Product Lifecycle Flow

A theoretical approach on visualising closed-loop systems for the Circular Economy

TU Delft

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Master Thesis
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Executive Summary

The company introduced their new circular economy objectives for 2025 with the statement that they will close the loop by offering a trade-in on all professional medical equipment and taking care of responsible repurposing. Recycling has the least amount of value according to the circular system diagram of the company which means that a lot of valuable material will be lost in this process. The main goal of this study is to propose a redesign that reduces the total amount of waste and generate more value for the current closed-loop system by 2025. Product X has been taken as a use case throughout this study.

A literature study on the Materials Flow Analysis in combination with Sankey's diagram has been performed to develop a visual representation of the life cycle of Product X. The goal is to provide insight into the End of Life practice of Product X and identify new circular opportunities for the company. The results led to a focus on refurbishment and part harvesting to increase the repurposing value of Product X.

The identified obstructions have been rewritten into design challenges which were the guiding principles for the redesign Product X. The redesign of Product X has an optimized architecture that facilitates material reuse up to 82%. Three different business cases have been performed concerning the lifespan of Product X to estimate the potential circular revenue of Product X in time. The results indicated that the early and mid-stage of the redesign are feasible for the current refurbishment process and the late stage of the lifecycle should be dedicated to part harvesting process to capture as much material value as possible. The summarized business case indicates that the current revenue income of the redesign could be increased by 11% of circular revenue if it would be implemented.

A final Material Flow Analysis is performed on the redesign of Product X to gain insight on the impact of switching to a strategy like refurbishment that increases the material value for the closed-loop system.

List of Abbreviations

CE = Circular Economy

CRR = Circular Ready Requirements

DfD = Design for Disassembly

DfR = Design for Refurbishment

EoL = End of Life

LCF = Lifecycle Flow

MFA = Material Flow Analysis

PRM = Product Recovery Management

Table of Contents

1. Introduction

Design challenge, definitions, and approach

1.1 Design challenge

The company introduced their new circular economy objectives for 2025 with the statement that they will close the loop by offering a trade-in on all their products and taking care of responsible repurposing. Recycling has the least amount of value according to the circular system diagram of the company which means that a lot of valuable material will be lost in this process. The main goal of this study is to propose a redesign for product X to reduce the total amount waste and generate more value for the current closed loop system by 2025.

There is a need from Group Sustainability to push and accelerate the transition towards a circular economy within the businesses to achieve these ambitious objectives of 2025. The group is currently focused on developing methods and provide guidelines for the I&D department to take action on these objectives on an individual level. The purpose of this graduation assignment is to explore a use case within the company that could be utilized as an example for the I&D Department to show how circular practices are implemented in a practical and quantifiable manner concerning the design. For this reason, a collaboration has been set up between TUDelft and the company

The main goal is to propose a redesign that reduces the total amount of waste and genrates more value for the current closed-loop system by 2025. Three specific project outcomes are expected:

PO1: A visual representation of the life cycle of product X to provide insight on the End of Life practice and identify circular opportunities.
PO2: A design proposal of product X that elaborates on the identified circular opportunities.
PO3: A business case that supports the redesign decisions from an economic and circular economy perspective.

Design challenge

"Propose a redesign for product X that reduces the total amount of waste and generate more value for the current closed-loop system by 2025."

1.2 Approach

Starting a project from scratch without knowing the context, the product, or the business is quite an undertaking. Having guidelines to commence a project is therefore vital for managing your time and delivering a successful result. In this case, there are many different angles on starting a design project regarding the circular economy. This study is not intended to analyze all the different methods that would be suitable for a circular redesign. Analyzing a multitude of these guides and strategies resulted often in similar high-level steps that you would have to take to execute a circular redesign. Eventually, the Circular Design Guide developed by Ellen MacArthur Foundation and IDEO has been chosen as a guide for this project (Ellen MacArthur Foundation & IDEO, 2018). This guide provided the most reference material for a concrete approach towards circular product design compared to others.

The process of the Circular Design Guide comprises four stages described in figure 1. These stages will be the guiding principles of every chapter to understand the circular design process executed in this study. Each chapter will discuss different focus points of that gate using methods provided by the Circular Design Guide as well as different methods that are specifically applicable for design medical equipment. These stages will be the guiding principles of every chapter to understand the circular design process executed in this study.

Circular Design Guide

Ellen MacArthur x IDEO

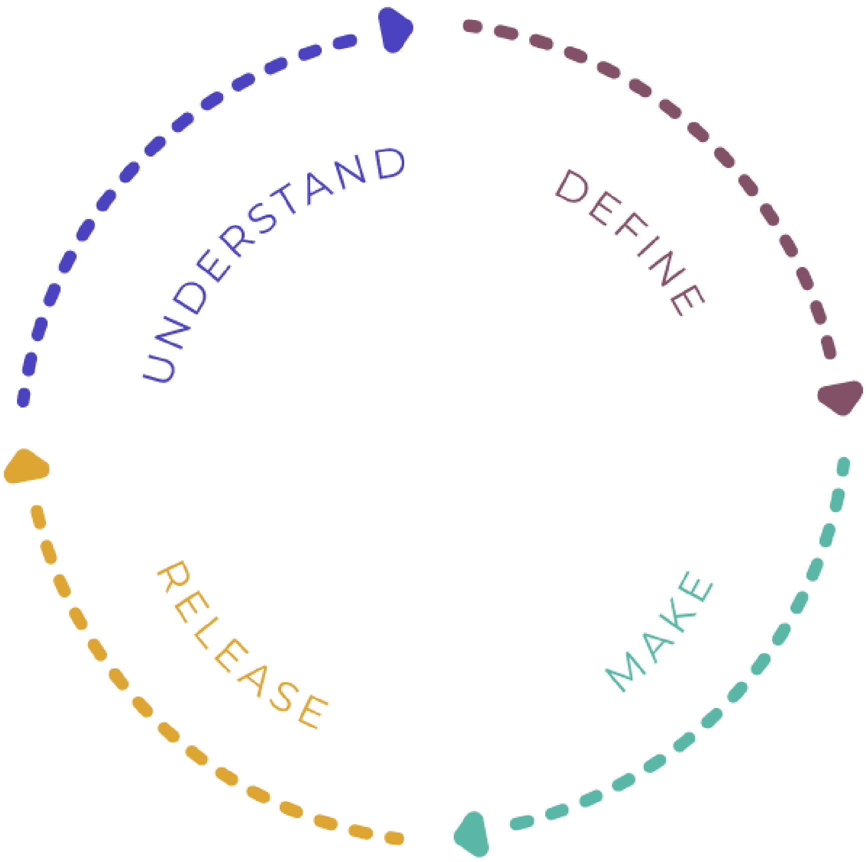


Figure 1: Schematic overview of the Cicular Design Guide

Understand

Get to know the user and the system

Define

Put into words the design challenge and your intention as the designer

Make

Ideate, design, and prototype as many iterations and versions as you can

Release

Launch your design into the wild and build your narrative - create loyalty in customers and deepen investment from stakeholders by telling a compelling story

1.3 Definitions

Definitions concerning the circular economy remain an ambiguous subject because there are no universal definitions formulated within the industry. One of the most influential works on product recovery management was conducted by Thierry, Solomon, Van Nunen, and Van Wassenhove in 1995. According to their framework, to optimize the value of products and reduce ecological waste, there are several tools that product recovery management (PRM) can use.

The five main recovery options to be used by PRM are repair, refurbishing, remanufacturing, cannibalization and recycling. Each of these options is qualified in terms of the level of disassembly, quality requirements, and resulting product (Table 1). The decision on which product recovery option is selected depends on: technical feasibility; supply of suitable used products and components; demand for reprocessed products, components, or materials; and economic and environmental costs and benefits (M. Thierry, M. Salomon, 1995).

The term "harvesting" which is used throughout this project is a synonym for "Cannibalization" of the PRM recovery options. The term "harvesting" will be used in this project instead of "cannibalization". Harvesting is one of the product recovery options which disassembles the selected parts for retrieval. The quality requirements for the harvested parts vary on the process in which these parts will be reused. After the parts of interest are reused, the rest of the product is recycled or scraped.

Term	Level of Disassembly	Quality Requirements	Resulting Product
Repair	To product level	Restore product to working order	Some parts fixed or replaced by spares
Refurbishing	To module level	Inspect all critical modules and upgrade to specified quality	Some modules repaired/replaced: potential upgrade
Remanufacturing	To part level	Inspect all modules and parts and upgrade to as new quality	Used and new modules/parts combined into new product:
Cannibalization	Selective retrieval of parts	Depends on process in which parts are reused	Some parts reused: remaining product recycled/disposed
Recycling	To material level	High for production of original parts: less for other parts	Materials reused to produce new parts

Table 1: PRM recovery Options according to Thierry Solomon and Van Nunen and Van Wassenhove (1995)

2. Literature review

Circular economy and Material Flow Analysis

2.1 Introduction

Chapter two will discuss the key principles regarding the circular economy including a reflection on the system diagram of the company and the diagram of Ellen MacArthur. The current design strategies of the company will be discussed which will be used to identify opportunities in the life cycle flow of product X.

In addition, literature research has been performed on the theory of Material Flow Analysis to understand how these models are build and visualized. This input will be used to visualize the first project outcome (PO1 – p.2).

2.2 Circular Economy

2.2.1 The concept of the circular economy

Looking beyond the current take-make-waste extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital (Ellen MacArthur Foundation, 2017). The concept is based on three principles:

1. Design out waste and pollution

2. Keep products and materials in use

3. Regenerate natural systems

These three principles will be the key drivers for our redesign. A further explanation on how these principles could be implemented in a circular design will be discussed in chapter 2.2.3 & 2.2.4

2.2.2 Personal definition of circular design

The term circular design is a definition that has become increasingly popular in recent years within the design community. It suggests being a version that includes the principles of the circular economy in relation to the design process. So far, there is no official definition of the word yet. Therefore, this report will use a personal definition that tries to encompass what circular design would entitle. The following statement is inspired by the definition of circular design by Tim Brown (CEO IDEO), the definition of design derived from the Montréal design Declaration (2017) and the definition of the European Environment Agency on eco-design (2001);

Circular Design

"An eco-systemic approach of developing products and services that strive for a continuous lifecycle with no beginning, middle, or end. The purpose is to prolong and regenerate material value in a closed system with limited resources."

2.2.2 System diagram

The Circular Design Guide provides a system diagram of the circular economy provided by the Ellen Mac Arthur Foundation that explains both technical and biological cycles (figure 2). Consumption happens only in biological cycles, where food and biologically-based materials (such as cotton or wood) are designed to feedback into the system through processes like composting and anaerobic digestion. These cycles regenerate living systems, such as soil, which provide renewable resources for the economy. Technical cycles recover and restore products, components, and materials through strategies like reuse, repair, remanufacture, or (in the last resort) recycling (Ellen Mac Arthur Foundation, 2017). This study focuses on medical products which means that the biological cycles are not considered in this study.

