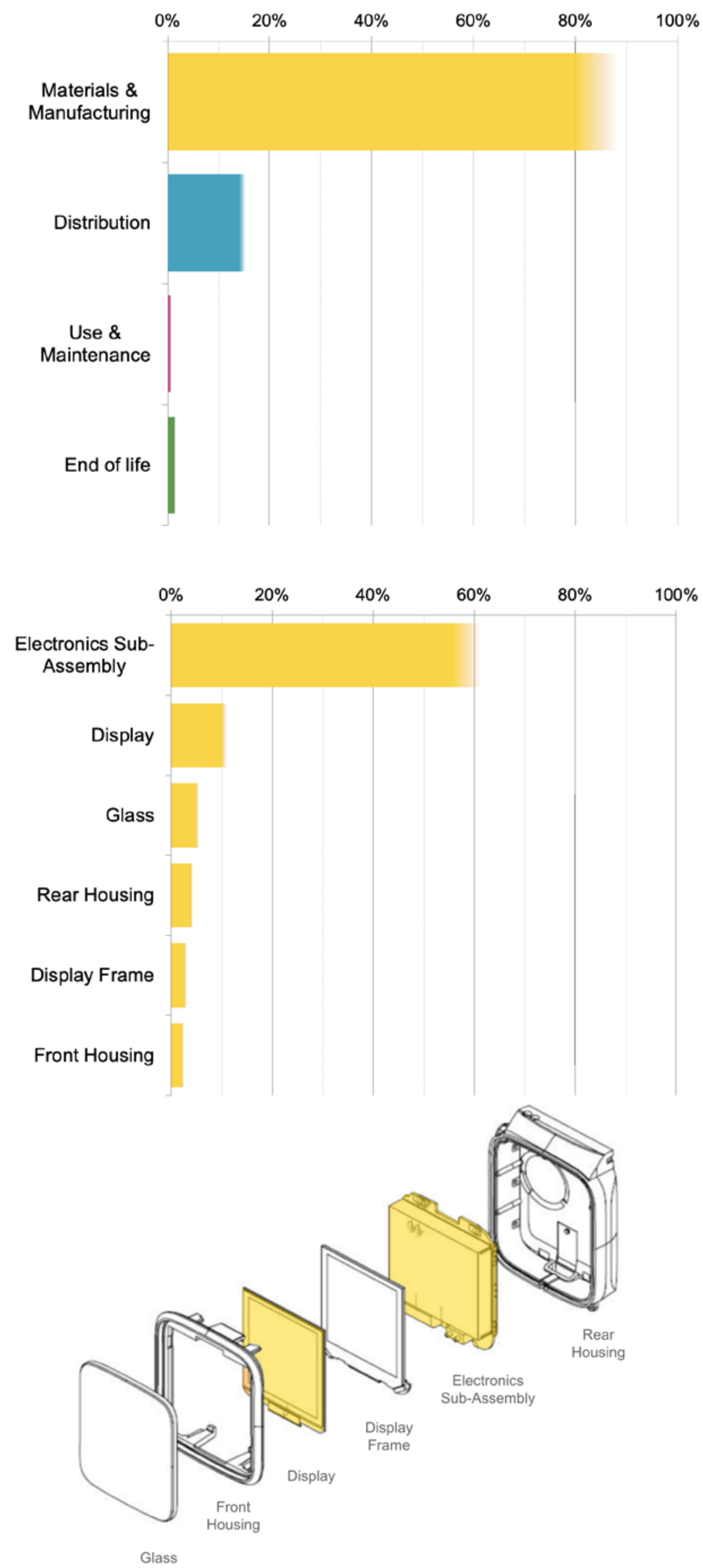
IDENTIFY

After performing an LCA, analyzing the results will reveal:

+ The product life cycle stages that have the greatest contribution to the overall impact
+ The components or processes that are responsible for the greatest impact

This information will allow system design iterations to focus on **minimizing the negative impacts from these biggest contributors**, using the strategies outlined in the ***Apply*** section of this document. Analysis of the results will spark ideas on how to design for improved environmental performance through design iterations or revisiting the business model and opportunities for circularity.

On this page we show an example of a sample product's LCA results. In this example, the greatest opportunity for making improvements in sustainability will be seen in strategies that impact the Materials and Manufacturing, particularly those related to the Electronics Sub-Assembly. Here, the product is well-defined, so there is little uncertainty in the results. For LCAs earlier in the design process, greater uncertainty in the results will be expected and should be communicated in the results, using error bars or other techniques such as blurring the end of the bars as shown in the charts to the right. This process is about maximizing impact, so while it would still be beneficial to improve end of life (e.g. making it recyclable), the initial focus should be on the biggest hot spots, which can be identified regardless of the amount of uncertainty.



LCA results, highlighting life cycle stage and components with greatest impact

Feasibility vs Impact Matrix

A Feasibility vs Impact Matrix (FIM) can be used to inform which areas to prioritize in the design process. The 2X2 matrix maps the environmental impact vs the feasibility of the change. In the example below, environmental impact is in terms of carbon reduction and the feasibility is in terms of technical feasibility, cost, and schedule. The highest feasibility and highest impact hotspot(s) should be the team's focus to have the biggest benefit with limited resources.

