Preparing For Tomorrow

Exploring design adaptations of a wheel loader for a circular business model

Master's Thesis within the *Industrial Design Engineering* and *Industrial Ecology* Programs

HAMPUS BERGSTRAND
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Department of Energy and Environment
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Chalmers Reproservice
Göteborg, Sweden 2017

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ABSTRACT

One suggested way of dealing with the ever-increasing demand for services and products from a continuously growing population is through circular economy. The concept of circular economy means, among other things, optimizing products´ use and useful life and making fewer products accessible for more users.

The purpose of this thesis project is to explore the potential of a *use and sustainability centred product development process*. The process is aiming to explore how a product system can be redesigned to become more resource efficient. To explore the potential of the process, it is applied on a case study. The targeted product is the Volvo wheel loader, L150H, presumptively involved in a functional sales business model, inspired by circular economy.

Since there seems to be no consensus about what the process should look like, the project first defines a suitable framework, based on the use(r) centred development process. The inclusion of ecodesign and a product life cycle perspective is used to emphasize the sustainability aspects.

Inspired by backcasting, a future sustainable scenario is developed and key areas for reaching the scenario are identified. Consumables, and more specifically, the main fuel filter is selected for the redesign phase. Requirements for a new solution are identified and solution paths are presented for reducing the environmental impact. An iterative design phase results in a remanufacturing concept, and the corresponding re-design of the fuel filter.

The new filter concept is designed to last the entire life of the machine through a robust design and by being remanufactured, instead of disposed, after each service. A conducted LCA shows that by using one filter over the expected machine life, instead of an estimated 40 filters, major material savings can be achieved. In addition, the assessment show that the concept also induces a reduction in global warming potential by almost 90 % over the life cycle.

The project result indicates that the use and sustainability centred product development process not only has the potential to generate a material resource efficient solution, but also, a solution which is sufficiently responding to the users' needs. Despite the promising result in this case, the process still requires further development, and to be tested on more cases before its potential can be verified in general terms.

Keywords: *EcoDesign, Circular economy, EcoDesign framework, Functional sales, Remanufacturing, Life Cycle Assessment (LCA), Design for environment, Backcasting, Design for circular business model, Sustainable design*

ACKNOWLEDGEMENTS

There are several people which we would like to thank for their contribution to this thesis. First of all, our academic supervisor from the department of environmental systems analysis at Chalmers University of Technology, Siri Willskytt, who has offered a lot of most appreciated support throughout the project. Secondly, we would also like to thank the research project Mistra REES, which initiated and made this thesis possible.

We would also like to send our warmest thanks to our industrial supervisors. Here in Gothenburg, from the advanced technology and research department at Volvo Group, environmental researcher Lisbeth Dahllöf. Lisbeth has supplied us with the best possible preconditions to carry out this project. Our warmest gratitude also goes to our second industrial supervisor, Peter Eriksson, technology planning manager at Volvo Construction Equipment in Eskilstuna; for the insights regarding the company and the technological advancements, and also, for his hospitality during our two visits in Eskilstuna.

Furthermore, we would like to direct gratitude to Helena Strömberg, director of the Industrial design engineering master's program at Chalmers University of Technology, for her most valuable support in the finishing stages of the project. We would also want to thank our committed examiner, Professor Anne-Marie Tillman, for the inspiration she shared, and for her most appreciated contribution to the finishing touches on the report. Next, our thanks go to environmental researcher, Mia Romare, at Volvo Group, for her support in conducting the final LCA.

Finally, we would like to kindly thank all interviewees for their much valuable contribution. Especially, the people at the service provider, who really enriched the project with very interesting and important insights to the user perspective.

Thank you!

Hampus Bergstrand *Cornelia Jönsson*

Gothenburg, January 2017

TABLE OF CONTENTS

1 INTRODUCTION

Humanity has only one Earth and it has limited resources. If resources are not used wisely, they will be more difficult to access in the future and the diversity of products we are used to have on the market will require more energy to maintain (Smuk L. 2015). One suggested way to tackle this problem is to decouple resource use from meeting the needs of the users by "*closing the loops*" and reuse materials, to reduce extraction. This is often called a circular economy.

