

DO BETTER. SUSTAINABLE PRODUCT DESIGN



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HOW TO INCORPORATE SUSTAINABILITY INTO YOUR
PRODUCT DEVELOPMENT PROCESS

EDITOR'S LETTER

Sustainability in product development is no longer an option, it's becoming 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. We expect this section to be used as a reference guide and interactive tool.

This is by no means the final word in sustainable design, 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. As this field evolves, we will all learn together, in pursuit of a more sustainable future.



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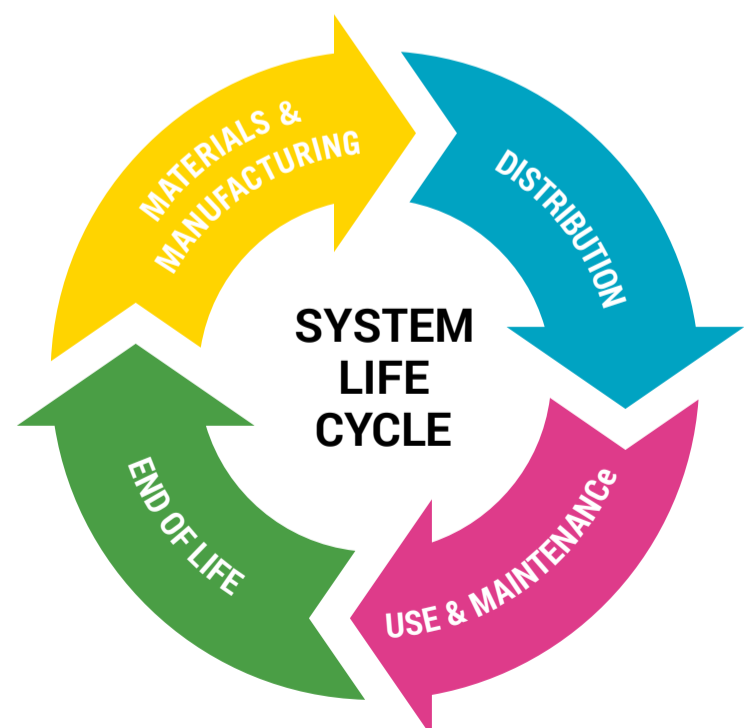
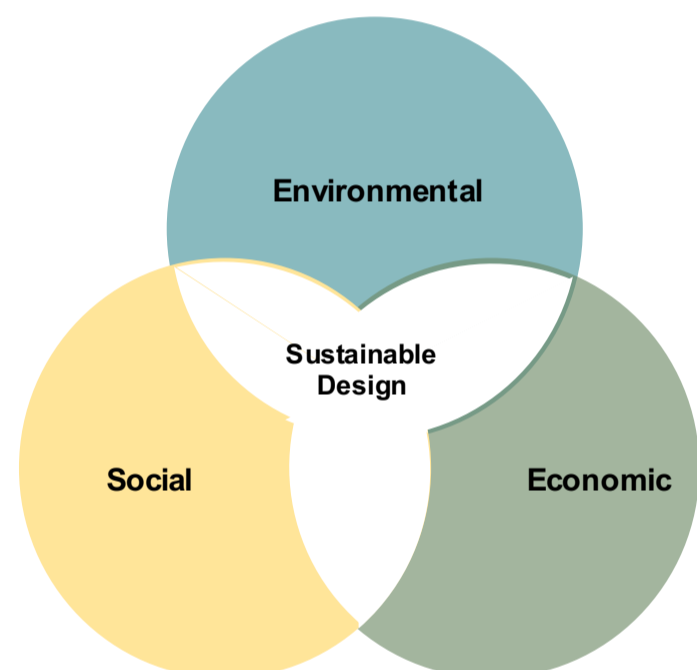
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WHAT IS SUSTAINABLE DESIGN?

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

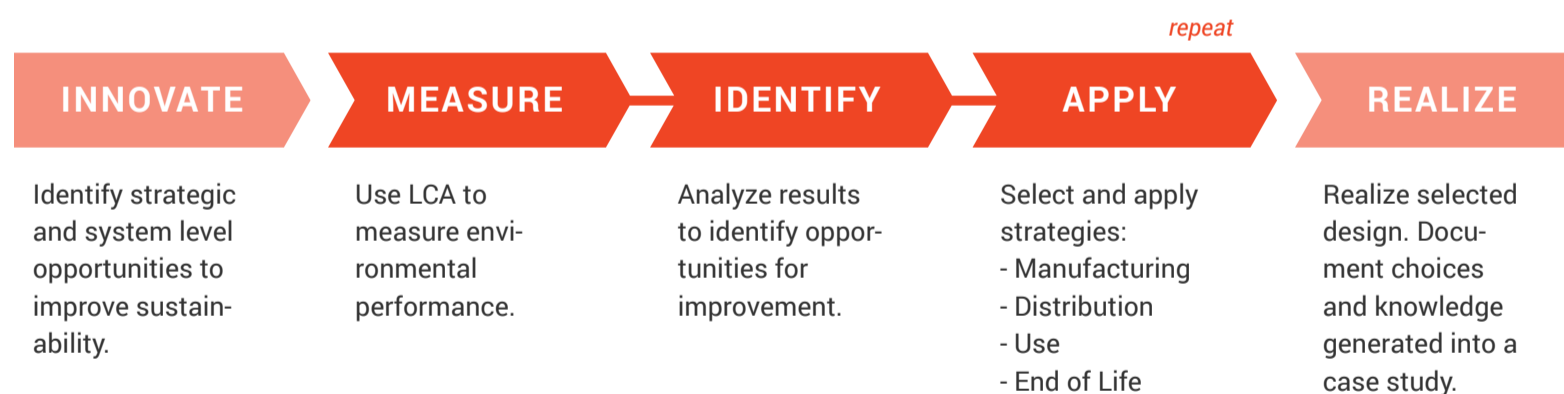
To meet this ambitious definition, strategies to produce sustainable products, systems, or services must be incorporated throughout the entire Product Development Process (PDP). At Synapse, we have developed an iterative process that ensures innovation opportunities are explored, data driven decisions 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

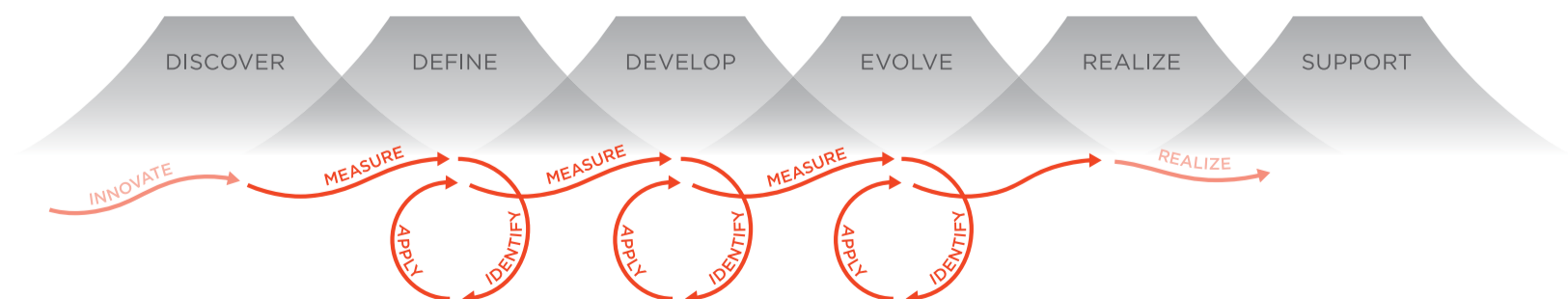
the long-term; perhaps through an innovative new business model, reduced product part count, or a lower carbon tax. By staying focused on the positive impact, tough decisions and tradeoffs can be made to generate truly sustainable systems.