APPLY

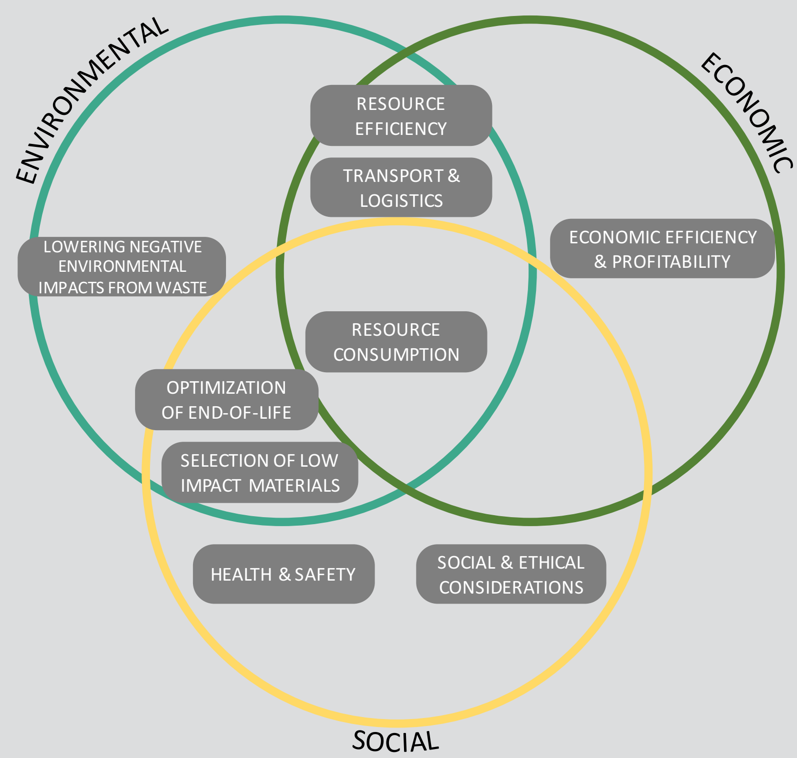
Having identified the biggest impact areas in the previous section, you can now implement specific strategies to reduce the system or product impact. These strategies allow for specific incremental improvements to the design; a cycle of ongoing or tiered improvements is common, in an effort to meet the sustainability product requirements. Furthermore, some strategies may spark ideas that influence re-evaluation of decisions made in earlier stages of this sustainable design process.

Because this is an iterative process—***Measure, Identify, Apply***—the strategies are mapped against the product development phases to allow focused efforts on strategies that can be applied at the current phase of development.

When implementing these strategies, it's important to evaluate trade-offs associated with the "triple bottom line", ideally finding ways to have a net positive impact on environmental, social, and economic factors.

Key Impact Areas

The Strategies described in the ***Apply*** stage were generated relative to 9 categories of impact, as defined by the United Nations Environmental Program (UNEP), to allow for comprehensive coverage of sustainability issues. These impact areas relate directly to the "triple bottom line" measure of sustainability and how we define Sustainable Design.



Key Impact Area Definitions

The nine impact categories as outlined by UNEP are defined here:

Resource efficiency refers to the use of material and energy in creating the system.

Resource consumption is the material and energy used during system operation or use.

Selection of low impact materials focuses on the quality of the resources used, especially looking at the toxicity and embodied energy of the material.

Optimization of End Of Life relates to the impacts of the system caused by the end of life mechanism. Optimization involves selecting an end of life strategy that minimizes negative impacts and maximises the potential for high-value reuse, recovery, or recycling.

Health and safety goes beyond the typical risk assessment for a system. It evaluates how the system could compromise the health or safety of any stakeholder in the system life cycle, from manufacturing, through distribution & use, to the end of life of the system.

Transport and logistics considerations are focused on how the transportation associated with the system contributes to the sustainability impact.

Social and ethical considerations encompass how a system has social and ethical impacts throughout its life. This includes labor conditions in the supply chain, how a technology can reinforce or remove discrimination, as well as many other factors.

Lowering negative environmental impacts from waste captures any negatives impacts from waste products and pollution throughout the whole life cycle.

Economic efficiency and profitability is how the system generates profit.

STRATEGY CONTENTS

DISCOVER DEFINE DEVELOP EVOLVE REALIZE SUPPORT

MATERIALS & MANUFACTURING

Avoid or Reduce Materials and Processes That Deplete Natural Resources

Summary

One way to reduce the environmental impact of a product or system is to reduce the use of materials that deplete natural resources.

For consumer electronics, the biggest impact is often related to the electronics hardware, specifically the integrated circuits. Minimizing the use of these and leveraging efficient software design to maintain performance is one strategy to reduce the impact of these products.

Key Questions

- How could you implement material reduction (lightweighting) or elimination (part removal) strategies?
- Which components could use lower impact materials?
  - Non-virgin / recycled materials
  - Renewable materials
  - Bioplastics
- How could you use renewable resources or materials in the system?
- How could you reduce the number of different materials used in the system?
- What are the environmental impacts from pre-manufacturing and manufacturing processes used to create your system?
- How are processes optimized to minimize waste of resources?
- What trade-offs between cost, quality, performance, and sustainability can be made?

Tools & Resources

Use material impact databases and material selection tools to make informed choices on lower impact materials and processes:

- Granta Material Selector
- Solidworks Sustainability
- LCA Tools and Databases (e.g. Ecolizer Database)

MATERIALS & MANUFACTURING

Identify, Comply With, and Exceed Social Sustainability Standards That Apply to the System and Supply Chain

Summary

There are a large number of social sustainability issues that need to be considered in the development and production of any system. Many of these issues have been summarized and regulated in social sustainability standards, which are effective ways to ensure social sustainability practices are considered and implemented.

At a minimum, these standards must be identified and met. Look for ways to have a positive impact on social sustainability by exceeding these standards.

Tools & Resources

+ [Example] 3M's EHS Standards for Suppliers
+ Occupational Health and Safety Profile for China
+ ISO 45001 Standard [Article]
+ Relevant ISO standards correlated to the SDGs
+ World Bank ESS Standards
+ SA8000 Standard

Key Questions

+ What are major social and ethical issues that apply to the system?
+ What social sustainability standards apply to the system?
  » SA8000?
  » World Bank ESS standards?
+ Which of the key elements of the identified standards are directly relevant to the system?
+ How can compliance with these standards be met and monitored?
+ What health and safety standards and certifications apply to the industry?
+ Are there tools, methods, or training opportunities to minimize hazards associated with material handling and prototyping?
+ What does your CM need to change to become SA8000 compliant?

MATERIALS & MANUFACTURING

Avoid Toxic Materials That Damage Human or Ecological Health

Summary

Refining material choices to avoid those that have been shown to be toxic to humans or the environment will have a positive impact on the sustainability of the system.

One opportunity is in polymer additives. In reviewing the requirements for these and the composition of them, look for ways to avoid known toxic plasticizers (e.g. phthalates), flame retardants, and other additives.

Tools & Resources

+ RoHS Compliance
+ Proposition 65 List
+ REACH Restricted Substances List
+ WEEE Calculation Tools
+ Other companies' publicly available Restricted Substances Lists

Key Questions

+ How can you avoid using any materials from the REACH List?
+ What needs to be changed to make your product RoHS Compliant?
+ How can you avoid using materials that require Proposition 65 declaration?
+ What are ways to test the toxicity of your product across its life cycle?
+ What is the contribution to ecotoxicity and human toxicity in the LCA ReCiPe score results?
+ Does your contract manufacturer comply with toxic substances standards that apply to the industry and geography?
+ How could materials be dealt with at the end of life?