The company has recently developed their own system diagram of the circular economy which is applicable for its product portfolio (figure 3). Comparing both system diagrams reveal an interesting insight regarding the perception of material value. The Ellen MacArthur foundation reflects on material from an environmental aspect focussing on returning the material to nature (e.g. finite materials, minimizing systematic leakage and negative externalities). Whereas the company approaches the model from a business perspective focussing on controlling the material value in their circular ecosystem. This is will be highlighted at the end of this report which reflects on the drivers behind the value creation of the system diagram (chapter 6.4.3)

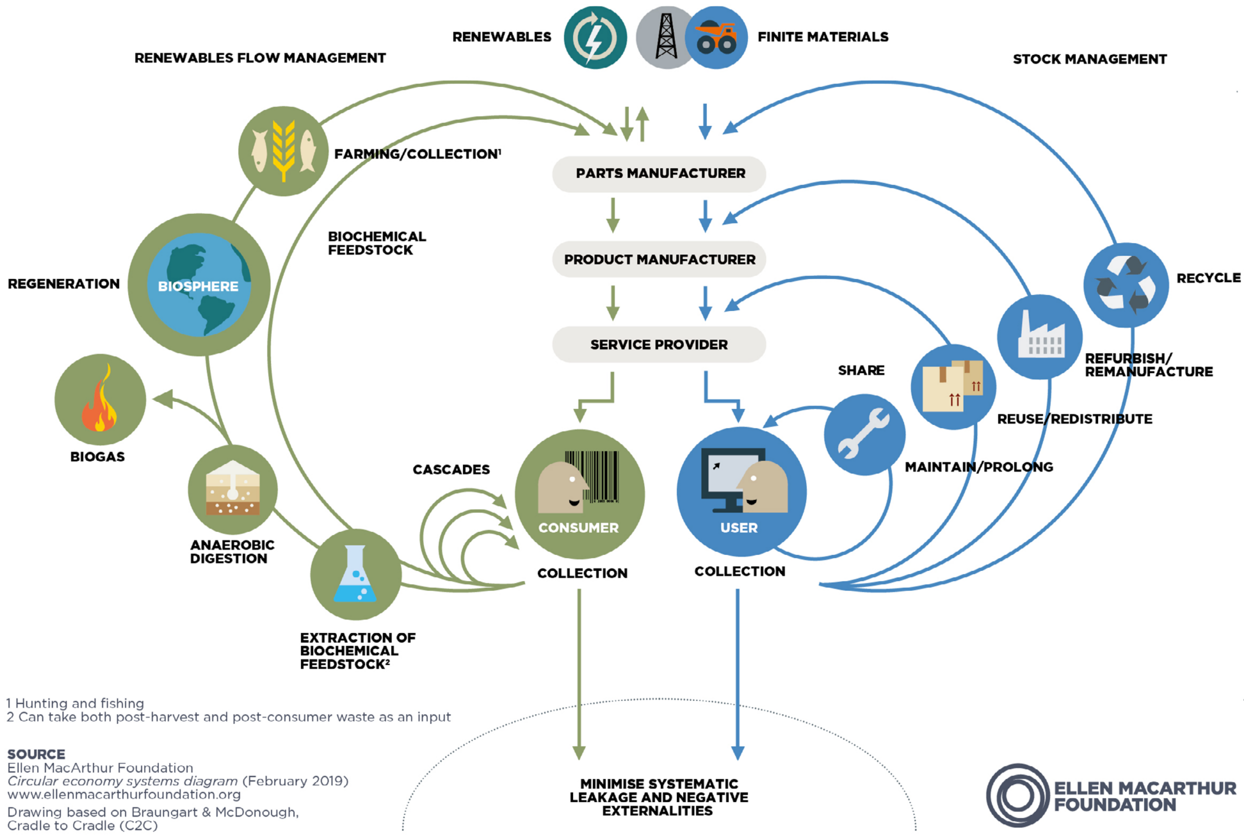


Figure 2: Circular system diagram of the Ellen MacArthur Foundation

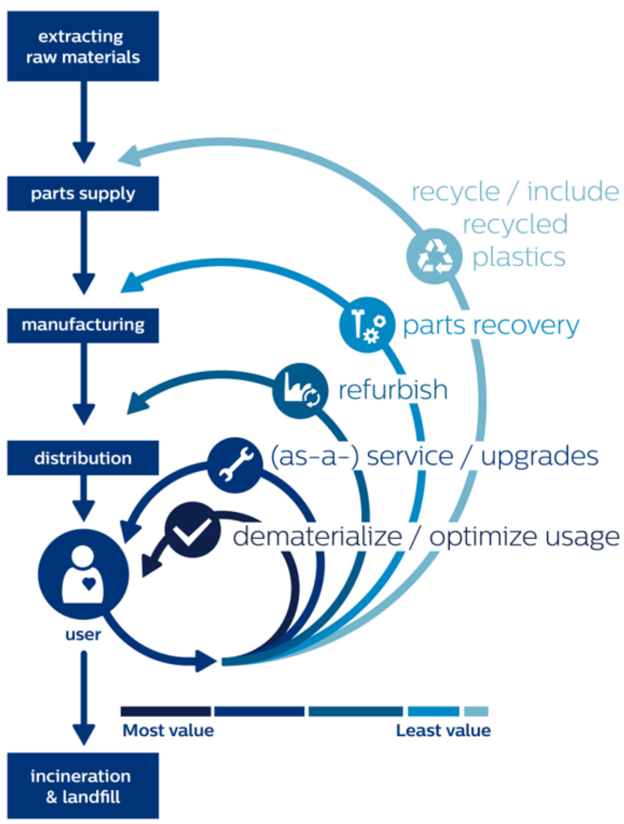


Figure 3: Circular system diagram of the company including their value circles

2.2.3 Design strategies

The circular system diagram describes, how the company can generate value for the circular economy through various loops (figure 3). Within the company, a circular design is supported by two levels that reinforce each other. On the one hand, there are circular revenues which can be expressed as a percentage of the total revenues. On the other hand, there are requirements that support the generation of circular revenues through the circular design of hardware or software. Depending on the product and business model Circular Ready Design will focus on one or more of the 8 Circular Economy design strategies (Circular Ready Requirements):

1. Easy to clean, sterilize and restore aesthetic state
2. Secure and private exchange
3. Easy to assess and track performance
4. Easy to disassemble, repair and re-assemble
5. Modular design for forward and backward compatibility
6. Standard, durable element selection
7. Sustainable material selection
8. Easy to dismantle back into pure materials

The different circular revenue models will be identified in the Material Flow Analysis of product X (Chapter 3.3). Based on one or more revenue models for the redesign, a set of circular requirements will be linked as described in Figure 4. These circular requirements/strategies will be added to the current requirements defined for the development of product X (Chapter 4.2). The Circular Ready Requirements (CRR) will be refined in a way that applies to this case study since they have not been quantified to this day.

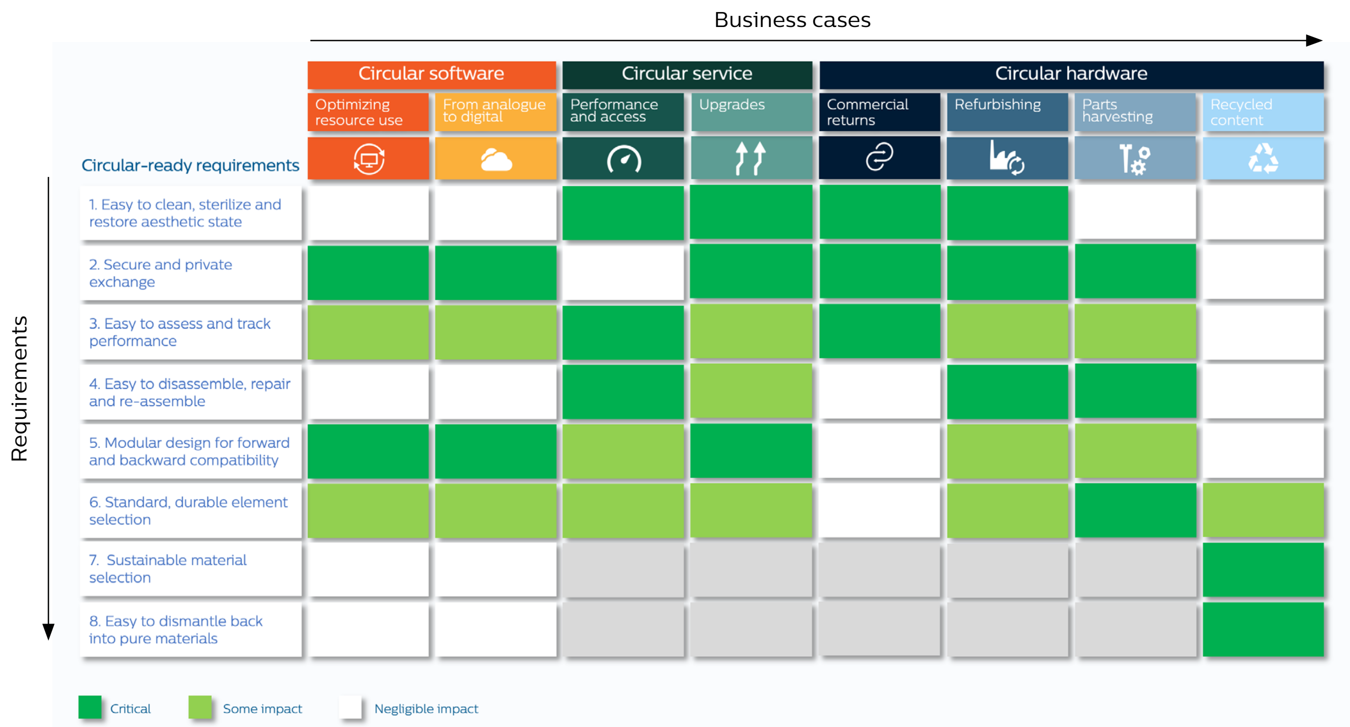


Figure 4: Circular design strategies

2.3 Material Flow Analysis

2.3.1 Methodology

A Material Flow Analysis (MFA) is a management tool that deals with the analysis of material and energy input and output processes, resource use and stock calculations, and hotspot assessment (Wang, Y., Ma, H., 2017). The tool is commonly used in the engineering and financial world but is less known among designers. In the following paragraphs, the literature of Material Flow analysis will be discussed to understand the structure of these models and the potential benefit of creating such a diagram.

Materials flow analysis is one of the key tools in industrial ecology. It has been defined as 'a systematic assessment of the flows and stocks of materials within a system defined in space and time' (Brunner and Rechberger, 2016). MFA is based on the law of conservation of mass and is, quite an accounting of goods and substances through a system (S. M. Kaufman, 2012) (figure 5).

MFA is based on two fundamental and well-established scientific principles, the systems approach and mass balance (Marina Fischer-Kowalski, 1998). The system definition is the starting point of every MFA study. The level of detail of the system model is chosen to fit the purpose of the study. An MFA system always consists of the system boundary, one or more processes, material flows between processes and stocks of materials within processes. The physical exchange between the system and its environment happens via flows that cross the system boundary. One of the main purposes of MFA is to quantify the metabolism of the elements of the system. Unlike economic accounting, MFA could also cover non-economic waste flows, emissions to the environment, and non-market natural resources. The process balance is a first-order physical principle that turns MFA into a powerful accounting and analysis tool. The nature of the processes in the system determines which balances apply.

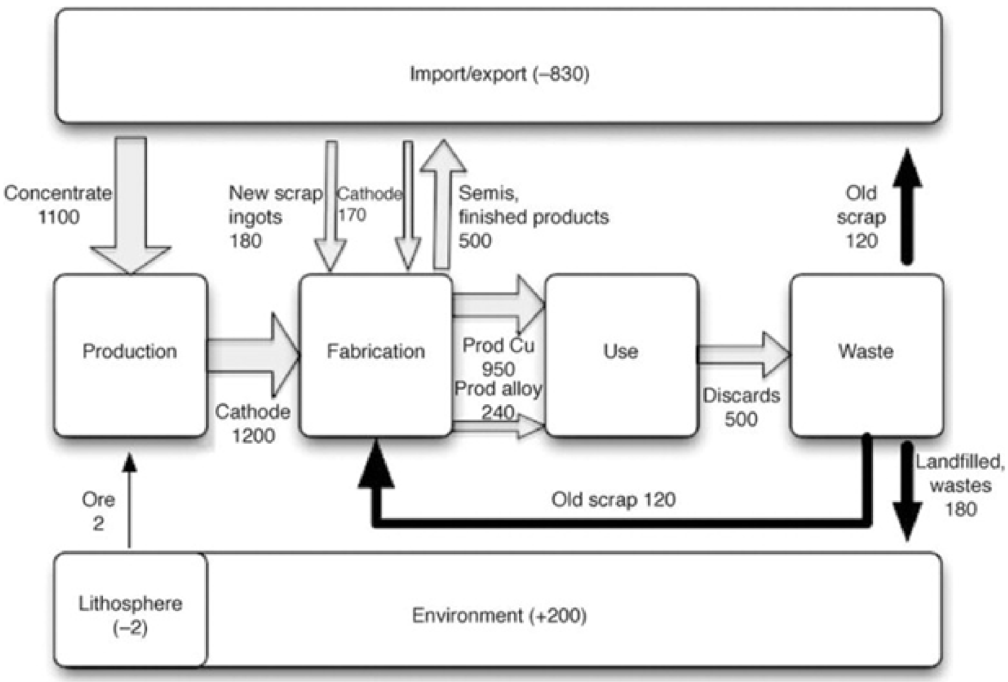


Figure 5: Illustration of a sample MFA study for copper (Lifset, et al., 2002).