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)



Applying the SDP to the Product Development Process



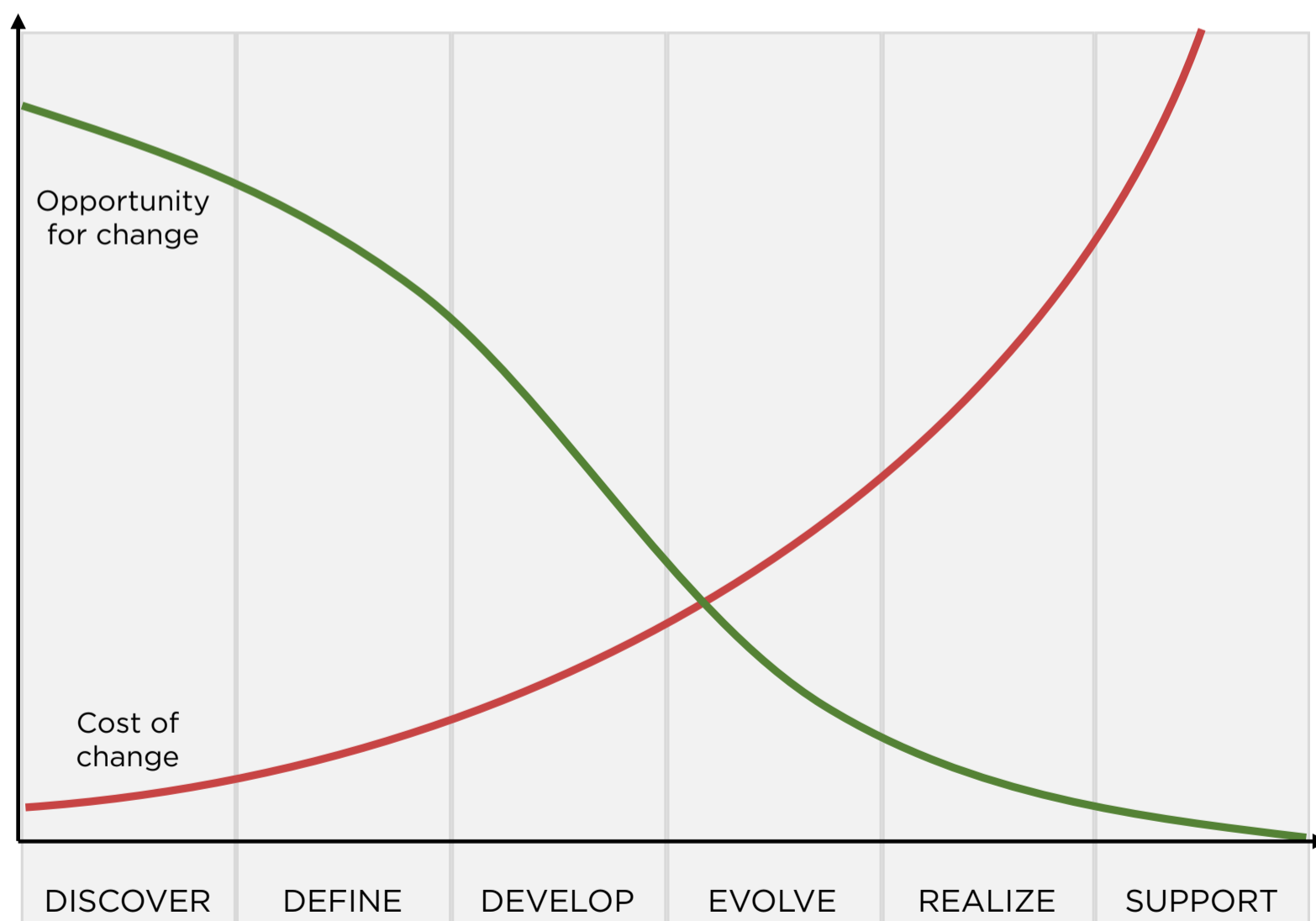
INNOVATE

Radical innovation is needed to develop systems that have positive environmental, social, and economic benefits that go 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 System Sustainability Objectives
2. Determine Sustainable Business Model
3. Utilize Sustainable Design Principles in System Definition & Concept Generation



INNOVATE

STEP 1

Identify System Sustainability Objectives

Setting appropriate sustainability objectives informs business planning and system design, ensuring that sustainability is effectively incorporated into product development. The key questions below should be discussed with senior stakeholders and market experts to develop these sustainability objectives.

DEFINITIONS

Sustainability Goals

Refer to targets that extend beyond a single system, for example a company's 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 objectives and Key Performance Indicators.

System Objectives

Specific targets for the system being considered. Could include: zero single use plastic, zero waste to landfill, use of local supply chain and manufacturing, among others.

Key Performance Indicators (KPIs)

Quantifiable ways to measure performance in critical system parameters. Could include: system energy use, CO2 emissions during manufacturing, water use throughout the product life cycle.

Key Questions:

- + What sustainability-focused company goals exist?
- + Which of the 17 UN Sustainable Development Goals (SDGs) fit with the market, sector and company?
- + What sustainability goals have competitors set?
- + What industry standards apply, and which ones do competitors adhere to?
- + Which aspects of sustainability are most important to the company?
- + How will this product/service system contribute to meeting the company goals?
- + Does the target market have a preference for alignment on sustainability?
- + Which aspects of sustainability are most important to the users?
- + Are industry standards around sustainability likely to be implemented in the future?
- + How does sustainability weigh against other value proposition and product definition considerations?
- + What trade-offs must be made between sustainability, cost, usability, reliability etc.?
- + What are the sustainability objectives and constraints for the system?
- + What are the sustainability-related Key Performance Indicators (KPIs) for the system?
- + How will sustainability KPIs be weighted versus others (business, usability, reliability, etc.)?