MATERIALS & MANUFACTURING

Avoid Conflict Minerals

Summary

Tantalum, Tin, Gold, and Tungsten are all materials that could be sourced from conflict minerals, the extraction of which are contributing to a humanitarian crisis and funding conflict, especially in the DRC region.

Avoid use of these materials or, if they are required for the functionality of the system, ensure these materials come from non-conflict sources.

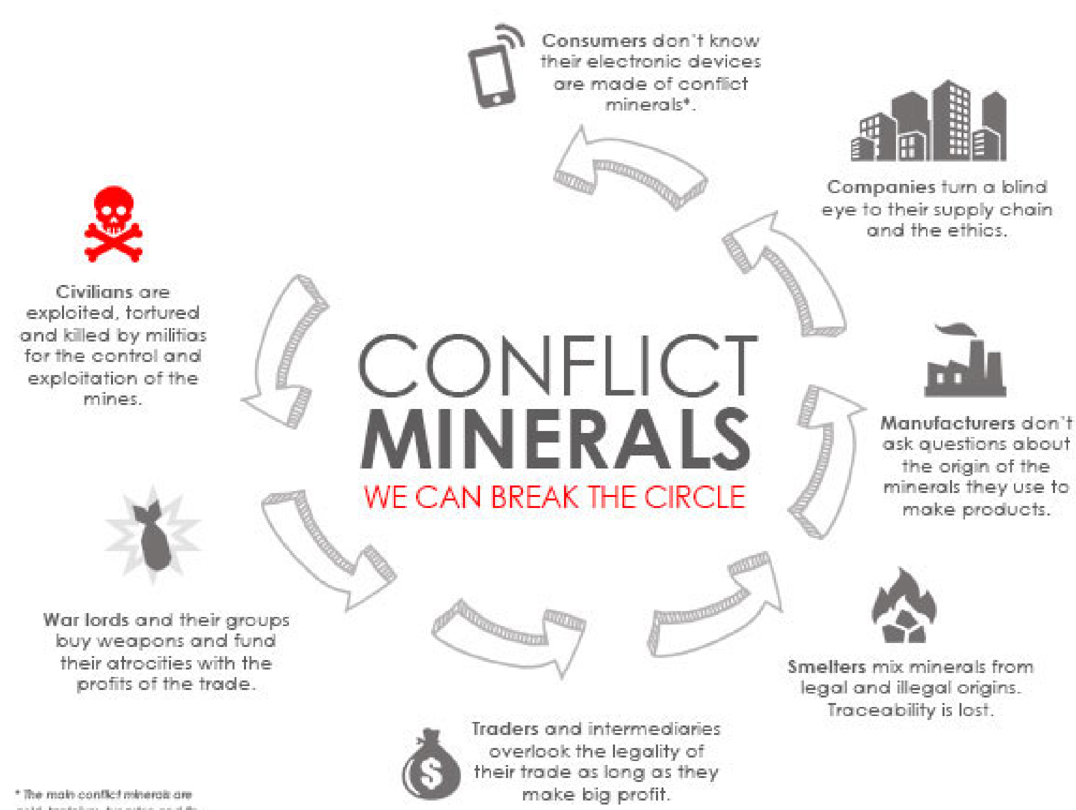
Key Questions

+ What alternative materials can be used in place of those that may be sourced from conflict minerals?
+ If potential conflict minerals are required for the product, are these sources certified as "DRC conflict-free"? Have the sources and supply chain been investigated with appropriate due diligence?
+ Can potential conflict materials be sourced from scrap or recycled sources instead of virgin material?

Tools & Resources

+ US SEC Fact Sheet on Conflict Minerals
+ Responsible Minerals Institute

Source: https://www.vikingelectronics.com/conflict-minerals/



Source: http://www.usconverters.com/index.php?main_page=page&id=82&chapter=0

MATERIALS & MANUFACTURING

Identify Materials with Lower Environmental Impacts Through Manufacturing, Packaging and End of Life

Summary

Material selection can significantly influence the overall impact of the system and should be carefully considered.

Using recycled materials is a good way to reduce impact and helps to generate demand for recycled materials, facilitating more effective recycling programs.

Key Questions

+ How can materials with lower embodied energy be used?
+ What alternative materials can be used that have lower overall environmental impacts?
+ What barriers are there to using bioplastics or recycled materials?
+ What trade-offs between cost, quality, performance, and sustainability can be made?

Tools & Resources

+ LCA Tools and Databases (e.g. Ecolizer Database)
+ Circular Economy Smart Material Choices
    » Safe & Circular Materials
+ Designing for a New Plastics Economy

MATERIALS & MANUFACTURING

Identify Material and Energy Efficient Manufacturing Processes

Summary

All manufacturing processes use energy and material, both of which can be minimized to reduce the impact of the system.

For injection molding, hot runners can reduce material waste, and provide cost benefits at high volumes.

Key Questions

+ How can the chosen manufacturing process be more material efficient?
+ How can the part yield be maximized for a given process?
+ What can be changed to use less energy in production?
+ How can renewable energy sources be used for manufacturing processes?
+ What techniques can be used to reduce material waste?
+ What strategies could be implemented to improve energy efficiency?
+ How can waste byproducts be used as a feedstock for other processes?
+ What opportunities are there for reduction of manufacturing complexity?
+ How are quality control processes used for continuous efficiency improvements?
+ What trade-offs between cost, quality, performance, and sustainability can be made?

Tools & Resources

Use process impact databases and selection tools to make informed choices on lower impact materials and processes:

+ Granta Material Selector
+ Solidworks Sustainability
+ LCA Tools & Databases (e.g. Ecolizer Database)

MATERIALS & MANUFACTURING

Manage, Mitigate and Find Uses for Waste From Manufacturing Processes

Summary

Often a large hidden portion of your product's/service's environmental impact will be from the waste developed during the manufacturing process. It's important to think at the system level when looking for ways to manage, mitigate, and repurpose waste.

Tools & Resources

+ Circular Design Guide
+ Lean Manufacturing Techniques

Key Questions

+ How might you use a 'waste' product as an input or feedstock in production of this or another product?
+ How can you maximize product/part yield?
+ How might you reduce the creation of material or energy waste?