2.3.2 Guidelines

A state-of-the-art MFA consists of the following steps according to the Practical Handbook of Material Flow Analysis (Brunner, P.H.; Rechberger, H. (2016):

1. Establish an explicit system definition: Specify the system boundary with geographical and temporal scope, processes (can contain stocks), and flows. Specify the material for which the system is to be quantified (product, substance, or indicator element). Make sure that each stock is associated with a process and that each flow connects one process to another. Flows can also begin or end outside the system boundary.

2. Define and name the system variables. The system variables include: All stocks within the processes, all flows between processes, and all flows coming from outside or going to outside the system boundaries. Sometimes, stocks are not considered and only the net stock changes are of interest. For each variable, it must be clear whether it is a stock or a flow, and this distinction needs to be reflected in the names and in the mathematical symbols chosen.

3. Quantify the system variables by linking them to literature, measurement, or modelled data.

4. Perform a mass balance check for all processes and the system as a whole.

5. Optional: Visualise your system by using the box-and-arrow scheme shown above or by using Sankey diagrams.

6. Document the MFA by reporting the explicit system definition along with the list of quantified system variables and the mass balance checks.

2.3.3 Sankey's Diagram

The Sankey diagram is the main tool for visualizing industrial metabolism and hence is widely used in industrial ecology (M. Schmidt, 2008). It is an important aid in identifying inefficiencies and potential for savings when dealing with resources. It was developed over 100 years ago by the Irish engineer Riall Sankey to analyze the thermal efficiency of steam engines and has since been applied to depict the energy and material balances of complex systems (see figure 6).

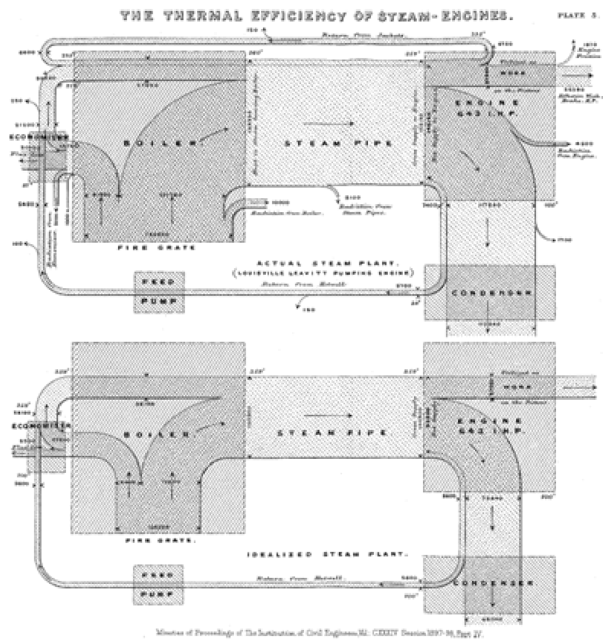


Figure 6: The first two energy flow diagrams of Captain Sankey (1898). They represent two steam engines—a real one (top) and an ideal one (bottom). Source: Sankey 1898, Plate 5.

Many engineers have been inspired by Sankey's representation and have used similar diagrams, often for popular publications. That is why there have been no rules for drawing up the diagrams, except those of visual perception and intuition. Despite this, a few aspects of Sankey's diagram have been assumed implicitly by users:

Sankey Guidelines

1. The diagrams concern quantity sizes that are related to a period in time or to a functional unit, such as a product unit.

2. The quantity sizes are extensive sizes (see figure 7).

3. The quantity scale uses the width of an arrow and is proportional (i.e., twice the quantity is represented by an arrow that is twice as wide).

4. Inventories are not taken into account (i.e., there is no stock formation).

5. An energy or mass balance is maintained.

These assumptions are important, as disregarding them can lead to incorrect interpretations. However, deviating from these principles is allowed within the diagram, but must be clearly communicated through a list of assumptions for example.

2.3.3 Approach

The following steps will be executed similar to the approach of Derek L. Diener and Anne-Marie Tillman in combination with the MFA and Sankey guidelines (D. L. Diener, A. Tillman, 2016).

First phase: System description

Setting up a system from scratch could be a challenging undertaking and will be highly dependent on the data that is available within the company. In this case, there are no overviews of product X concerning any material flow. Multiple interviews with different stakeholders related to the life cycle flow will be performed and collaboratively the system will be expanded further with multiple reflections and iterations along the way to set up a first draft of the system description.

Second phase: Data collection and applying the system to specific cases

A second iteration will be carried out after gathering and analyzing the data related to product X Specific models will derive from this analysis to perform an MFA using the MFA and Sankey diagram guidelines. Additional interviews will be executed to fill in data that is missing or create assumptions to finalize the model.

Third phase: introduction to Value drivers, insights, and opportunities

A final model of product X will be developed to discuss and identify circular opportunities.

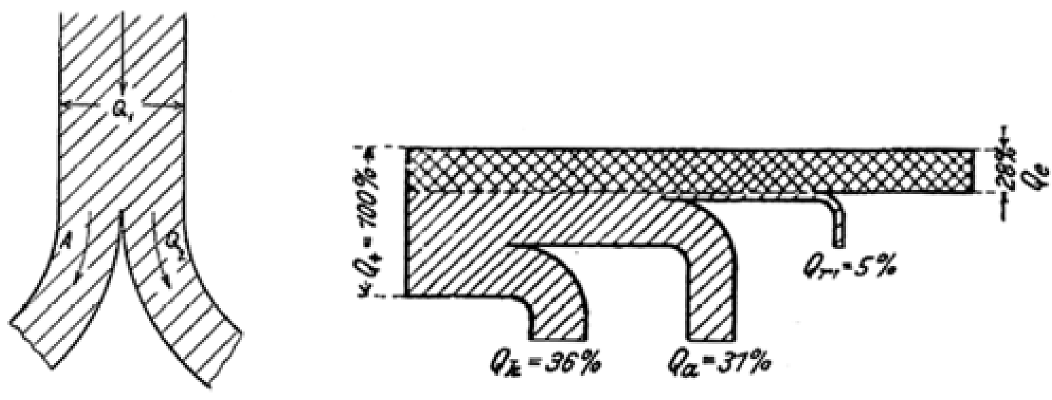


Figure 7: Left: Sankey diagram with splitting of an energy flow. Source: Tafel 1924, figure 11. Right: Sankey diagram with fanning and relative data. Source: Gueldner 1913, figure 12

2.5 Key insights

Chapter summary

A summary is provided on the concept of the circular economy and the terminology that is involved. The study reviews the literature on the principles of the Material Flow Analysis and uses them as guidelines for the development of a Sankey diagram for product X.

1. Circluar ready requirements

There are currently no Key Performance Indexes (KPI's) for the Circular Ready Requirements that are linked to the company's business opportunities. This means that the requirements need to be further elaborated as the design process progresses and assumptions need to be made with regards to quantifying these requirements (chapter 4.2).

2. Impact of a Material Flow Analysis

An MFA can only be developed if you have sufficient data concerning the life cycle of a product. The methodology is based on the visualization of energy or material flows concerning their position in a given timeframe. The more assumptions are introduced, the poorer the model will reflect reality. Data sets such as; Bill of Material, Consumption data, Install base data of your product are considered essential (chapter 3.3).

3. Sankey diagram visualisation

There are no clear guidelines for the visualization of a Sankey diagram, which results in varying results within the literature. It is important to follow the guidelines accurately and indicate the deviations within a List of Assumptions (chapter 3.3).

3. Understand
The Product Lifecycle of product X

3.1 Material Flow Analysis - product X

The goal of the development of the Material Flow Analysis is to develop a strategic collaboration tool that holistically visualizes the lifecycle of a product offer. It should serve as an 'eye-opener' to reflect on circular business opportunities.

3.1.1 First phase: system description

The first step to set up a Material Flow Analysis (MFA) is to create a framework that describes the different steps within the life cycle of a product (Figure 16; p. 25 & 26). The framework includes the process of material extraction up to the End of Life practices around a product.

A block in the framework represents a process linked to the location of the material. An arrow indicates the traveled path of the material weight to the following process (figure 17). This model does not take into account any stock formation of individual parts of a product. Currently, the size of the arrows is similar in weighted because there is no input in the model like material weight (figure 18). Every time a box is added it is important that the Sankey guidelines are taken into consideration (chapter 2.2.3)

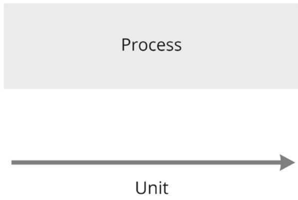


Figure 17: Two variables within the framework of the MFA

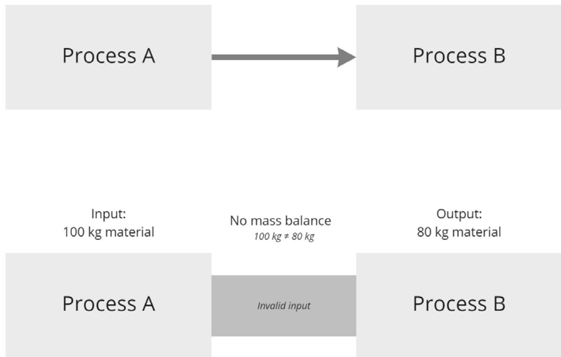


Figure 18: An example of input of 100 kilograms of material into the framework.

A mass balance in the framework needs to be maintained to prevent misinterpretations regarding the tool (Figure 19). It should be explicitly mentioned within the framework if you would consider deviating from this guideline.

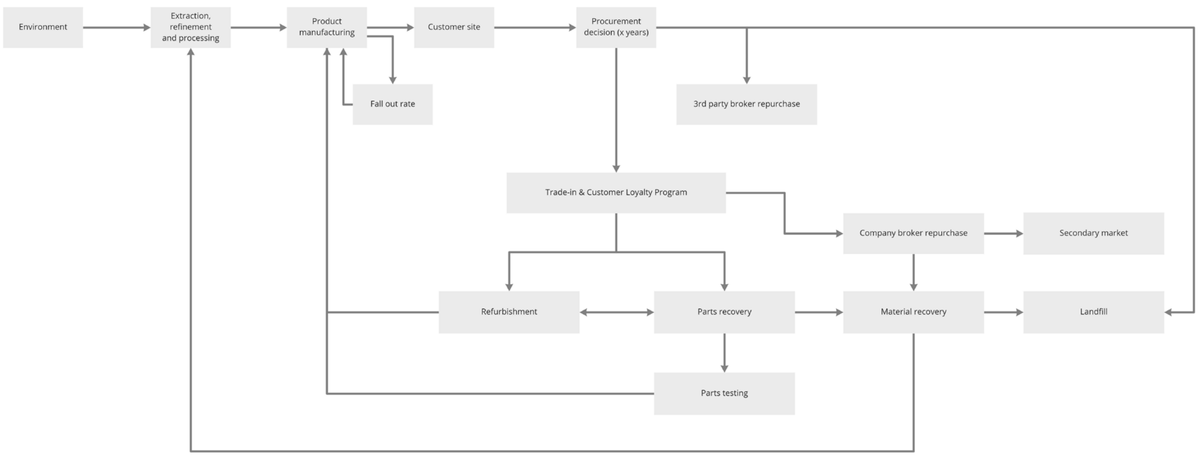


Figure 16: A framework of a Material Flow Analysis

Figure 19: An example of output where there is no mass balance.

The processes described in the framework will be briefly explained to provide a clear overview of how the framework functions for professional medical equipment. An explanation of the reasoning behind the development of the framework can be found in Appendix C.

Environment
Composition of natural processes that are linked to your product such as ore genesis, oil, and deposit formation, and other processes. To approximate these ratios you need to know specific materials composition in your product

Extraction, refinement, and processing
Process of extracting raw materials from the biosphere and lithosphere, refining and/ or processing them, and supplying them to manufacturers. This happens at hundreds of thousands of sites globally, by multiple companies, usually specialized according to the material type and extraction process. Includes transport.

Product manufacturing
Conversion of materials into parts.