The answers to these key questions (on page 7) should be documented to record the system objectives and KPIs for use in the following stages of system development. Iteration and refinement of system objectives and KPIs over time is expected, but outlining them now is critical for early system development and evaluation. As the system is refined in the following steps, these objectives and KPIs should be reflected in the system requirements.

SUSTAINABILITY WORKSHEET

Find the expanded worksheet at the end of this ebook

1. What sustainability goals are relevant to the company, market or geography?
2. What are the sustainability objectives that will enable the system to support the company's goals?
3. What are the KPIs that will be used to measure sustainability performance?
4. How are the sustainability KPIs weighted against other system KPIs (economic, performance-related, etc.)?

Resources

The logos included here link to the relevant websites for these sustainability focused goals, targets and certifications that can help in identifying system sustainability objectives.



INNOVATE

STEP 2

Determine Sustainable Business Models

Identifying sustainable business models should be prioritized at an early stage, in order to develop a system that meets both the sustainability and business objectives. Although it may not be possible to fully define the business model at this early stage, opportunities identified here will seed ideas that can be refined as system concepts are developed. This will focus future development efforts on opportunities built from sustainable business models.

Here we summarize three existing sustainable business model concepts that are useful in these evaluations:

- + Circular Economy Principles
- + Cradle to Cradle Principles
- + Moving from product to service business models

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. It describes how a shift to sustainable systems can generate business and economic opportunities, while providing environmental and societal benefits.

To implement circular economy principles:

- + Consider all stakeholders and systems that interact with your system. Review and modify material & energy flows between them to maximize value and remove waste.
- + Design for evolution to avoid product obsolescence.
- + Consider material life cycles in system design to keep them in circulation.
- + Use renewable energy sources to facilitate the manufacture, use, reuse, repair, remanufacture or recycling of products, components and materials without depleting natural resources.

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

- » [CircularDesignGuide.com](https://circularDesignGuide.com)
- » [Ellen MacArthur Foundation](https://ellenmacarthurfoundation.org/)

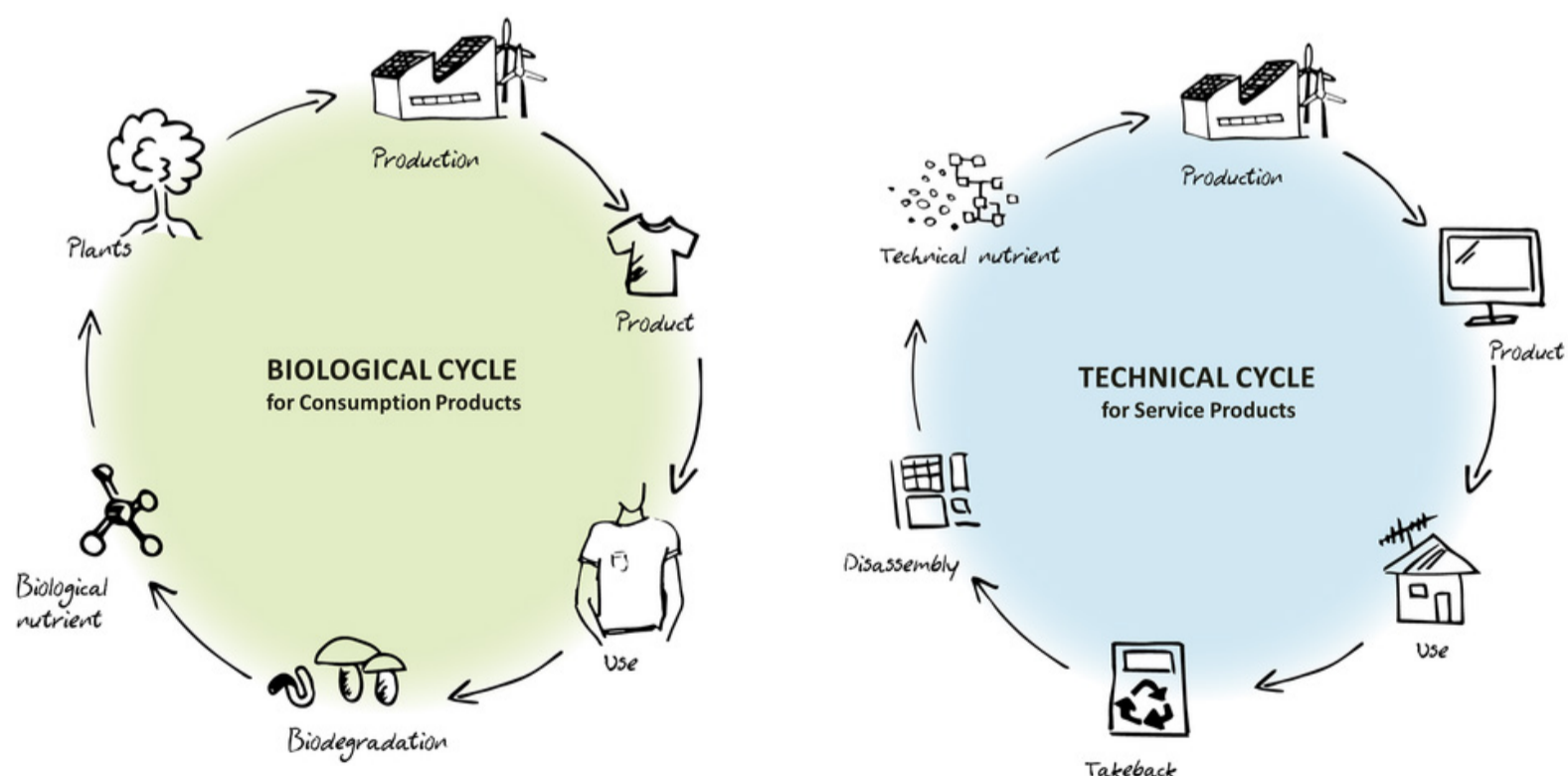
Cradle to Cradle Principles

'Cradle to Cradle' is a design approach to help achieve a circular economy, focused on the circulation of materials and nutrients, where waste is eliminated and used as a feedstock for new materials. It is heavily dependent upon the use of renewable energy to facilitate the circular processes without generation of harmful emissions.

'Cradle to Cradle Certified' products are evaluated against 5 criteria, all of which should be considered when developing business model and system concepts:

- + Material health of used ingredients
- + Recyclability of the product in the technical or biological cycle
- + Use of renewable energy
- + Responsible water management
- + Compliance with social standards

For more information on Cradle to Cradle certification, see: <https://www.c2ccertified.org/>



Source: <https://epea.com/en/about-us/cradle-to-cradle>

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 maximizing the utilization of fewer goods. The full spectrum of combined product and service business models is illustrated below.

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 facil-

itate increased insight into consumer behaviors through data generated. This increased insight can be used to improve customer satisfaction and to identify opportunities for increased sustainable performance of the system. This doesn't have to be a shift fully exclusive of product offerings either, IoT devices are designed for this exact reason, where the data collected can lead to more informed business decisions, increased system efficiencies, and greater user satisfaction of the overall system.