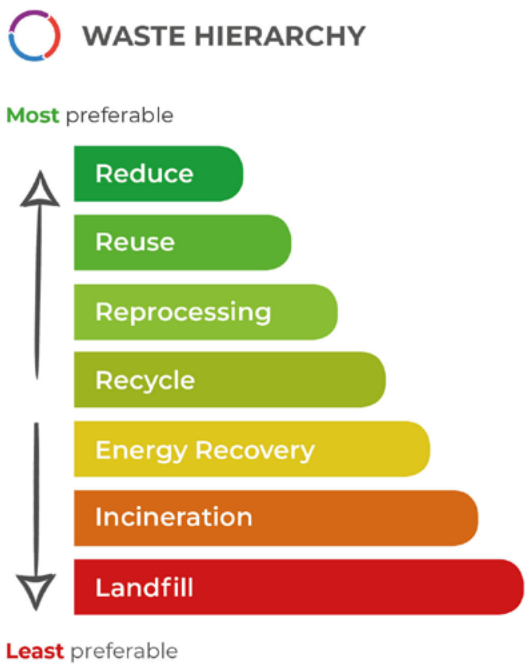


Image taken from https://www.encore-environment.com/what-we-do/

DISTRIBUTION

Inquire About the Social and Ethical Considerations That Apply to The Client's Distribution Network

Summary

When developing your distribution network, it's important to select partners who have positive social and ethical practices. Ensure they follow relevant standards and have clear systems in place to guarantee health and safety are maintained.

Tools & Resources

+ Relevant ISO standards correlated to the SDGs
+ World Bank ESS Standards
+ SA8000 Standard

Key Questions

+ How do distribution partners ensure their employees are fairly compensated?
+ What systems are in place to ensure a safe working environment is maintained for those in distribution?
+ What social sustainability standards apply to the system?
    » SA8000?
    » World Bank ESS standards?
+ Which of the key elements of the identified standards are directly relevant to your supply chain? How can compliance with these standards be met and monitored?

DISTRIBUTION

Optimize Facility Planning and Distribution Strategies for Environmental & Economic Factor

Summary

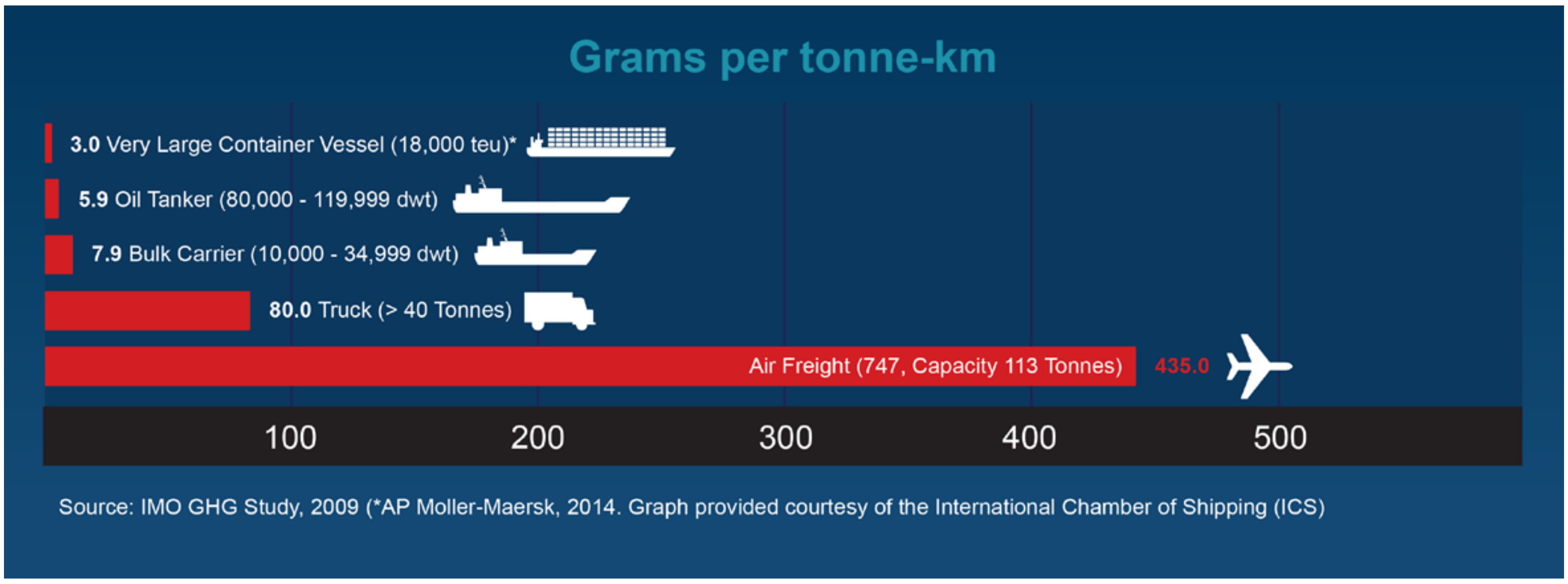
Trade-offs between schedule, cost, and environmental impact must be evaluated as you develop your supply chain and distribution. Decisions such as the location of final manufacturing, location of subcomponent suppliers, and how the final product will be distributed can play a large role in the overall environmental impact.

Key Questions

+ How can the distribution network be optimized to minimize distance the product travels?
+ What strategies can be used to minimize the transportation-associated impact in the product life cycle?
+ How can you plan your supply chain to minimize distribution distances?
+ How can the schedule be optimized to minimize impacts from shipping?
+ Can you use lower impact energy sources for distribution?

Tools & Resources

+ LCA Tools and Databases (e.g. Ecolizer Database)
+ Schedule Gantt Chart
+ SourceMap



Source: http://www.worldshipping.org/industry-issues/environment/air-emissions/carbon-emissions

DISTRIBUTION

Optimize Packaging Strategy to Minimize Environmental Impact of Distribution

Summary

Where possible, packaging strategies should be selected to minimize the environmental impact not only of the materials used, but also of the impact associated with transporting the packaged product.

Tools & Resources

+ LCA Tools and Databases (e.g. Ecolizer Database)
+ Packaging Sustainability: Tools, Systems, and Strategies for Innovative Packaging Design

Key Questions

+ What purpose does your packaging serve?
+ How can packaging be avoided or minimized?
+ How can you design packaging to pack products more efficiently for distribution?
+ Where in the supply chain is packaging (intermediate or final) introduced? Can any be avoided or reduced?
+ How can packaging maximize packing efficiency of products during shipment?
+ How can individual product packaging be avoided or minimized?
+ What alternative packing materials or architectures can be used? Compostable? Manufacturing byproduct?
+ What other purposes can packaging serve in the product life cycle?
+ What is the lowest impact packaging material you can use?
+ How can circular economy principles be implemented in packaging strategies? Can it be collected and reused?
+ What alternative packing materials, manufacturing processes, or architectures can be used?