Customer site
This process includes the installation of the product, use, and routine maintenance. It is important to have an overview of the cumulative install base of your product. This overview will tell you how many products are still in the market, what has been sent back to the company.

Fall out rate
The number of products that are returned by the customer due to technical issues or manufacturing errors

Procurement decision
Customers will decide whether they will upgrade, replace or maintain equipment. Customers will issue a new tender, which the company or competitors can respond to. In some cases, trading-in in old equipment will factor into this deal. In other cases, customers will hold onto old inventory as a backup.

Third-party broker purchase
Competitor brokers repurchase equipment, for resale.

Trade-in Triage
A location or facility that collections the equipment

Company broker repurchase
Process of waste management in which waste streams are approved and sent to landfill (released to biosphere), or incinerated (released to the atmosphere).

Secondary market
Company Brokers and new customers for older generations of equipment which can no longer be upgraded.

Refurbishment
Professional refurbishment. Involves the following steps: disinfection and cleaning, covers/coils repair & repainting, technical check, installation/ upgrade latest available software, performance and image quality check, installation and configuration to customer specs, full warranty, and Service.

Parts recovery
A process conducted by the company stripping the product down to its part level

Material recovery
A process conducted by the company stripping parts down to their material components and selling materials to recyclers to be further re-used.

Landfill
Process of waste management in which waste streams are approved and sent to landfill (released to biosphere), or incinerated (released to atmosphere).

Parts testing
Testing of recovered parts for quality.

Point of consideration
The framework has been set up to guide designers who wish to make their MFA. It is therefore possible to add extra steps or blocks to tailor the framework to your own needs (e.g. size and coloring of the boxes). However, during the development of the current framework, it turned out that an overview like this quickly becomes complex when you go into detail. It is therefore advisable to only add extra blocks when this is would leave out circular opportunities that need to be communicated. Always keep in mind that it should be a tool that is easy to read and understand to provide insight into the various material flows within a product.

3.1.2 Second phase: Data collection and applying the system to specific cases

To construct Material Flow Analysis the first information needed is data to fill in the blocks. For making an MFA of product X, the following data sets were used:

- Bill of Materials
- Market consumption data
- Cumulative Install base data
- Consumable analysis of refurbishment process
- Recycling data

To be able to visualize the data, there are various types of software that you can use to easily construct a Sankey diagram. It is important to consider the complexity of your framework. More complex software facilitates a wider range of functions in the creation of a Sankey diagram. On the other hand, the effort to learn this software takes longer. Below is a list of software you can use;

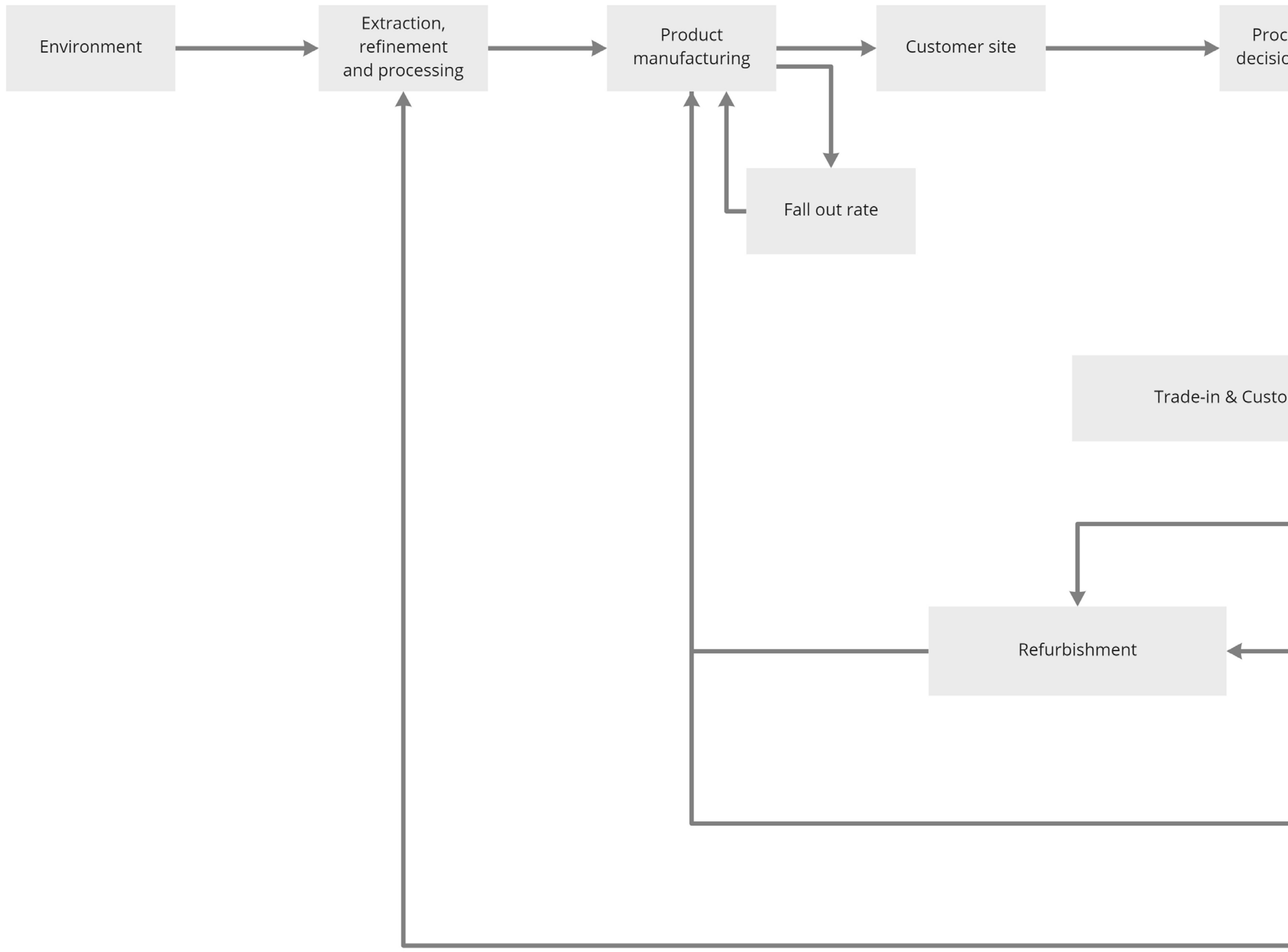
SankeyMATIC
+ Software that is easy to use without needing to write scripts.
+ Free to use
- Capabilities of the software are limited

e!Sankey
+ Software that is easy to use without needing to wire scripts.
- After a 14-day trial you have to pay for a monthly subscription

Excel (in combination with Power-user)
+ Large capabilities for complex MFA's
+ Free to use
- Experience in CC+ or Javascript

None of the software contains an integrated time scale that postulates the processes. The duration of these processes was obtained from interviews with the the company to estimate the timescale. This is also mentioned in Appendix D. The result of the material flow is shown on page 27 & 28.