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>

INNOVATE

STEP 3

Utilize Sustainable Design Principles in System Definition & Concept Generation

In this last step of the *Innovate* stage, the sustainable business model principles and agreed upon system objectives and KPIs (Key Performance Indicators) are used to develop **system requirements** and **sustainable design concepts**. This is broken up into three phases:

1. Define Requirements
2. System Concept Generation
3. Downselection of System Concepts

Define Requirements

Incorporating sustainability into the system requirements ensures that the identified sustainability objectives are realized in the system and can be measured against in verification testing. This is one of the most critical steps of the process and can sometimes 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 and KPIs at the system level, and ideally are able to be derived into subsystem requirements as the design process progresses. Examples of requirements include: greenhouse gas emissions associated with a system, water use through the product life cycle, or the meeting of a product certification such as Cradle to Cradle. 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 sub-system requirements?

System Concept Generation

As the system definition is developed, concepts can be generated. These will take into consideration the sustainability objectives, proposed business model, and system requirements. The concepts generated may stimulate some rethinking of the business model, and iteration here is expected.

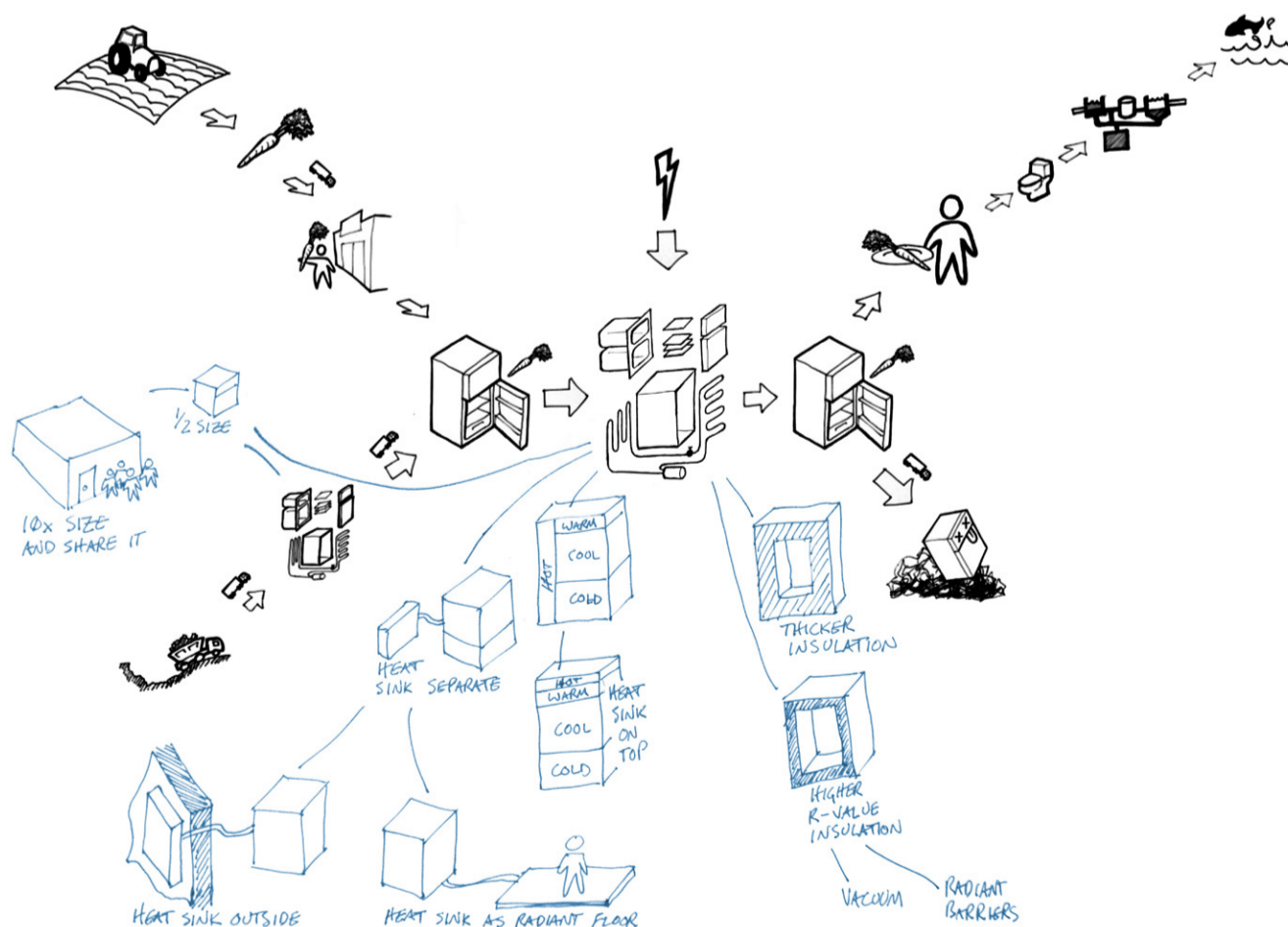
Instead of going into detail on the range of brainstorming strategies that can be used for effective ideation, below we've highlighted one that is particularly relevant in the context of sustainable innovation.

System Mapping

System mapping is a visual and graphical process for concept generation that starts with drawing a system map, showing the user stories, interactions, dependencies, stakeholders and full life-cycle. Brainstorming is then focused on this map to encompass 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 lifecycle and can often be more effective at 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



Source: https://venturewell.org/tools_for_design/whole-systems-mapping/whole-systems-mapping-exercise/

Downselect system concepts

Downselection of system concepts is done by first screening them against the system requirements, and then ranking the remaining concepts against the system objectives and KPIs. Below are a few evaluation tools to consider.

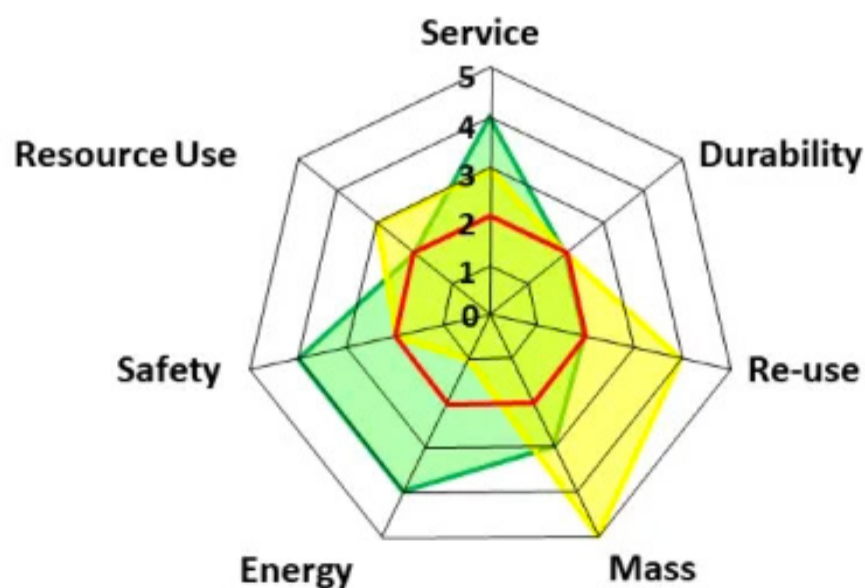
Eco-Innovation Compass

The eco-innovation compass is a visual way of evaluating system concepts against 7 sustainability criteria:

- + Service: creat more value from the intangible part of the system
- + Reuse: design for improved ease of reuse, remanufacturing or recycling
- + Mass: minimize the amount of material used
- + Energy: minimize the energy used by the system
- + Safety: reduce toxic material usage and emissions
- + Resource Use: minimize use of depleting resources, maximize the use of renewables
- + Durability: maximize system lifetime

Concepts are plotted on a 'compass' to illustrate the relative performance in these areas, highlighting opportunities for further innovation, and even opportunities to combine positive features from multiple concepts to maximize the performance of a system.

An example of this 'compass' is shown below. The red line is the benchmark, the yellow field shows one concept, and the green shows a second. Each concept is evaluated against the criteria, with higher numbers indicating better performance. In this example, neither concept is clearly better, but when compared against the company sustainability objectives established in Step 1, a preferred concept may emerge.



Source: <https://miller-klein.com/2018/02/12/the-eco-innovation-compass/>

Decision Matrix

In a decision matrix, concepts are assessed against a broader range of key criteria, inclusive of, but not limited to those related to sustainability. These criteria reflect Key Performance Indicators (KPIs) of the system and they 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 KPIs.

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.

		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.

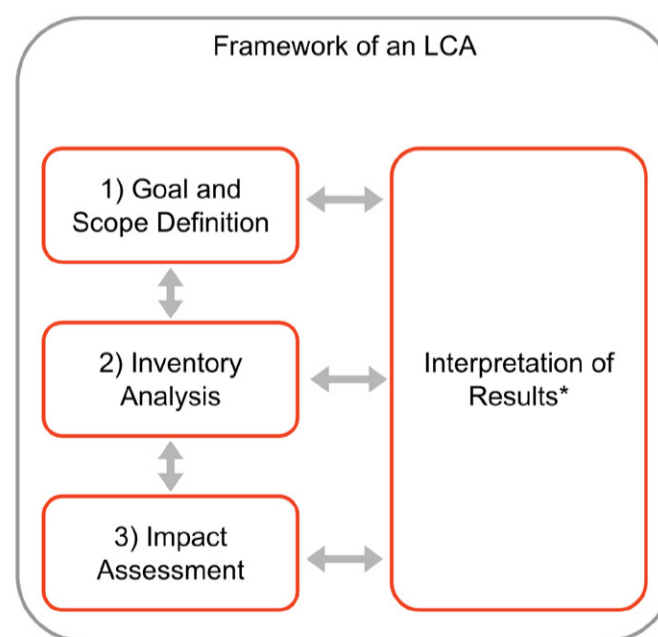
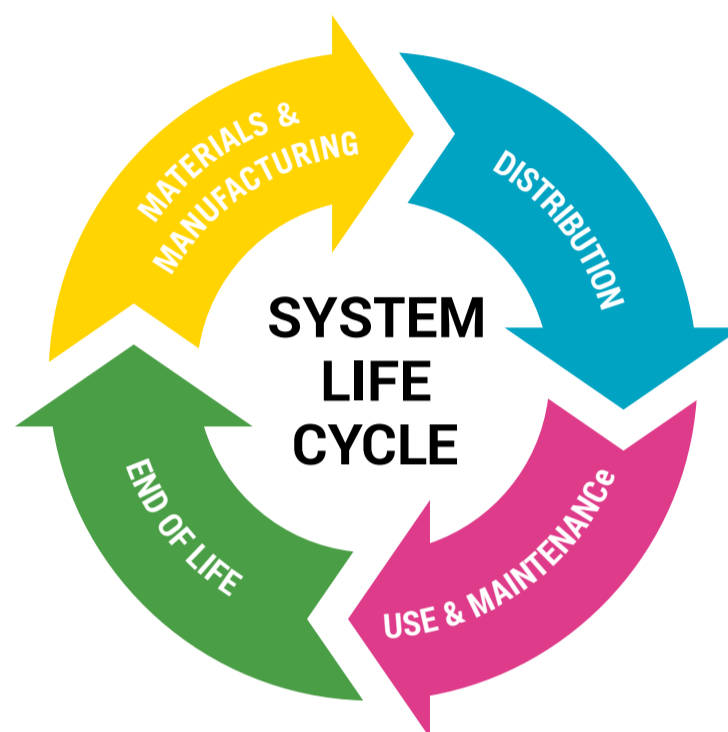
Whether it is a concept or detailed design, a **Life Cycle Assessment (LCA)** is the recommended, industry-standard method to quantify the environmental impact of the design across the system or product life cycle.

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 KPIs.

The LCA process is outlined to the right, 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 and KPIs 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 KPIs 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