DISTRIBUTION

Identify and Communicate Health and Safety Risks to All Stakeholders in the Distribution Networks

Summary

Health and safety risks of your product should be clearly communicated to all stakeholders, including those involved in the distribution network. This can affect how the product is packaged and distributed.

Key Questions

+ What health or safety risks are associated with the product?
+ What hazardous, toxic, and/or flammable materials are found within your product?
+ Are there any subcomponents that are considered 'dangerous goods' or that could interfere with navigation or transport communications?

Tools & Resources

+ Promoting Occupational Health and Safety in the Supply Chain [Review]

USE & MAINTENANCE

Design to Amplify Positive Social and Behavioral Impacts and Minimize Negative Impacts from the Product's Use

Summary

All systems impact society, whether directly or indirectly through user interactions, or through ethical dilemmas that arise during its life. These factors should be considered in the design, to encourage positive social and behavioral impacts where possible, and to mitigate any negative impacts.

Key Questions

+ How inclusive is the system?
+ How has the diversity of users been included in the design, verification, and validation process?
+ Are there any prejudices that are being reinforced or broken down by technologies used in the system?
+ How could the data from your product be misused?
+ What strategies are in place to ensure privacy & data security is maintained?

Tools & Resources

+ Inclusive Design Toolkit

USE & MAINTENANCE

Minimize Materials & Energy Consumed by the System During Its Use

Summary

The impact from the Use life cycle stage can be significant, especially when the system consumes large amounts of material and energy. Washing machines are a great example of this, where minimizing the consumption of material and energy during the system lifetime will reduce its overall impact.

Key Questions

+ What materials & energy usage is complementary to the product use?
    - Water & chemicals for cleaning?
    - Energy consumption?
    - Any consumables?
+ How can the materials & energy usage associated with the product be reduced?
+ How can energy use during the product life be minimized?
+ Are there any energy inefficiencies in your product or service?

USE & MAINTENANCE

Design for Improved Durability and Longevity

Summary

Extending the life of a system is one of the most effective ways to reduce its overall impact. Designing to an appropriate level of durability and for longevity will help achieve this. Care should be taken to avoid over-designing the system, which could use additional resources without increasing the product lifetime usefully.

Key Questions

- How can the system be designed to avoid obsolescence?
  - What design themes can be used to make the system 'timeless'?
  - How can you design with future technologies or consumer trends in mind?
- What are the weak points of the system that will fail first?
  - Use HALT testing or analysis tools to identify the failure modes
- How can the design be modified to increase robustness against known failure modes?
- What is driving the current intended life of your product?

Tools & Resources

- VentureWell & Autodesk Design for Durability

USE & MAINTENANCE

Design for Easy Serviceability

Summary

Extending the life of a system is one of the most effective ways to reduce its overall impact. By designing for serviceability, the life of the system can be extended with maintenance procedures, repairs, and component replacements.

Key Questions

+ Which components or modules will require servicing or replacement in the product lifetime?
    » How can these components/modules be accessed and replaced?
+ How can you simplify, standardize, and mistake-proof your design for serviceability?
    » Module design, poke-yoke, connectorized, single fastener types, labels, color codes...

Tools & Resources

+ VentureWell & Autodesk Design for Product Lifetime Resource

Design for **Product Lifetime**

Access a product's components. > **Keep it alive longer.**

Design for Disassembly
Ensure products are easy to take apart quickly.

Parts
- Minimize the number of parts.
- Simplify structure and form.
- Use ferromagnetic materials to enable sorting and disassembly.

Tools & Fasteners
- Require only a few standard tools.
- Avoid requiring tools for the most common actions.
- Minimize the number and variety of fasteners.
- Use intuitive snap-fits, clips, or sliding connections.
- Design connections that are visually and physically accessible.
- Access fasteners from the same axis.
- Hold multiple parts with one fastener.
- Use coarse threaded screws for speed; use nuts and bolts for strength.
- Use human-scale fasteners.
- Use hand-strength press-fits instead of tight press-fits.
- Avoid glues, and use only glues that are easily soluble or heat reversible.
- Ensure fasteners are adequate for structural integrity.
- Use fasteners that will hold up over repeated use.

Documents
- Embed clear, graphical disassembly instructions onto the product.
- Document materials and methods for deconstruction for the user.

Design for Repair
Ensure product repair is simple for everyone.

Product Architecture
- Use modular assemblies that enable the replacement of discrete components.
- Ensure easy access to parts likely to need maintenance.
- Use self-locating parts.
- Use robust connectors.
- Label and color-code parts to enable troubleshooting.
- Standardize between product lines and across generations.

Documents
- Make technical documentation freely available or open-sourced.
- Include parts list and part numbers.
- Create user interfaces and troubleshooting tools to diagnose problems.

Business
- Make repair and services options clear to customers.
- Consider repair-friendly warranty terms.
- Make replacement parts available and affordable.

Design for Upgrade
Keep products relevant and useful longer.

Product Architecture
- Use standard-size modular parts to enable interchangeability and customization.
- Design easy access to parts likely to become obsolete.
- Use standard, cross-platform connections (for example, USB).

Documents
- Build diagnostic tools to help users understand the components that are limiting performance.

Autodesk Sustainability Workshop
sustainabilityworkshop.autodesk.com

Source: https://venturewell.org/tools_for_design/design-lifetime-sharing/

USE & MAINTENANCE

Mitigate Impact of Waste During System Use

Summary

Minimizing the waste generated, and the impact of the waste generated by the system during its use, will help reduce the overall system impact.

Key Questions

+ Can waste products be reused or repurposed?
+ Are waste products compostable or recyclable?
+ Can waste production be prevented or minimized?
+ How can you use lower impact materials or energy during the product use to reduce the impact of waste?

USE & MAINTENANCE

Ensure That Possible Modes of Failure and the Associated Health and Safety Risks to the User are Identified and Communicated

Summary

Any system can fail, and it is the responsibility of the designer to ensure that if the system fails, it does so in a way that minimizes the risk to the user.