Framework of a Mat



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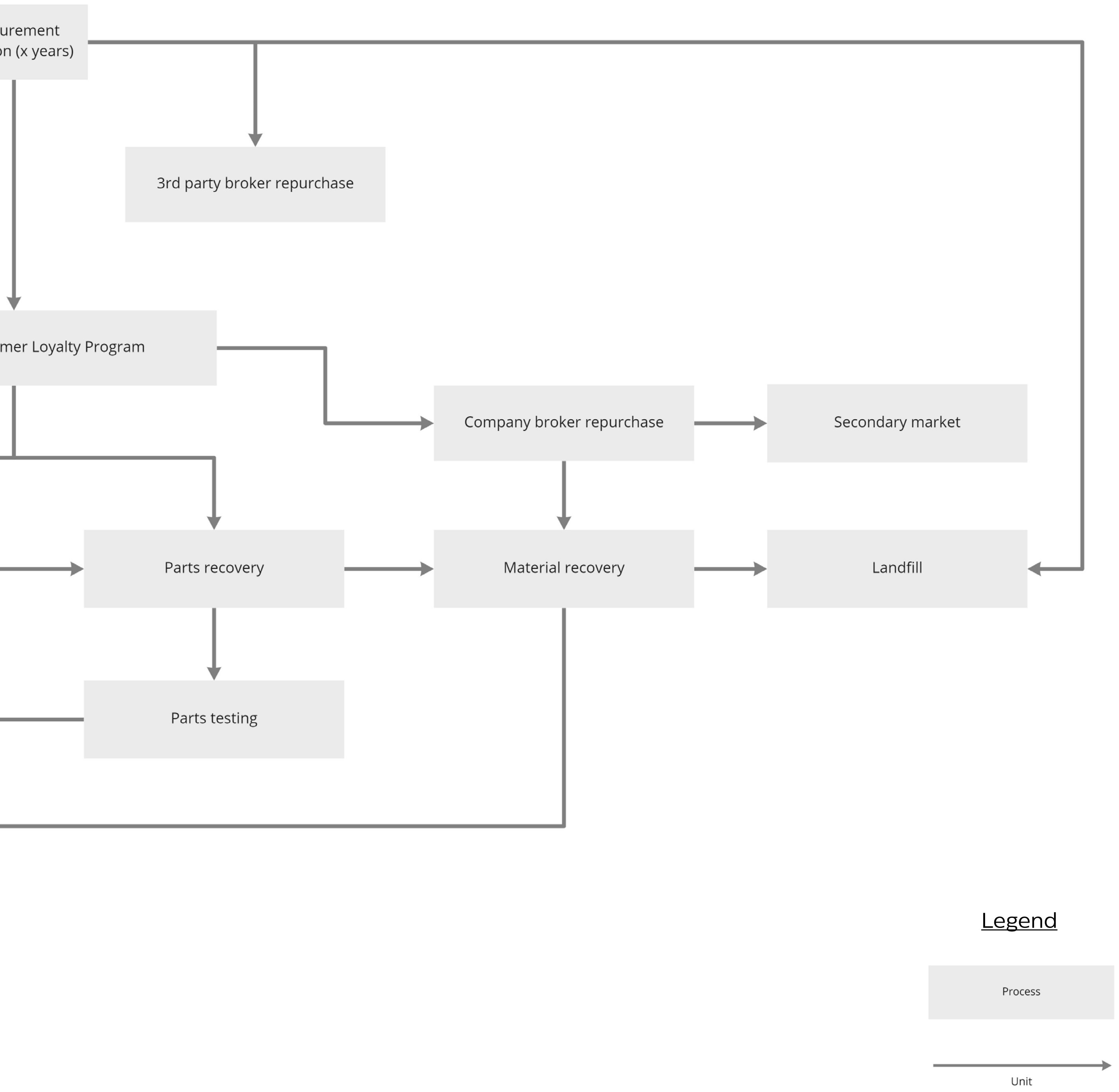
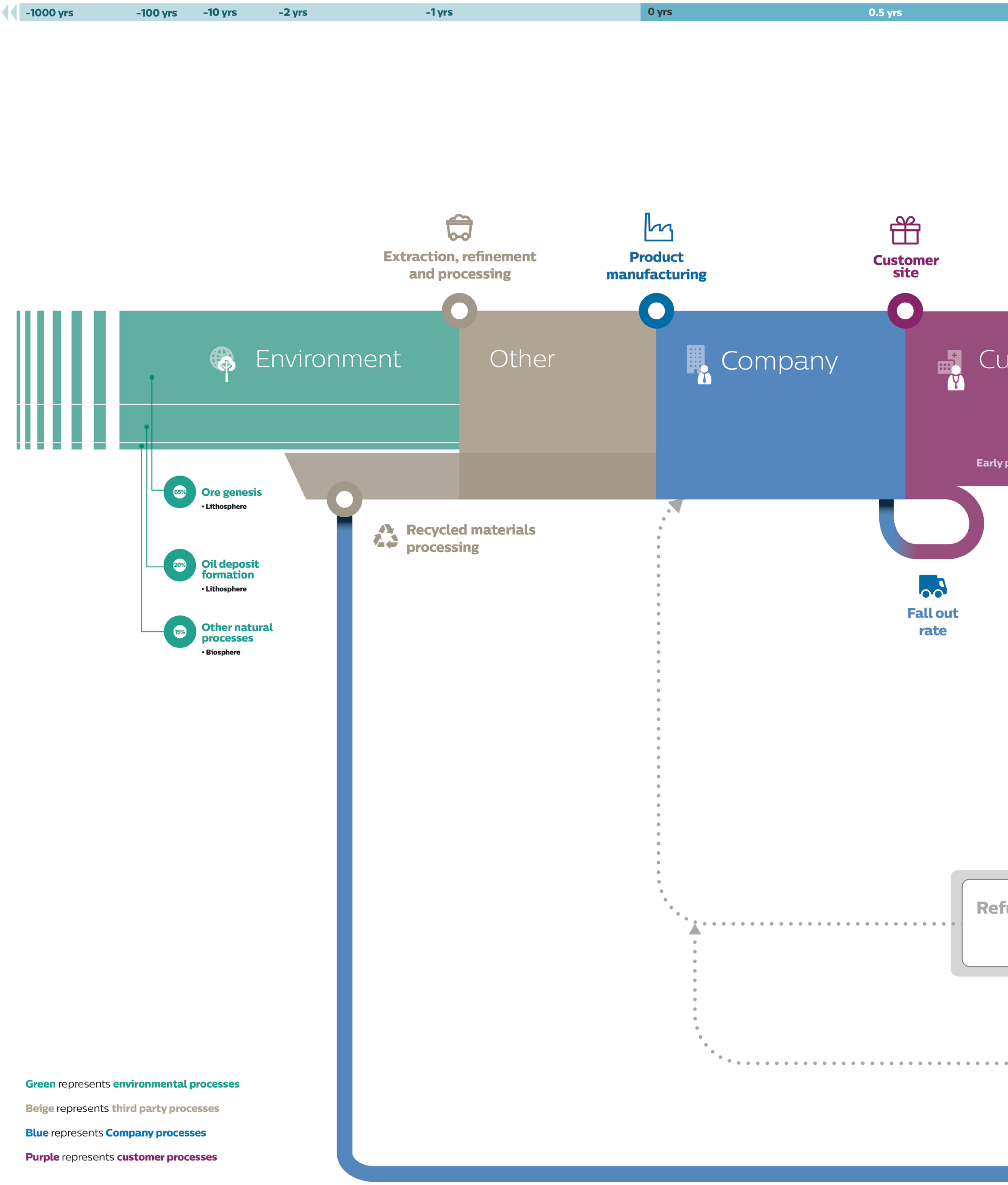
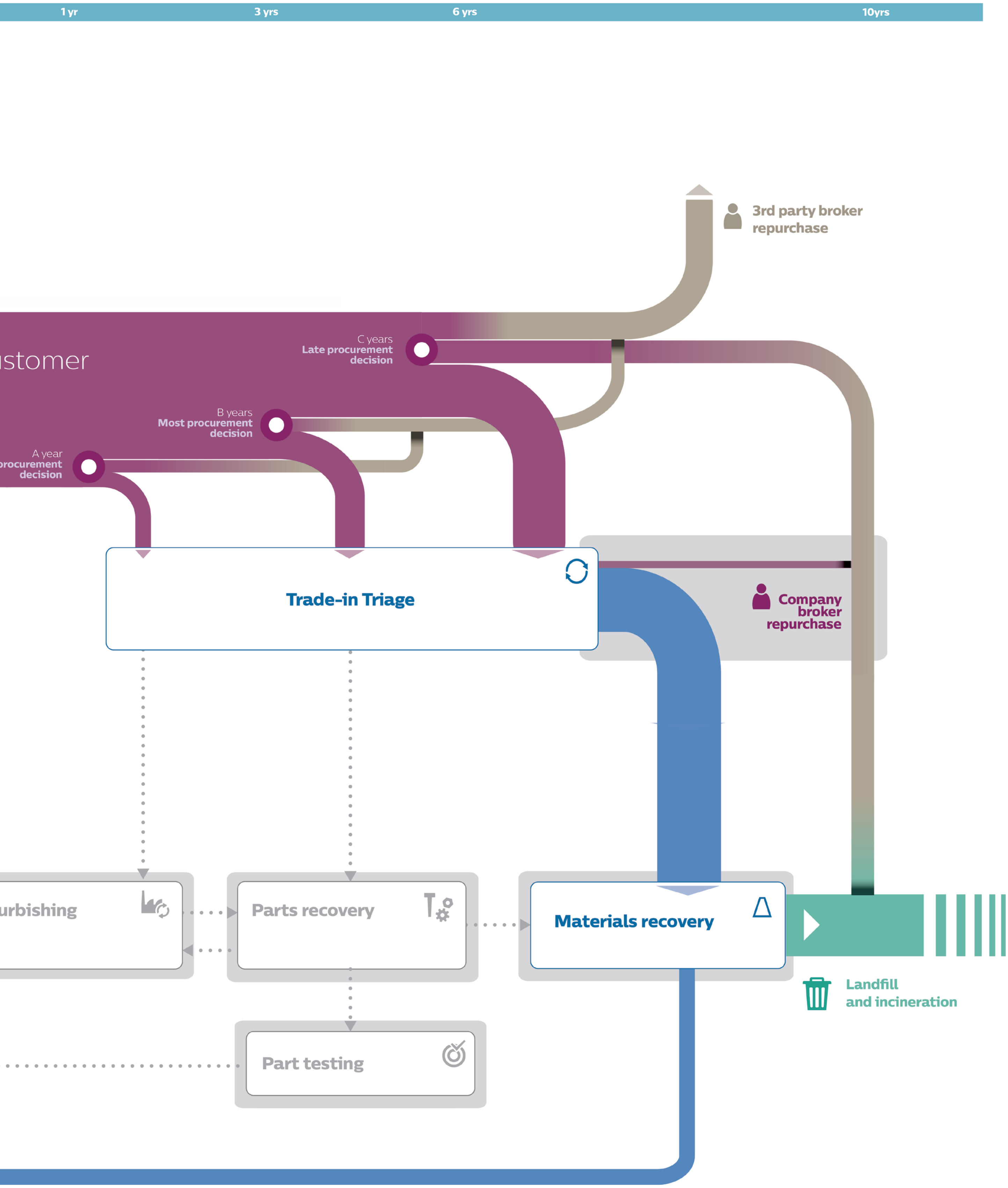


Product Lifecycle Flow

Material Flow Analysis Framework




1 yr
3 yrs
6 yrs
10yrs
3rd party broker repurchase
stomer
C years
Late procurement decision
B years
Most procurement decision
A year
procurement decision
Trade-in Triage
Company broker repurchase
urbishing
Parts recovery
Materials recovery
Landfill and incineration
Part testing

The model on page 27 & 28 has been adjusted in comparison to the Framework of an MFA (p.25 & 26). These adaptations were initially made to create a hierarchy within the MFA to enhance the communication of the flow. Each of these modifications will be briefly explained.

Color guidance

An MFA does not initially contain any colors. In this case, the stakeholders involved in the process are colored to get a better understanding of where the material flow is in time (see legend p. 26). In case of a direct transition, there is a specific point in time when the material is transferred from one stakeholder to another (e.g. company factory (blue) to the customer site (purple). If no specific point in time is indicated, it means that the transfer of material takes place over a period of time and will be indicated with a color transition (e.g. customer to third-party broker). Environmental processes have been shortened with intervals to decrease to total bar length (e.g. environment form -1000 years t0 100 years).

Block formation

The step from the finished framework to the MFA is a visualization exercise that was not carried out in one go. The decision was made to adapt the size and shape of the blocks to make a better distinction between flows. In the end, the flow does not resemble the framework but remains the same. See Appendix E for the Sankey visualization of the plain version.

Inactive processes

Processes in which the company has the infrastructure but does not use it for the specific product are indicated with a grey color. This allows you to still assign opportunities to processes that are there, but not originally visible in an MFA.

Procurement decision (early, most and late)

One specific procurement decision proved difficult to attribute to a specific block in the case of a product. Based on the data sets and interviews, three specific periods have been identified as key decision factors for the End of Life scenario for a product.

Year A: The duration of the companies warranty for a product.
Year B: The average life of a product.
YearC: Commonly the xth year of a products life when the product is checked for product survivability by the company

Distinguishing these time units helps you understand the failure rate of a product in a specific timeframe which changes the perspective on which circular strategy would be more appropriate for your product (chapter 3.3.3).

3.1.3 Third phase: Introduction to insights, opportunities and value drivers

The third phase is an additional addition to the MFA to be able to more clearly indicate where the opportunities for the business are found. Firstly, this is achieved by adding extra steps within the MFA that can be linked to insights. These insights are obtained through 30+ interviews with various stakeholders within the business (appendix F). An overview of the outcome of these interviews can be found on page 29. Insight and opportunities are represented with the following symbols (figure 20).

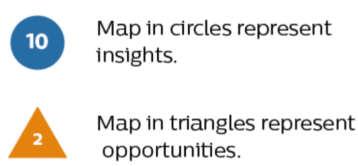


Figure 20: Indicators for insights and opportunities

Next, Value Drivers developed by the company are added to the MFA. Three stakeholders are considered: the customer, the environment, and the company themselves. A value driver is linked to a process to indicate what the added value is for that particular stakeholder. Each block is briefly explained to understand the added value of the value drivers.

Customer Value Drivers

The premise of these value drivers for the customer is to identify opportunities that contribute to customer satisfaction. The symbols below show which opportunities the company has identified (figure 21). Examples include minimizing ownership costs by leasing your product, for example. Extended care options (e.g. upgrades) or the prevention of service interruptions can be used to improve the overall customer experience.

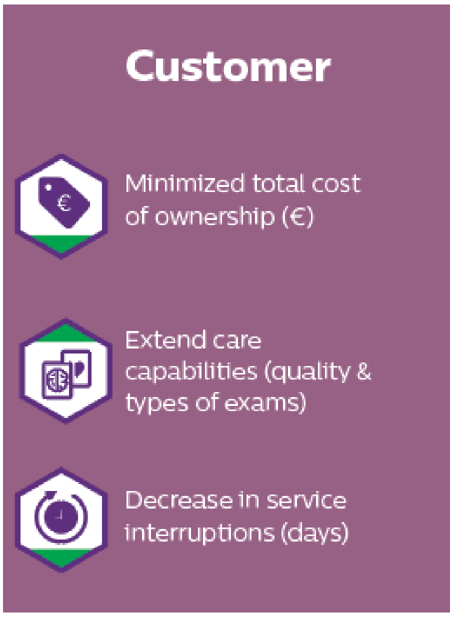


Figure 21: Customer value drivers identified by the company

Environmental Value Driver

The environmental value drivers look at how you can minimize the damage to the environment during the life cycle of your product.

Examples of this are optimising your product so that fewer parts are used in the production process and less waste is produced, or using less energy at the customer site and therefore reducing the total amount of CO2 during the use of your product (figure 22).

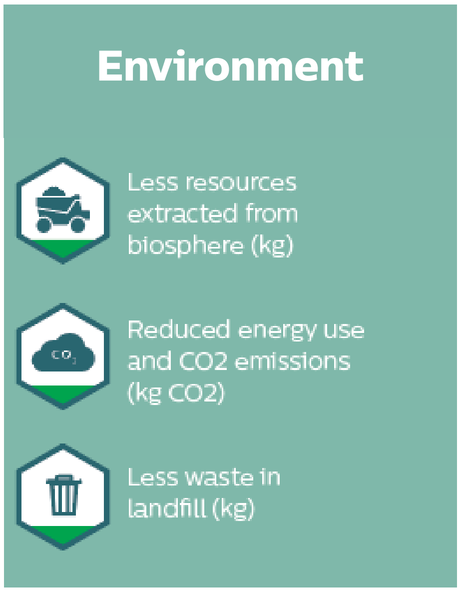


Figure 22: Environmental value drivers identified by the company

Customer Value Drivers

The companies value drivers revolve mainly around generating profit from circular revenues and reducing operational costs in, for example, the refurbishment site. Also, they want to use circular models to strive for higher customer retention (figure 23).