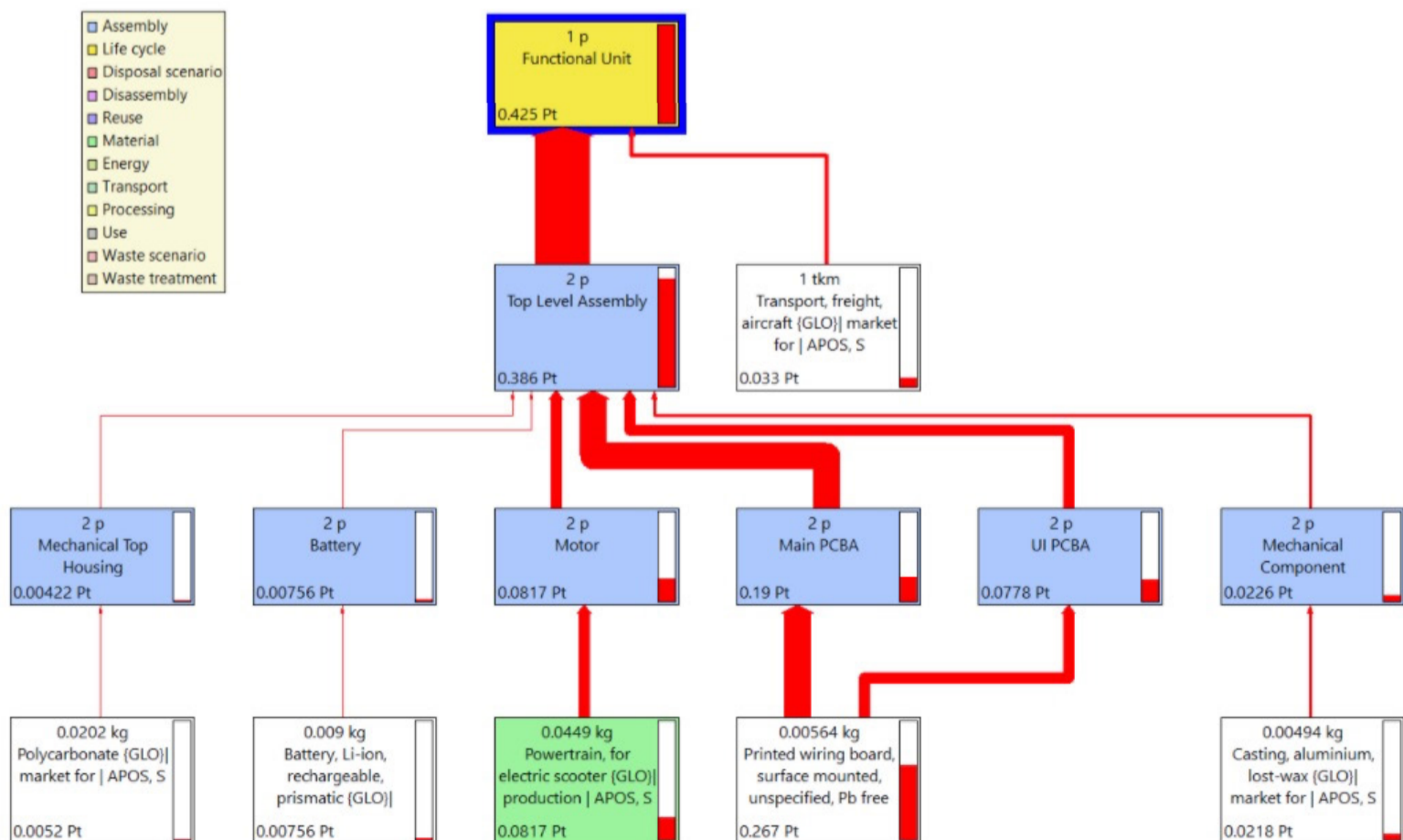
By nature of the iterative process, you may rely on different LCA tools and resources throughout the product development process. For a well defined system late in the development process, SimaPro or GaBi, two of the industry standards, can be used. For less defined systems early in the design process, 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.



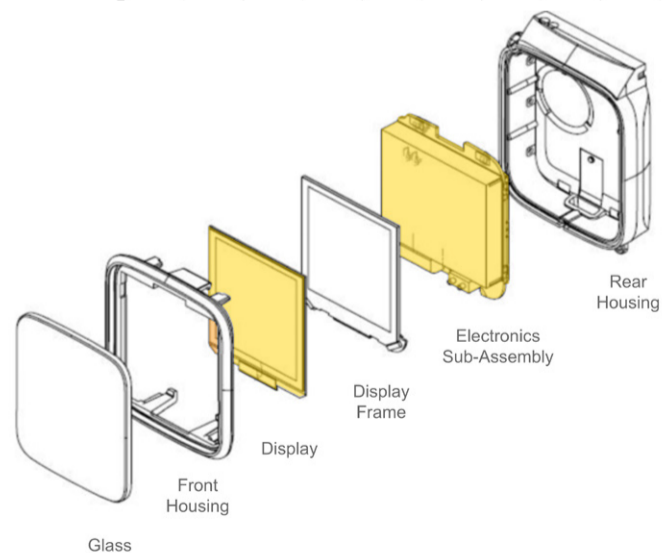
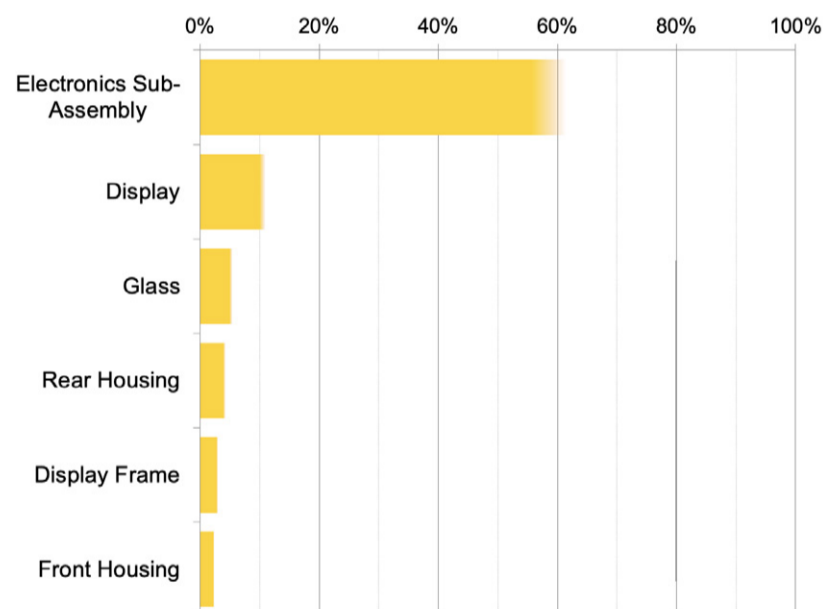
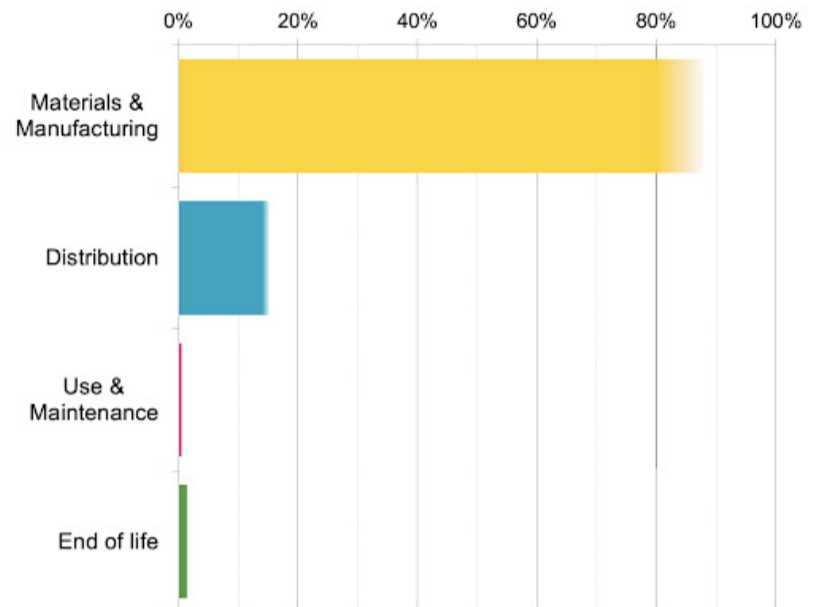
IDENTIFY

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.