Key Questions

+ What failure modes have been identified using a Failure Modes & Effects Analysis (FMEA)?
+ How can these failure modes be avoided or mitigated?
+ How are the remaining failure modes communicated to the user?

Tools & Resources

+ Six Sigma FMEA Template
+ OSHA Safety Manual Templates

END OF LIFE

Select End of Life Strategy Based on Relative Environmental Impacts

Summary

With so much energy and material invested into developing a system, it's important to consider the end of life strategy early in the design process.

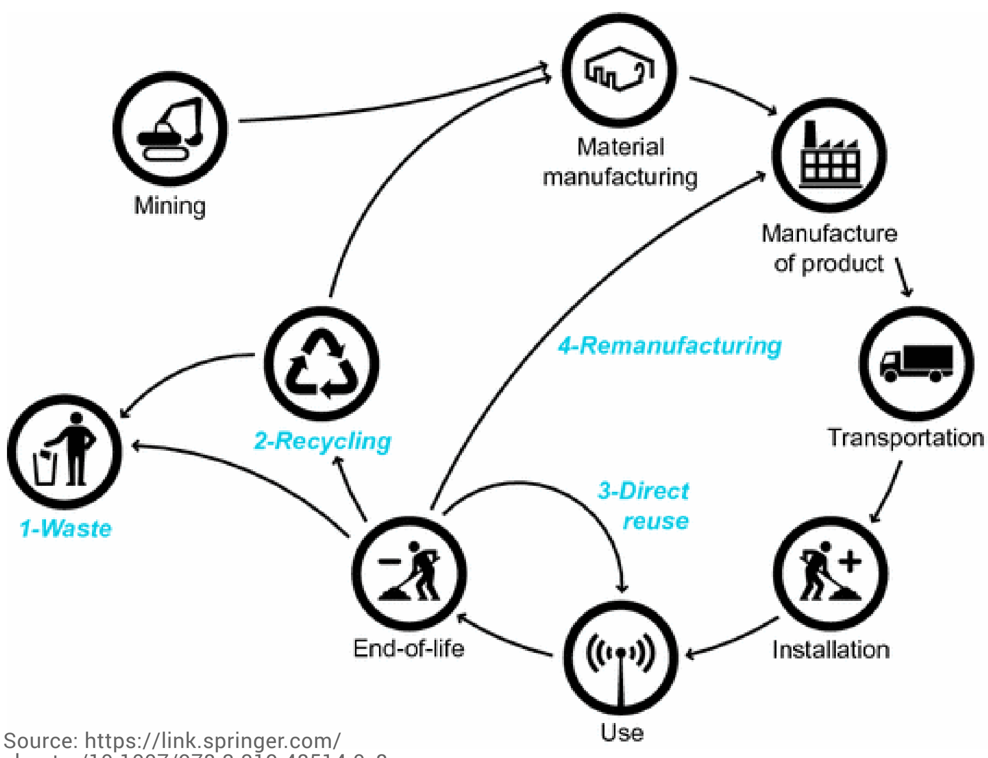
Often when running an LCA, you'll find that the end of life isn't highlighted as a large contributor to the environmental impact. Instead, the benefit of reusing and recycling components is seen in the environmental impact of the next product that uses them. Look for ways to close the loop in your system design.

Key Questions

+ What are the relative impacts of alternative end of life strategies for the system?
+ If the end of life strategy includes recycling, how can you incorporate recycled materials into the system to close the loop?
+ What end of life infrastructure exists where your system is being used?
+ How has your end of life strategy influenced your design (reuse, repair, refurbishment, remanufacturing, recycling)?

Tools & Resources

+ LCA Tools
+ End Of Life Strategy Report
+ Product Journey Mapping



Source: https://link.springer.com/chapter/10.1007/978-3-319-48514-0_8

END OF LIFE

Design for Easy Disassembly

Summary

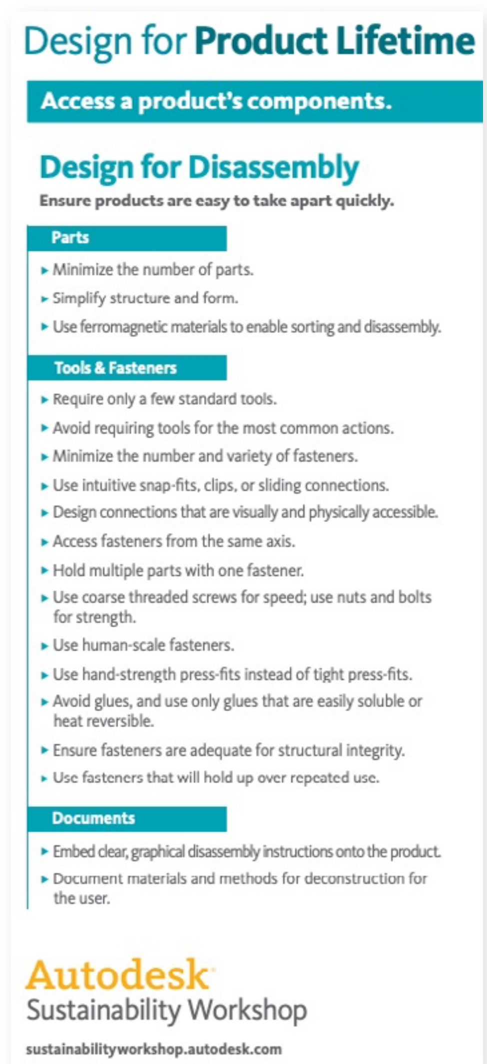
Any end of life strategy is likely going to involve some disassembly of the system. Reducing the effort, energy, and time required to perform disassembly will facilitate many end of life strategies.

Key Questions

+ How can the number of tools required for disassembly be minimized?
+ How can the design minimize the disassembly time?
    » Can the product be designed such that all fasteners are on one side?
+ How can the system design facilitate automation of disassembly?
+ What is the strategy for dealing with toxic or harmful materials?
+ How has disassembly been considered in the design process?
+ What components will be disposed of at the end of life?
+ How will components be disposed of at the end of life?
+ Which materials in the system are difficult to separate?
+ What material joining strategies can be used to facilitate material separation at the end of life?

Tools & Resources

+ Circular Economy Smart Material Choices Guide
+ VentureWell & Autodesk Design for Product Lifetime Resource



Design for Product Lifetime

Access a product's components.

Design for Disassembly

Ensure products are easy to take apart quickly.