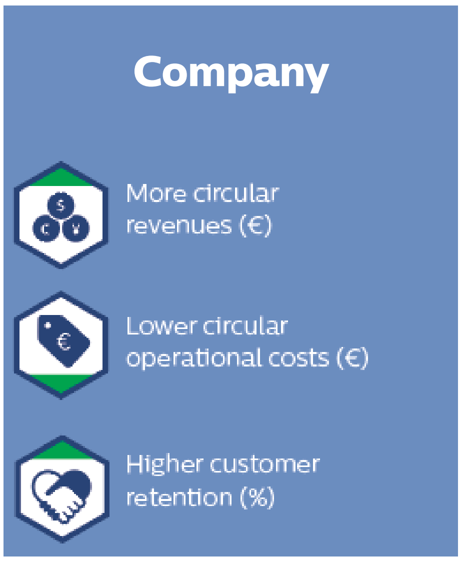
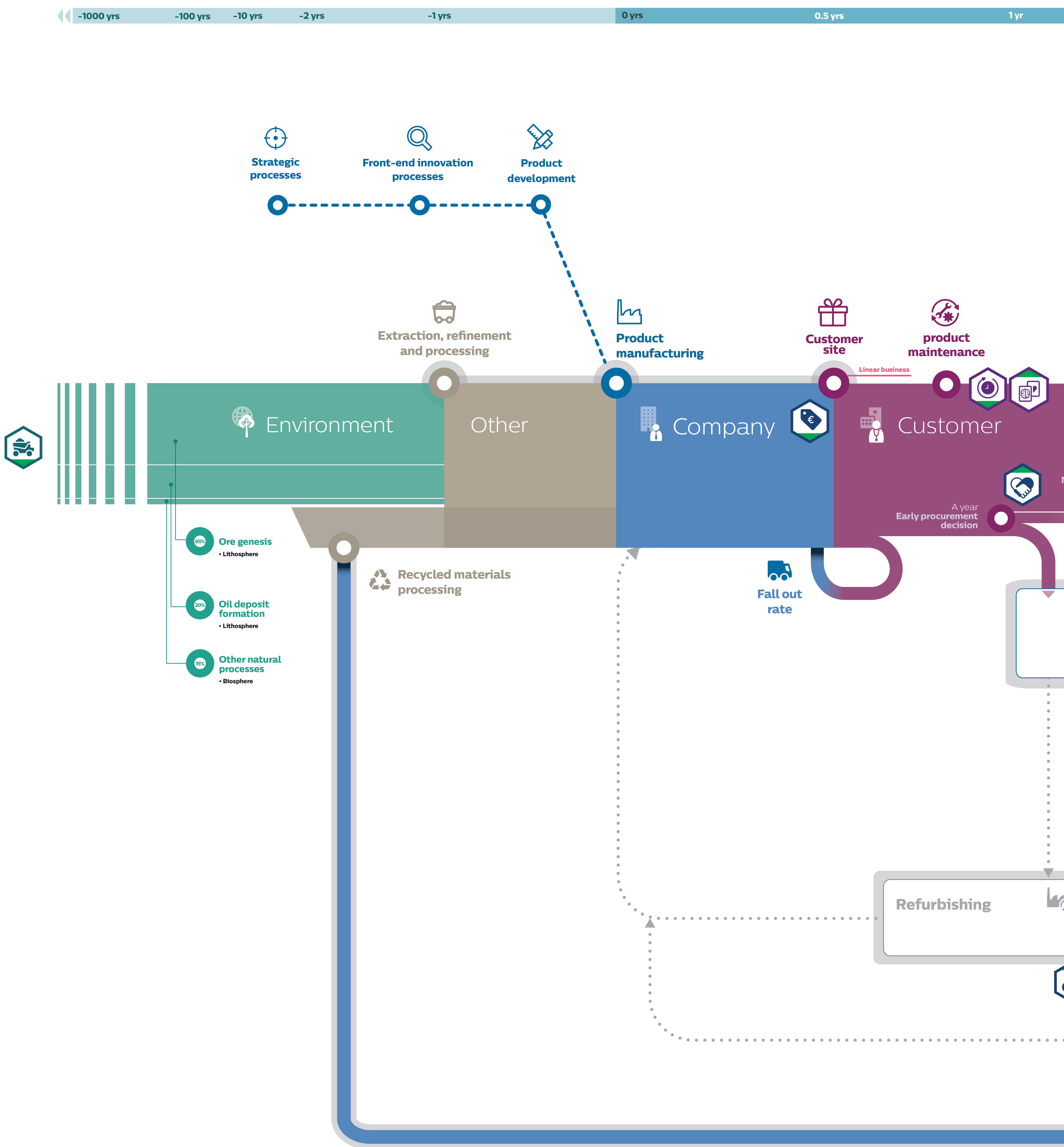
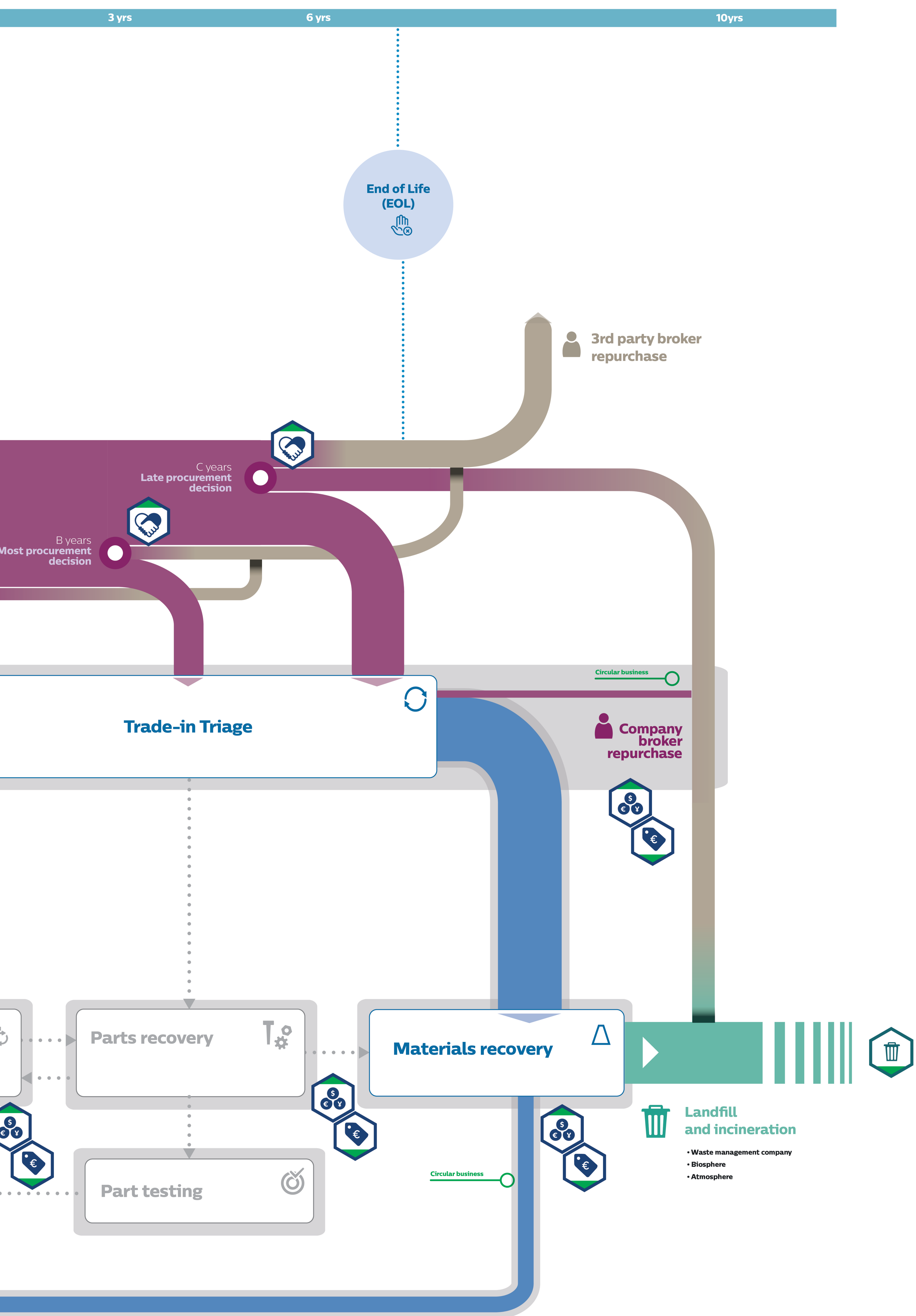


Figure 23: Environmental value drivers identified by the company

Product Lifecycle Flow

Material Flow Analysis Framework





Legend

Green represents **environmental processes**

Beige represents **third party processes**

Blue represents **Company processes**

Purple represents **customer processes**

10 Map in circles represent insights.

2 Map in triangles represent opportunities.

Hexagons represent value drivers i.e. the main drivers towards a circular economy.

Value drivers

Customer

- Minimized total cost of ownership (€)
- Extend care capabilities (quality & types of exams)
- Decrease in service interruptions (days)

Environment

- Less resources extracted from biosphere (kg)
- Reduced energy use and CO2 emissions (kg CO2)
- Less waste in landfill (kg)

Company

- More circular revenues (€)
- Lower circular operational costs (€)
- Higher customer retention (%)

3.1.4 Results

The MFA of product X gives a total overview of the first life cycle with all insights obtained from the interviews with the the company. With this overview, the first project outcome is finalized (**PO1**). The result section discusses why part harvesting and refurbishment are chosen as suitable revenue models for product X. Each circular model will be briefly discussed concerning the MFA to evaluate the feasibility of each design strategy. The focus of the study is to redesign product X therefore the circular hardware design strategies will be the focus in this paragraph (figure 24).

Recycled content

The current strategy ofproduct X is to recycle the content that is sent back through their trade-in program. This strategy has the least economic and environmental potential for the business. This is clearly illustrated on p.29. There is only 25% percent of the material that can be regenerated into the loop which is 9% of the total amount of material weight that is initially produced.

According to the interview, the development of product X is primarily attributed to the labor cost. All this value is lost if the business would proceed with this strategy in the future.

Part harvesting

The failure rate relating to a component within product X is high which is according to the failure mode data 62% of the cases. The component within product X is the most expensive part and is seen as the critical part for refurbishment. If this part is damaged the costs of repair will be too high to make refurbishment profitable for the business. However, the connector and cable do still contain valuable material for part harvesting. It would be an interesting design strategy to redesign the cable in such a way that is compatible with part harvesting and allows interchangeability between different products to lower circular operation costs and increase circular revenue for the business. The alternative is currently that this value is recycled where most of the value is lost and will not be reused in the development of new products.

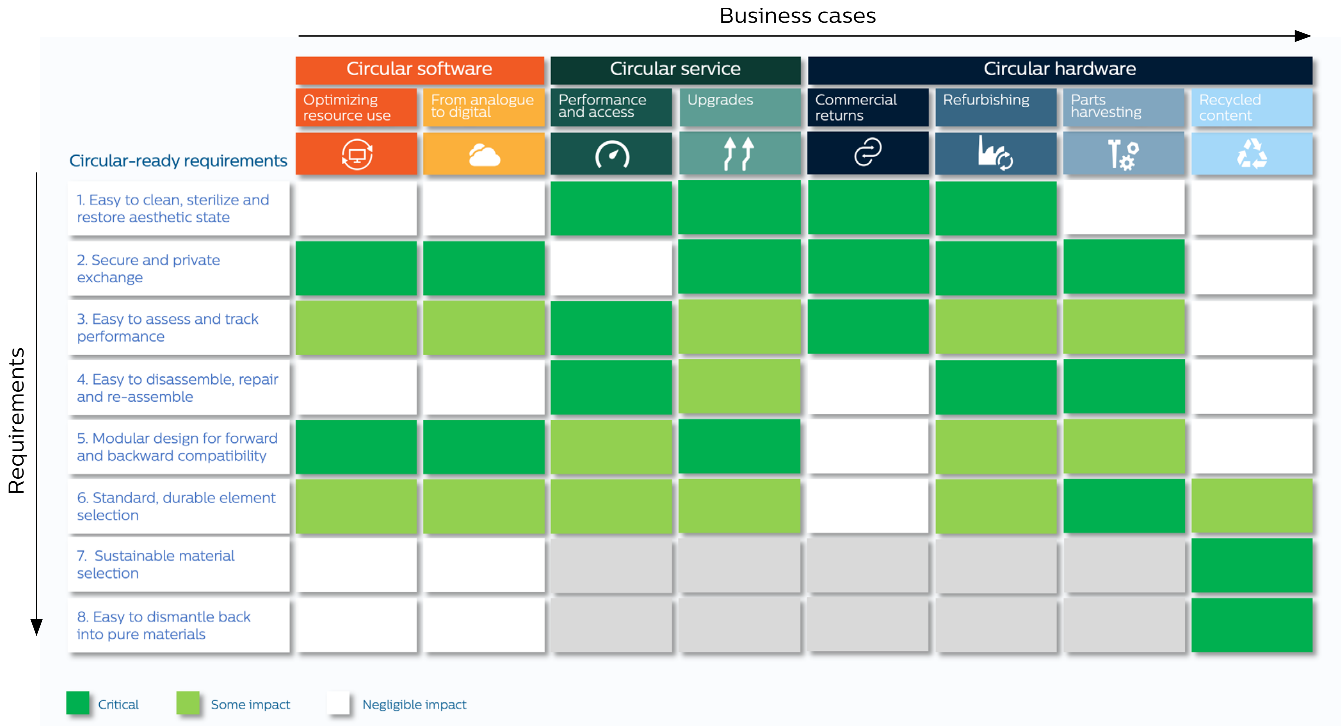


Figure 24: Circular design strategies

Refurbishment

The current refurbishment processes would throw away the entire cable with connector because it is considered to be one assembly bought by a third-party part supplier. A lot of valuable material and economic value is therefore not used up to their full potential. Secondly, the current disassembly process is time-consuming which results in high labor costs. A design challenge would be to reduce disassembly time to lower circular operation costs striving to reintroduce the refurbishment process for product x.