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 spot, which can be identified regardless of the amount of uncertainty.



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

APPLY

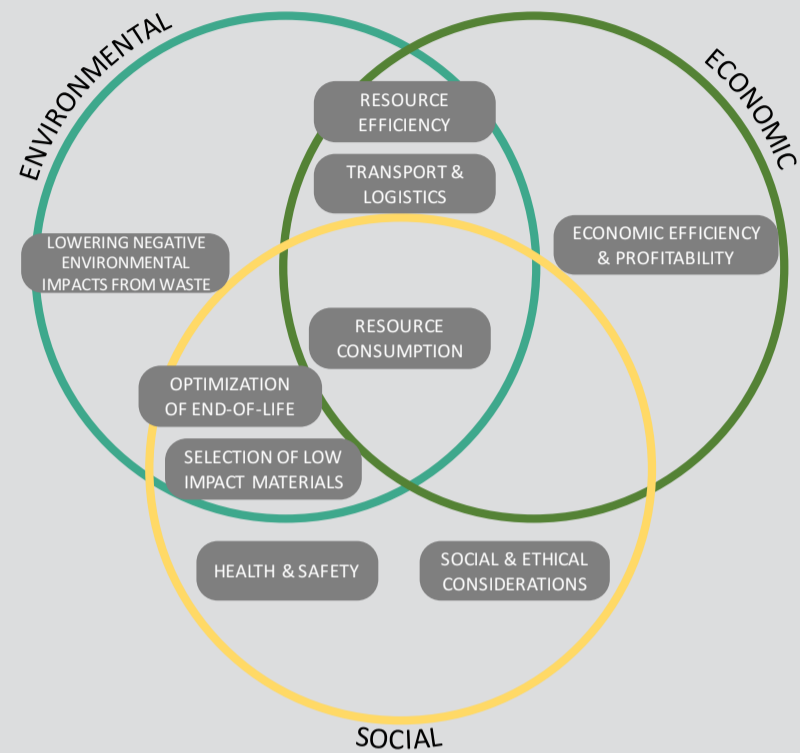
Having identified the biggest impact areas in the previous section, you can now implement specific strategies to reduce the system or product impact. These strategies allow for specific incremental improvements to the design and a cycle of ongoing or tiered improvements is common. Furthermore, some strategies 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.

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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.

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?

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](#)

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.

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?

Tools & Resources

- + [RoHS Compliance](#)
- + [Proposition 65 List](#)
- + [REACH Restricted Substances List](#)
- + [WEEE Calculation Tools](#)
- + Other companies' publicly available Restricted Substances Lists

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.

Tools & Resources

- + [US SEC Fact Sheet on Conflict Minerals](#)
- + [Responsible Minerals Institute](#)

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?



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.

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?

Tools & Resources

- + [Circular Design Guide](#)
- + [Lean Manufacturing Techniques](#)

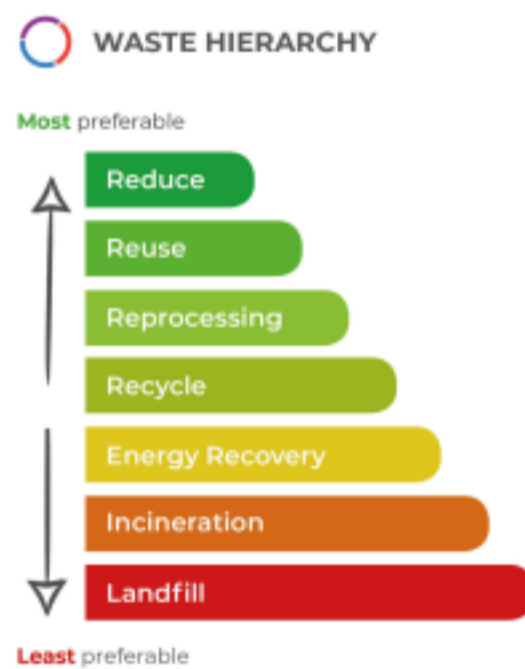


Image taken from <https://www.encore-environment.com/what-we-do/>

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.

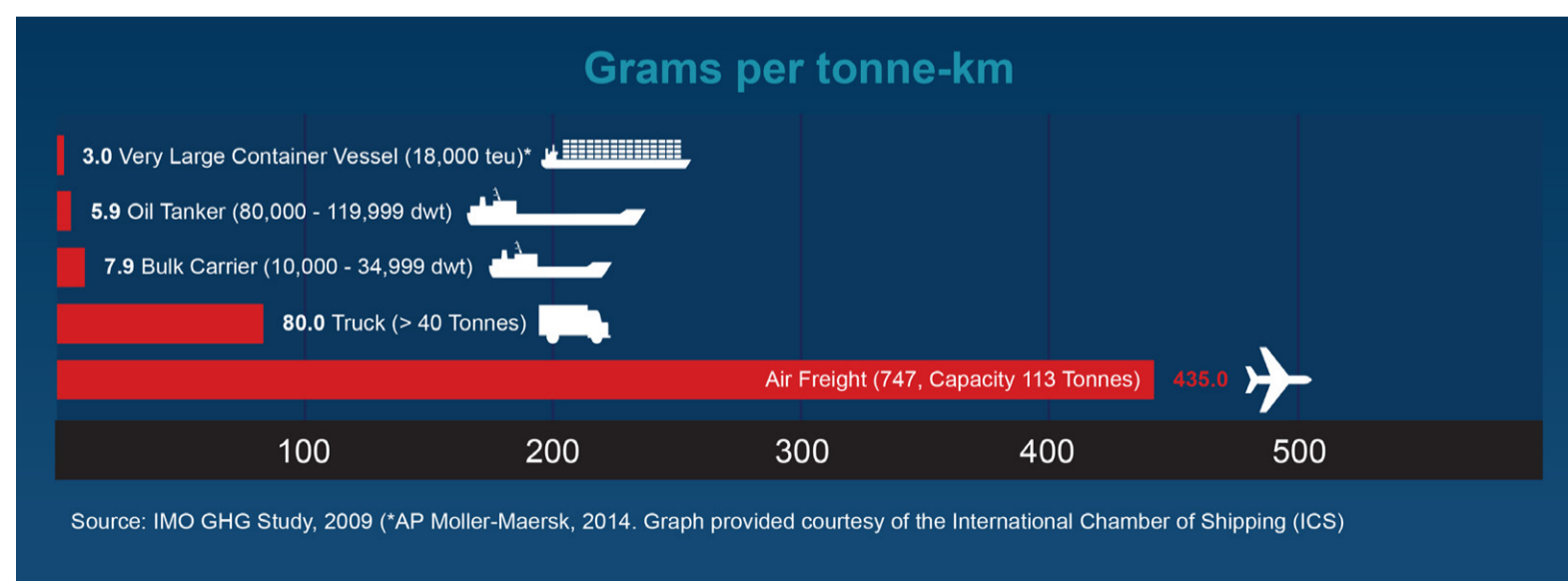
Key Questions

- + 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.