Parts
- Minimize the number of parts.
- Simplify structure and form.
- Use ferromagnetic materials to enable sorting and disassembly.

Tools & Fasteners
- Require only a few standard tools.
- Avoid requiring tools for the most common actions.
- Minimize the number and variety of fasteners.
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- Avoid glues, and use only glues that are easily soluble or heat reversible.
- Ensure fasteners are adequate for structural integrity.
- Use fasteners that will hold up over repeated use.

Documents
- Embed clear, graphical disassembly instructions onto the product.
- Document materials and methods for deconstruction for the user.

Autodesk
Sustainability Workshop
sustainabilityworkshop.autodesk.com

Source: https://venturewell.org/tools_for_design/design-lifetime-sharing/

END OF LIFE

Design for Reuse, Remanufacturing and/or Recycling

Summary

Allowing for remanufacture or reuse of your system can play a huge role in reducing its overall environmental impact. Look for ways to elongate the life of your system or subsystems to allow for this.

Key Questions

- What portions of your system have a limited life span? How can this be extended to allow for reuse?
- What are the highest impact areas of your system? How can your design allow for these subsystems to be remanufactured?
- How can the number of different materials in the product be minimized?
- Which materials in the system are difficult to separate?
    - » Select joining strategies to facilitate material separation at the end of life

Tools & Resources

- Circular Economy Smart Material Choices Guide

END OF LIFE

Plan Distribution and Processing Infrastructure to Support the Chosen End of Life Strategy

Summary

Once an end of life strategy has been selected, the infrastructure to support it must be developed. This infrastructure is just as important as the supply chain development to create the product or service in the first place.

Key Questions

+ How will your supply chain and distribution network interact with the system at the end of life?
+ How can you address distributed products at the end of life?
  » What local infrastructure is in place that could support your end of life strategy?
  » What regulations may impede or prohibit transport of products at the end of life?
+ How will you promote and encourage users to support your end of life strategy?
+ How might you take advantage of your upfront supply chain to address some of the steps in your end of life cycle? Could distribution networks be utilized on their way back to product hubs?

Tools & Resources

+ Building a Reverse Supply Chain
+ Reverse Logistics Maturity Model, by the Ellen MacArthur Foundation

END OF LIFE

Mitigate Health and Safety Risks of End of Life Strategy

Summary

End of life strategies can have health and safety risks associated with them, and these must be considered alongside any other benefits of the strategy.

Key Questions

- What additional health and safety risks does the end of life strategy introduce beyond those associated with the system during normal operation?
    - Have any materials within the product been classified as hazardous since the time of production?
- What risks can be associated with the end of life strategy operating the system outside its designed use case?

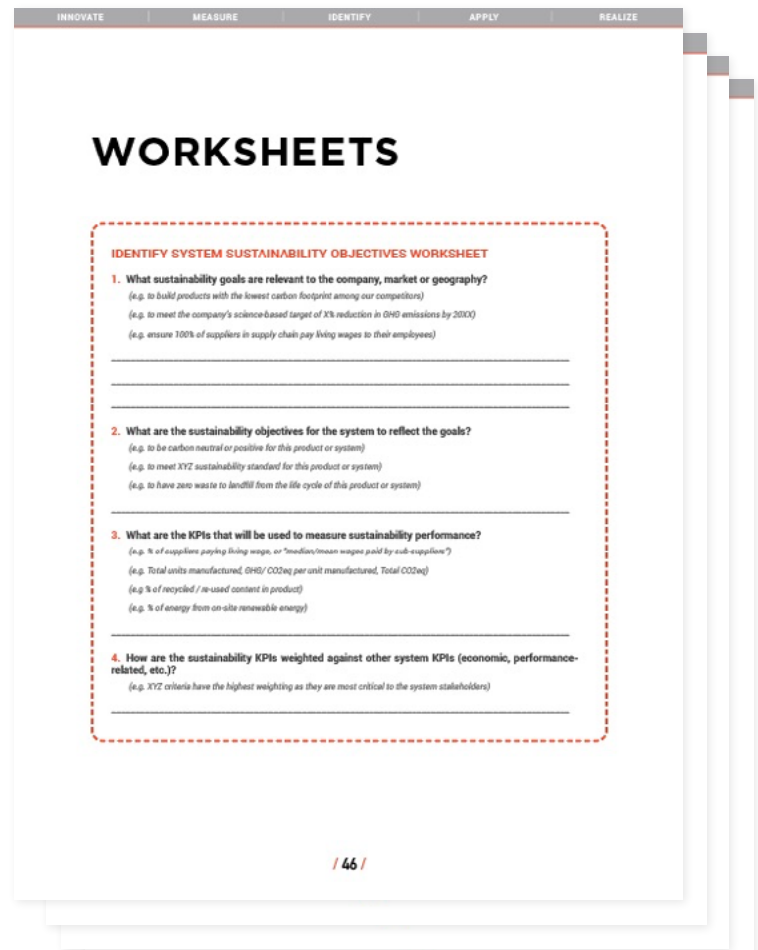
REALIZE

Having followed this iterative process, and performed a final comprehensive LCA, it's time to turn the design into a realized system. Realizing products is a much bigger topic than we can adequately cover here, but in the previous section, ***Apply***, you'll find that even at the ***Realize*** phase, there are strategies that can improve the sustainability of the system; optimizing the manufacturing processes, finding ways to minimize and use waste products, or reducing the impact from the distribution strategies. Keeping system objectives in mind during realization will ensure sustainable decisions are made.

Reflecting on the system design once completed will highlight areas for improvement in the future. It will be possible to determine which strategies were most effective, which could be implemented successfully in the future, and what other opportunities there may be for future generations.

The design process is also something that will improve over time, by incorporating knowledge that is gained, and evolving to reflect the economic and technological landscape.

The very title of this section is perhaps misleading. While the goal is to realize your product into reality in a more sustainable way, this work may never be truly finished. By continuing to evaluate, maximize, and re-evaluate, we can have the best possible outcomes for our companies, our customers, and for the world.