Commercial returns

Interviews with the company reveal that there is an upward trend in the number of products that are returned as faulty but turn out to be working properly in the end. According to the failure mode data, this concerns 7% of cases. This is a number that is sent to the second-hand market. An interesting design strategy that is not yet being considered is to stimulate repair in the market. This is the most profitable strategy in terms of circular revenue and a decrease in circular operational costs because you keep the product close to the market. Two major challenges are the strict restrictions on opening a product in the market. Until now, this has not been allowed due to safety requirements. As a result, only minimal repair operations can be performed. Secondly, the quantity of products being returned is currently so low that it is economically unfeasible to set up a location in the market specifically for product repair. Alternatives to this could be to look at repair collaborations with third parties to stimulate local repair. Another option is to reconsider the commercial return strategy utilizing repair centers that the company is placing in the market where there is a broader focus on not only product X repair.

Conclusion

In this chapter, an overview is given of the current situation of the close loop system for product X with a current strategy on recycling. The Material Flow reveals that a large part of the material ends up in material recovery and little remains in the closed-loop system. The challenge for repurposing product X is the variation in the condition of the product from the moment it is received at the trade-in. For example, a six-year-old product is no longer worth refurbishing while after one year it could be an interesting proposition for the the company.

The focus is therefore on being able to distinguish when product X is suitable for part harvesting and when it is interesting to refurbish it, and how you can use a redesign to encourage these processes to get as much economic and environmental value from the product. The decision was thereby to leave commercial returns out of the scope of this study. This is a different part of the process with stakeholders outside of the company. Also, the failure mode data that is devoted to this part is so small that preference is given to focusing on refurbishment and part harvesting to create the largest impact in terms of environmental gain and circular revenue (7% of the cases are considered for commercial returns). To gain insight into what competitors are doing in the field of closing the loop, a short analysis is done using Porter's five forces method. Chapter 4 will focus on defining which scenarios are relevant for part harvesting and repair and how to link specific circular requirements to them.

4. Release

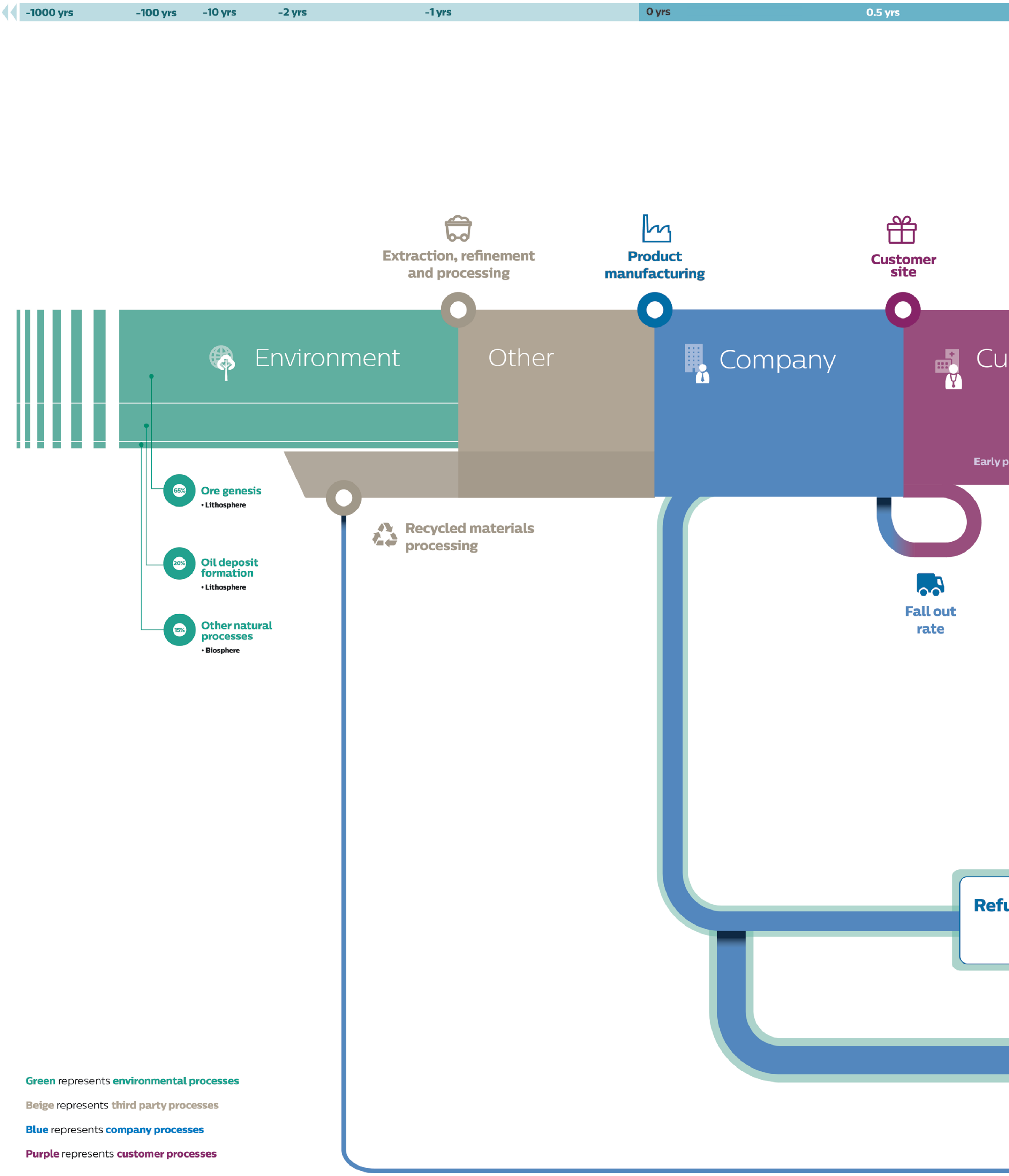
The redesign of product X

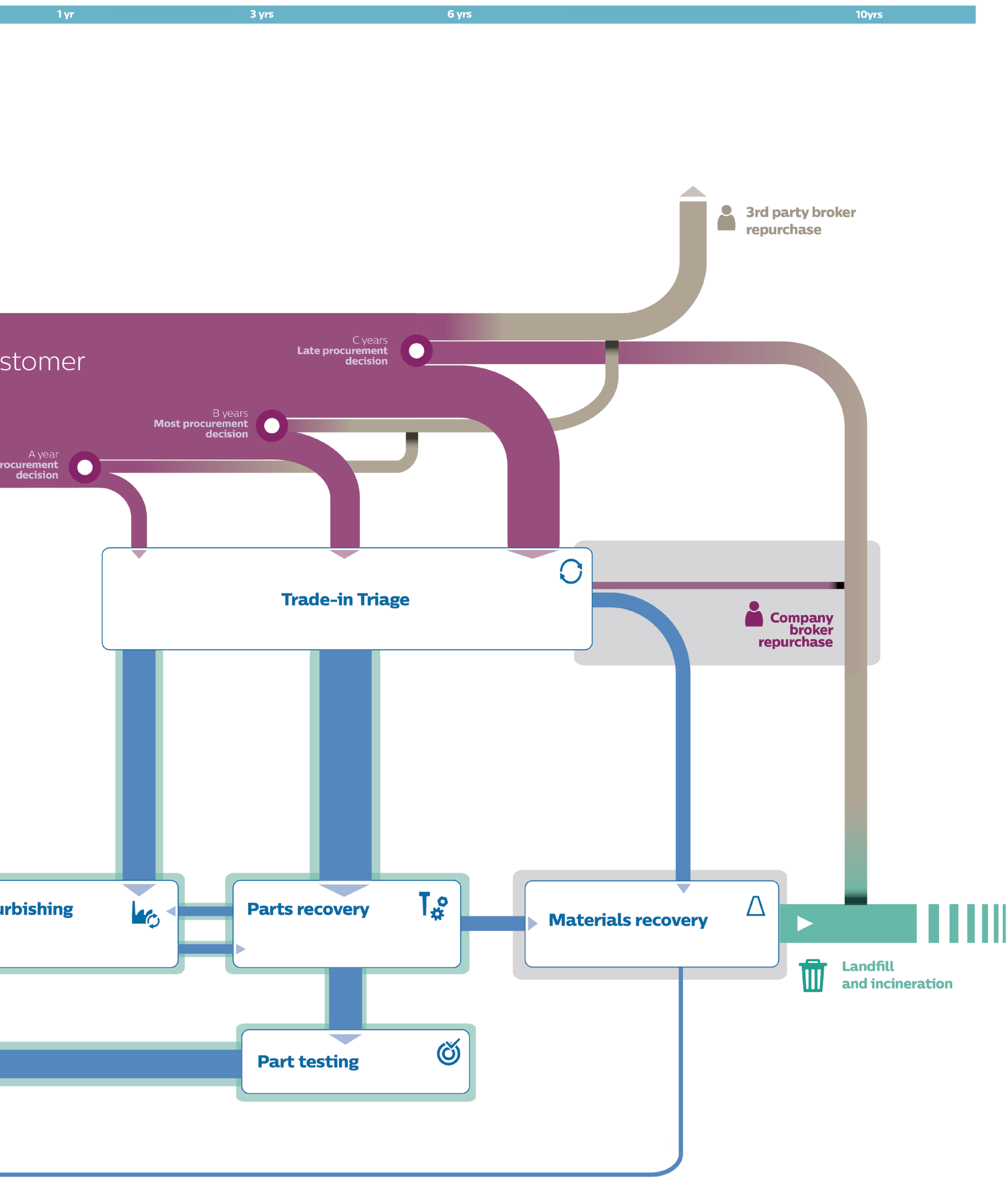
4.1 Material Flow Analysis - Redesign

This chapter concludes with a Material Flow Analysis of the redesign to be able to compare it with the version of the current design of product X. The new MFA visualizes the impact of the redesign and applying refurbishment and part harvesting as a strategy. The result is shown on page 33 & 34. The new Material Flow Analysis clearly illustrates that more value is created by refurbishment as more material streams are released into the production flow of the product in the first life cycle. The redesign of product X closes the loop more effectively by using multiple loops, therefore, reducing the total waste stream of product X by 39% in a single lifecycle and increasing the potential circular revenues by 11%.

Product Lifecycle Flow

Material Flow Analysis Flow Framework - redesign




1 yr
3 yrs
6 yrs
10yrs
3rd party broker repurchase
stomer
C years
Late procurement decision
B years
Most procurement decision
A year
rocurement decision
Trade-in Triage
Company broker repurchase
urbishing
Parts recovery
Materials recovery
Landfill and incineration
Part testing

5. Practical project outcomes

5.1 Introduction

This chapter discusses two project outcomes that are applicable for the I&D department to further develop the Material Flow Analysis tool and to introduce a new set of Circular Ready Requirement that could be implemented in the development of new products. Each of the outcomes will be discussed concerning the implementation procedure and the further development of both outcomes.