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.

Autodesk Sustainability Workshop
sustainabilityworkshop.autodesk.com

Keep it alive longer.

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.

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.

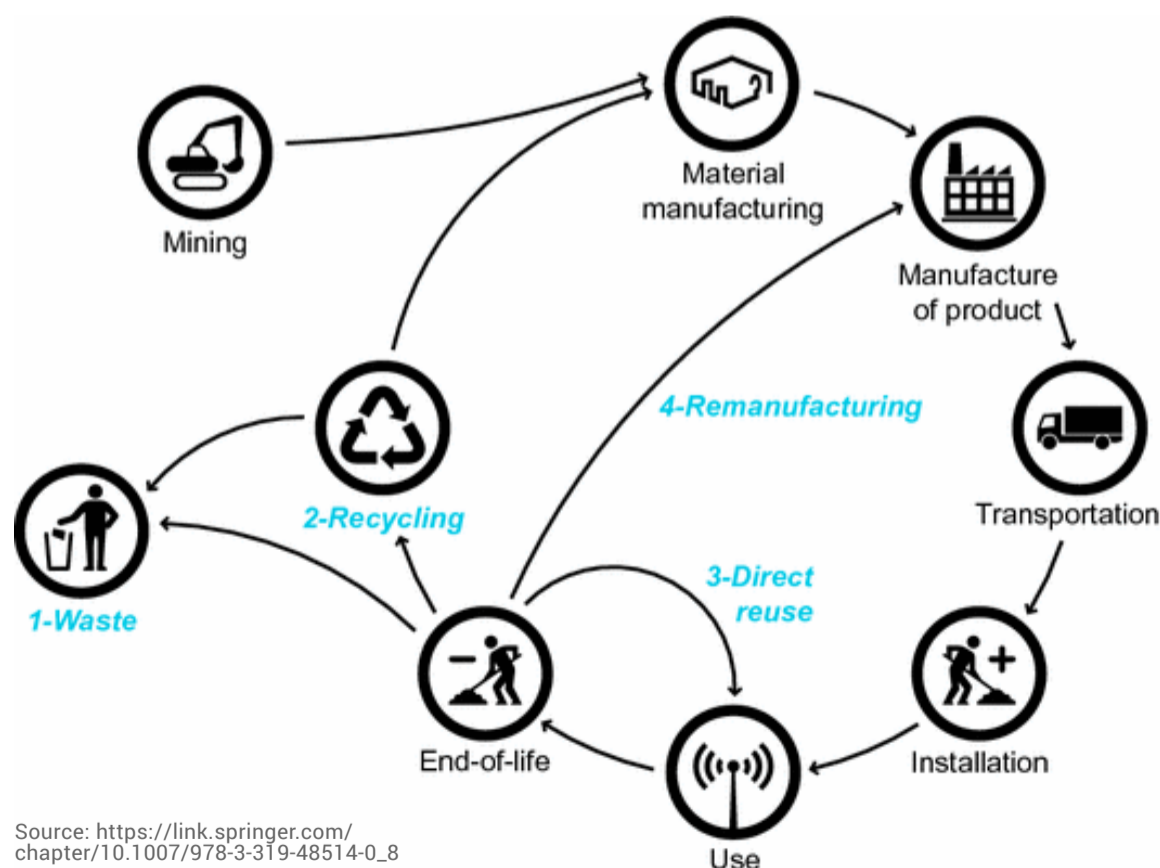
Often when running an LCA, you'll find that the end of life isn't highlighted as a large contributor to the environmental impact. Instead, the benefit of reusing and recycling components is seen in the environmental impact of the next product that uses them. Look for ways to close the loop in your system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

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?
- + 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](#)

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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?
- + 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?
- + 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?
- + What risks can be associated with the end of life strategy operating the system outside its designed use case?

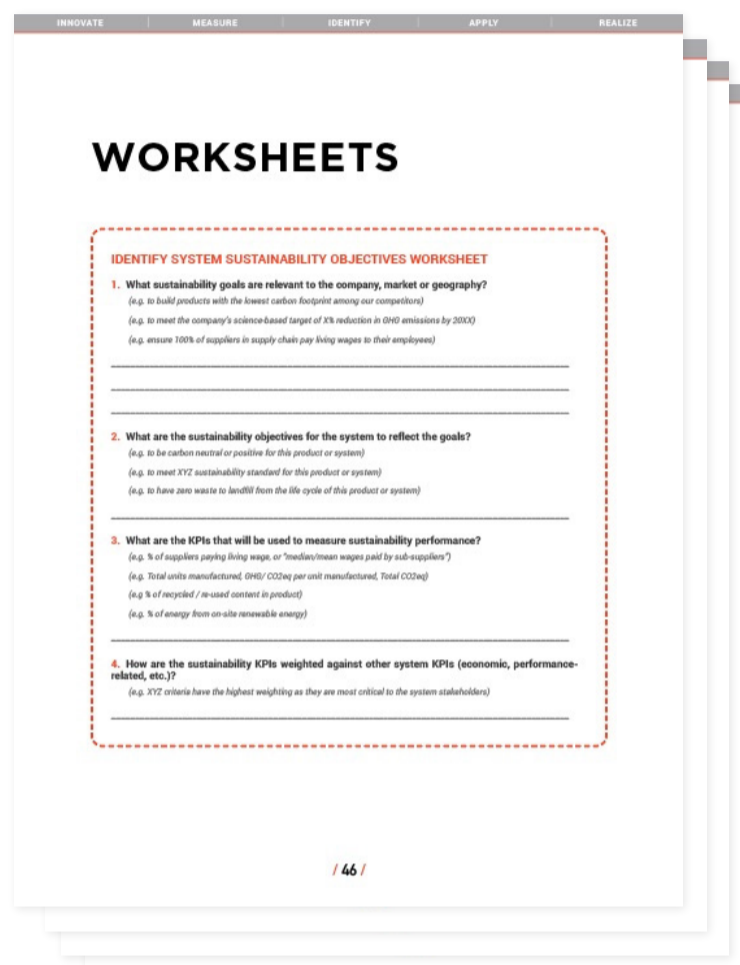
REALIZE

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.



WORKSHEETS

IDENTIFY SYSTEM SUSTAINABILITY OBJECTIVES WORKSHEET

1. What sustainability goals are relevant to the company, market, and/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 / reused 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)

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:

		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:

		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 <i>(e.g. product life)</i>		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							
Energy Usage		X Watts per use					
Number of uses		1500 over the course of the functional unit					
Disposal/End-of-life Strategy							
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 E-book.

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

Updated versions of this e-book can be found at:

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Project Ideas?

Give Andy a shout.

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