INNOVATE | MEASURE | IDENTIFY | APPLY | REALIZE

WORKSHEETS

IDENTIFY SYSTEM SUSTAINABILITY OBJECTIVES WORKSHEET

1. What sustainability goals are relevant to the company, market or geography?
   (e.g. to build products with the lowest carbon footprint among our competitors)
   (e.g. to meet the company's science-based target of X% reduction in GHG emissions by 20XX)
   (e.g. ensure 100% of suppliers in supply chain pay living wages to their employees)

2. What are the sustainability objectives for the system to reflect the goals?
   (e.g. to be carbon neutral or positive for this product or system)
   (e.g. to meet XYZ sustainability standard for this product or system)
   (e.g. to have zero waste to landfill from the life cycle of this product or system)

3. What are the KPIs that will be used to measure sustainability performance?
   (e.g. % of suppliers paying living wage, or "median/mean wages paid by sub-suppliers")
   (e.g. Total units manufactured, GHG/ CO2eq per unit manufactured, Total CO2eq)
   (e.g % of recycled / re-used content in product)
   (e.g. % of energy from on-site renewable energy)

4. How are the sustainability KPIs weighted against other system KPIs (economic, performance-related, etc.)?
   (e.g. XYZ criteria have the highest weighting as they are most critical to the system stakeholders)

/ 46 /

WORKSHEETS

SYSTEM SUSTAINABILITY PRIORITIES & MATERIALITY ASSESSMENT

1. What stakeholders exist? Which of these have the biggest impact on system design?
   (e.g. end users, service providers, maintenance engineers)

   ____

   ____

2. What aspects of sustainability are most important to these stakeholders?
   (e.g. responsible supply chain, social equality, carbon emissions)

   ____

   ____

3. Which aspects of sustainability are most important to the company's business?
   (e.g. climate change, water use, waste reduction, energy efficiency)

   ____

   ____

4. What aspects of sustainability does the company impact? Which are likely to impact the business?
   (e.g. the system utilizes large amounts of water in its use phase, or the product consumes resources and generates waste throughout its life, or climate change could impact the product supply chain)

   ____

   ____

DEFINE SUSTAINABILITY REQUIREMENTS

1. Which system requirements reflect the identified sustainability objectives?

   (e.g. X GHG/ CO2eq per unit manufactured)

   (e.g. system or product must meet X certification)

   (e.g. CM must be SA8000 compliant)

   ____

   ____

   ____

2. How will the sustainability-related requirements be verified?

   (e.g. through a life cycle analysis using the applicable assessment method - GHG, ReCiPe single score, etc)

   (e.g. evaluate the system life cycle in relation to the certification criteria)

   ____

   ____

   ____

3. How can the system-level sustainability requirements be derived into sub-system requirements?

   (e.g. break out GHG emission requirement into soft goods and hard goods)

   (e.g. require sustainable certifications for select products that fit into the broader ecosystem)

   (e.g. set specific requirements and end of life strategies for high volume consumables)

   ____

   ____

   ____

DECISION MATRIX

EXAMPLE:

Input Code:
CRITERIA WEIGHT (0.1 [least important] - 1 [most important])*
CONCEPT OPTION SCORE (1 [low] - 10 [high])

		Sustainability Criteria			Product Criteria			Total:
	Criteria:	Emissions	Consumption	Waste	Cost	Performance	Time to Market	
	Weight:	0.3	0.1	0.5	0.5	0.7	0.1	
Options:	Sell e-bike	3	3	3	3	8	5	10.3
	Sell e-bike conversion kit	5	5	5	5	5	7	11.2
	E-bike long term lease	9	9	7	5	6	5	14.3
	Floating e-bike share program	8	8	7	7	4	3	13.3

FOR YOU TO FILL IN:

Input Code:
CRITERIA WEIGHT (0.1 [least important] - 1 [most important])*
CONCEPT OPTION SCORE (1 [low] - 10 [high])

		Sustainability Criteria			Product Criteria			Total:
	Criteria:	____ (e.g. emissions)	____ (e.g. consumption)	____ (e.g. waste)	____ (e.g. cost)	____ (e.g. performance)	____ (e.g. time to market)	
	Weight:	____	____	____	____	____	____	
Options:	____ (concept 1)	____	____	____	____	____	____	____ (sum of weight x score)
	____ (concept 2)	____	____	____	____	____	____	____ (sum of weight x score)
	____ (concept 3)	____	____	____	____	____	____	____ (sum of weight x score)
	____ (concept 4)	____	____	____	____	____	____	____ (sum of weight x score)
	____ (concept 5)	____	____	____	____	____	____	____ (sum of weight x score)

LCA WORKSHEET

1. What is the goal of your LCA?

   (e.g. Compare alternative product architectures)

   (e.g. Identify hot spots in the system design)

   (e.g. Measure the system impact to ensure it meets the sustainability requirements before realizing the design)

____

____

2. What is the system boundary for the analysis?

   (e.g. Analysis includes materials/manufacturing, distribution, energy used, and end of life for a single product only and not separately sold accessories)

____

____

3. What is the functional unit for the system?

   (e.g. X years of product use)

   (e.g. Number of X long system uses)

____

4. Collect the system inventory, best done in a separate BOM document as shown below:

LCA Inventory							
Functional Unit *(e.g. product life)*	X	years					
System Boundary	XYZ	Included in LCA					
BOM Cost		$					
Sale Price		$					
System/Product BOM							
Assembly Level	**Part (name/functionality)**	**Qty**	**Material**	**Manufacturing Process**	**Is this part made from recyclable materials (yes/no)**	**Mass (g)**	**Volume (mm3)**
1	*Top Level Assembly*						
1.1	*Subassembly 1*						
1.1.1	*Subassembly 1, Component 1*						
1.1.2	*Subassembly 1, Component 2*						
1.2	*Subassembly 2*						
1.2.1	*Subassembly 2, Component 1*						
1.2.2	*Subassembly 2, Component 2*						
Distribution							
Y transport mode shipping distance	X	km					
Z transport mode shipping distance	X	km					
Energy Usage	X Watts	per use					
Number of uses	1500	over the course of the funtional unit					
Disposal/End-of-life Strategy		take-back/recycling/landfill					

5. What level of uncertainty exists in your system inventory?

   (e.g. High % uncertainty in distribution as final supply chain has not been established)

   (e.g. Low % uncertainty in materials as the design is near realization)

____

____

6. What impact assessment method is most appropriate for the system?

   (e.g. Greenhouse gas protocol (GHG) based on CO2eq product requirement)

   (e.g. ReCiPe single score for wholistic measure of system impact)

____

____

SYNAPSE

Thank you for reviewing our ebook.

If you have any follow-up questions, please email us at sustainability@synapse.com

Project Ideas?

Give Andy a shout!

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