5.2 Circular Ready Requirements for product X

The redesign of the Product X is a specific example that demonstrates what the potential benefit would be for the business in terms of circuclar revenue and material savings. The product is eventually based on the following requirements;

Sub Requirements

1. The product architecture must facilitate an optimized repair sequence that reduces the total circular operational cost to stimulate refurbishment.

2. The product must contain standard and durable parts that can be reused on different models to stimulate product modularity and spare part stock formation.

3. The product must facilitate forward and backward compatibility by replacing permanent connections with reusable connectors to stimulate part harvesting.

4. The product must facilitate the aesthetic restoration of individual components to stimulate refurbishment and part harvesting.

To create a larger impact for the business it will be important to apply the Circular Ready Requirements to the entire company. Each of the sub requirement should be quantified to the specific needs of the product type to meet the following main requirement.

Main Requirement

The product must be compatible with the refurbishment process which focuses on keeping the shortened life cost below 70%.

It should be the endeavor of the company to ensure this main requirement for the product is met to reduce the total amount of waste and contribute to the circular economy objectives of 2025.

5.3 Material Flow Analysis for the I&D deparment

The Material Flow Analysis of the Product X started as a tool to find specific opportunities for the company but appeared to have much more potential than only providing an overview with insights and opportunities. The Material Flow Analysis has been used in this study to compare a redesign with the current design to reveal the added value of the design adaptations that are reflected in the MFA. It has also provided a guide to set up the circular business case and estimates the potential circular revenue. This paragraph explains how the tool can be used up to its full potential two levels can distinguish the amount of detail that can be implemented in the MFA;

- Basic Material Flow Analysis
- Advanced Material Flow Analysis

It is necessary to invest in software that can easily visualize the data before the MFA tool can be applied on a broader scale (e.g. e!Sankey). The methodology described in the study is currently too manual and ineffective for the everyday designer. Also, clear agreements must be made with the third party about access to the data described on page 24 before the analysis is carried out.

Basic Material Flow Analysis

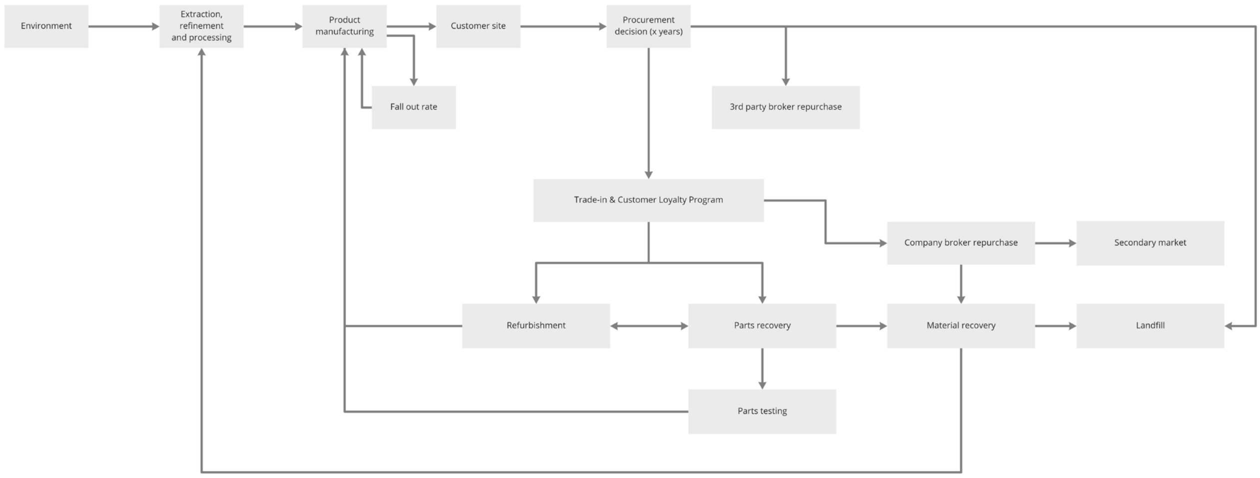
This type is most suitable for designers who want to make a visualization of the current MFA of a product in a relatively short time. The framework from page 24 can be used and the MFA can be visualized using the data and the software package. Here the value drivers can visually indicate where the opportunities lie within the MFA related to the specific stakeholder. This flow is primarily intended as a tool to discuss opportunities with stakeholders and providing insight into the current material flow of the product.

Advanced Material Flow Analysis

The second version is a variation on the basic MFA by adding economic aspects to the Life Cycle, zooming in on one or more processes that quantify the economic value behind certain material streams (e.g. Refurbishment and part harvesting process - Appendix S). This study has attempted to identify the economic value of multiple streams but requires additional research to validate if the calculation is executed correctly and reflects a truly realistic scenario. It is advisable to do this in collaboration with stakeholders that have a financial background who could support the designer in this.

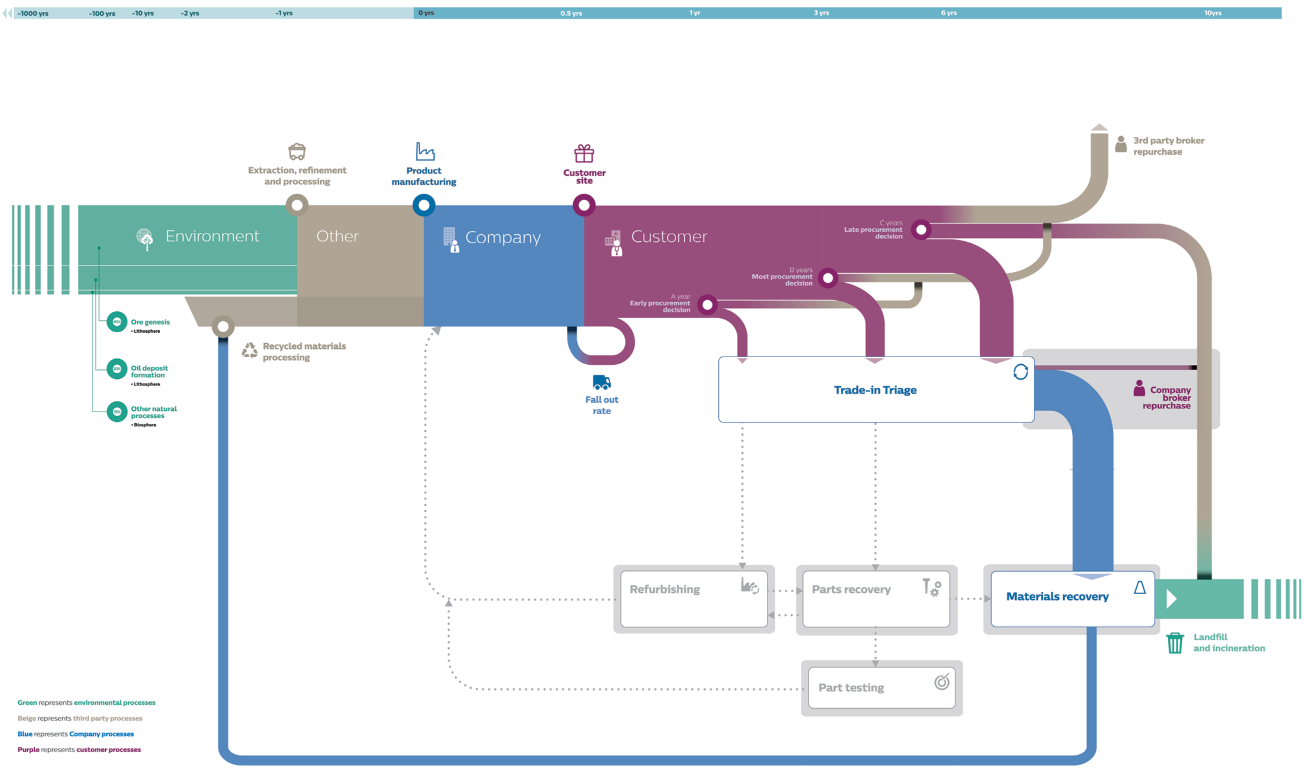
The next step is to apply the framework to multiple products within the company portfolio to see if the framework holds up. Each product has its unique characteristics that could lead to deviations from the framework.

In the end, the main goal of the tool is to use the MFA as a tool for every start of a new project to identify which strategies have been applied to the previous product concerning the system diagram and how it could be improved in the redesign of the product (fig 3-p.9). Besides, it should create awareness among company employees to see where the current portfolio is lacking in terms of circular objectives set for 2025.



Lifecycle Experience Flow

Material Flow Analysis Framework



6. Closing the loop

A final reflection

This final conclusion reflects on the approach of the Circular Design Guide of Ellen MacArthur and IDEO that has been used as a guiding thread throughout this project. Additionally, It discusses personal insights that have been gathered during this study that will are considered vital to adapt to a circular economy model for the company.

The Circular Design Guide

The four steps of understanding the user and system, defining the challenge, develop a concept, and building a narrative have helped me to plan the project in a specific timeframe and keep track of the panning. At first, the approach worked like a slow gateway process but eventually appeared to be much more dynamic than I had anticipated by switching between steps or go through the entire cycle multiple times in a short period. The hardest part was to define the design challenges because product X had so many exceptions for the reason why it would or would not be refurbished which made it difficult to conclude. An employee from the company that has helped a lot during the process of defining this challenge would send me a link to the James Bond movie 'Never Say Never Again' when I wanted to draw a specific conclusion for this study. It is a funny anecdote that reflects on the complexity of the topic.

The guide overall was useful on a high level but did not help me to achieve proficiency within the design process. This could only be achieved by interviewing stakeholders to understand the total picture of the products ecosystem.

Future repair legislations for professional medical equipment

The right to repair a is topic that is gaining momentum on a global scale. The future products of the company must anticipate these legislations before they are imposed on them. The focus in the past has been to design professional medical equipment that lasts and focus on quality and durability. It should be a point of discussion if professional medical equipment cannot be designed for durability while anticipating product repair through modular configurations for example. Safety has always been a challenge for these cases. This study has explored ways to facilitate repair while striving for medical safe products. It will increase the complexity of the product and the entire eco-system around it, but necessary for the transition to happen.

Ciruclar awareness among stakeholders

Circular economy objectives can only be achieved when people understand the importance of these objectives and incorporated it into their current way of working. Creating circular awareness within companies is important to explain the added value of a circular economy and how they can contribute to this goal on a personal level. Group sustainability is exploring ways to facilitate structural corporate change through organizing circular trainings and developing tools that help employees to contribute to the circular economy. This is a slow process, but will eventually be necessary to be able to switch to a fully circular economy within a company.

Quantifying the Circular Ready Requirements

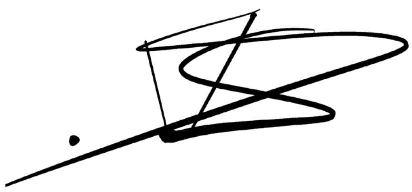
This study has investigated methods to quantify the circular economy objectives in addition to redesigning product X. The first step within Omp has been established where requirements for circular product design are set. The next step will be to quantify these requirements. The quantification of these requirements will facilitate measurable results to ensure that circularity does not remain a general concept, but will become a measurable standard within the industry.

The future of circular product design

Product designers play an important role in the transition towards a circular economy. It takes a lot of imagination to create a new eco-system as described in this study in a medical environment where everything is bounded. I started this project as a student who was interested in the complexity behind the circular product design and assumed that an individual like me could make a difference. It turned out that the individual is not a very significant factor in a large company. Ultimately, it is the power of connecting different groups within the organization that has helped me as a designer to achieve the goals that I had set at the start of the project. This allowed me to comprehend the complexity of the circular economy. I also realize that there is still an incredible lot to learn in the field of circular design. Therefore I would like to further develop myself in this area of expertise striving for practical approaches to transition towards a circular economy. Although the self-developed definition now feels a bit vague reflecting on this process, I still think it is a strong aim as a designer to take with me into my future career. It is important to think big to be able to make small steps towards the transition towards of a circular economy.

Circular Design

"An eco-systemic approach of developing products and services that strive for a continuous lifecycle with no beginning, middle or end. The purpose is to prolong and regenerate material value in a closed system with limited resources."



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