An emerging area of interest today is what implications the design phase can have on the environmental impacts of a product. Today, the design phase only consumes about 15% of the economic resources during a products life, but the decisions made to the function and design determines the future environmental impact of the product (Tischner 2000). Despite that no clearly defined process has yet been explicitly defined to guide designers through pitfalls in the early stages of product development. However, general tools and new perspectives on design exist, most of them based on a life cycle perspective. Some of them are the eco strategy wheel (Brezet and van Hemel 1997, Okala 2012), design checklists and ecodesign (Brezet and van Hemel 1997, Tingström 2007). All of them offers new and useful perspectives on design for the environment, but none of them offers a well-defined development process.

Vezzoli et al. (2015) calls for more knowledge within the area of customer satisfaction in sustainable product service systems (SPSS) to understand more about the design factors that makes costumers likely to start, and continue to use SPSS. Moreover, if we are about to introduce new products and habits on the market, it is useful to start with the users. With them in the centre it is possible to understand the implications of a change, and design a product which encourage sustainable satisfaction of needs. Therefore, the process used as a foundation in this project was the use centred product development process which emphasizes the needs of the users and affirms the importance of these throughout the process. This report will describe how the challenge of fitting ecodesign tools in the use centred product development process was handled and how the process was tried on a real case. In the end of the project the new concept was evaluated with life cycle assessment to assess the potential in the process, the methodology used and the product concept itself.

1.1 PURPOSE

The purpose of this master thesis is to explore the potential behind the suggested use and sustainability centred product development process when redesigning an existing product. The potential is decided based on obtained product improvements, in terms of user benefits and environmental impact reduction, assessed from a life cycle perspective.

1.2 AIM

The project aims to apply the use and sustainability centred product development process on a given product system, through a case study. In the case study, an appropriate component, or system of components, will be selected for redesign. The redesign will be focused on improvements which promotes user and environmental benefits. In addition, the aim is to evaluate the product concept with life cycle assessment, to verify the improvements.

1.3 DESIGN BRIEF

The case, on which the process could be tested was defined as follows: *"Explore design adaptations of the wheel loader, L150, for a circular business model and assess the change in environmental impact related to the design adaptions, with a life cycle assessment".* The L150 was chosen since it had been part of a life cycle assessment study before and some of that work was believed to have value in this project.

The timeframe for the project was 20 weeks and two master students comprised the project group. The deliverables were an illustrated concept description and two reports; the complete master thesis, describing the entire project and a complementary report describing the conducted life cycle assessment.

The only predefined condition for the circular business model was that the wheel loader should partake in a functional sales business model. However, the intended outcome of the circular economy business model from an environmental perspective was to lower resource consumption of any resource except fuel[1]. Thus, the focus for this project has been in the pillar of environmental sustainability rather than economic or social. The concept sustainability will represent environmental sustainability throughout the report.

The case was given, and made possible, by two parts: Mistra REES and Volvo Group. Mistra REES (Resource-Efficient and Effective Solutions) is a 4-year program run by a consortium of Swedish companies, universities and social actors with the vision to hasten the transition towards circular economy. The program aims to make a comprehensive study of circular economy to create a knowledge base that can be useful when resource efficient and circular solutions are being developed (MistraREES 2015). This thesis plays a part of the Mistra REES program and will contribute with knowledge about how the environmental impact is affected when a studied product is designed to fit in a function sales business model. At the end of the program the Mistra REES group is hoping to have created an information exchange between industry and academia; feed relevant knowledge into the process of designing for resource efficient business models and understand more about in which sectors the gain from a transition is bigger, for the company and the environment.

Volvo Group, with the divisions: Buses, Trucks, PENTA and Construction Equipment, is one of the industrial partners in the Mistra REES project. This thesis project was carried out in collaboration with Volvo Construction Equipment (Volvo CE or VCE) located in Eskilstuna, Sweden. Volvo CE is developing off-road machinery, which includes everything from dumper trucks and wheel loaders to heavy road work equipment. Perhaps the most versatile of the products in the Volvo CE portfolio are their different wheel loaders. The design work at Volvo CE is guided by the corporate core values: Safety, Environmental sustainability and Equipment quality (Volvo 2015).

1.4 REPORT STRUCTURE

The thesis starts with an introduction (Chapter 1), including a background to the project, the purpose and aim, followed by the definition of the project brief. The theoretical framework is presented in Chapter 2 and 3; where the first chapter introduces *circular economy* and the later presents the *development framework*, which will then be utilized in the case study. The case study, which is constituting the main body of the thesis is presented in Chapter 4 through to 9. The case study contains the overall *Process* (Chapter 4), and three stages: *Prestudy* (Chapter 5), *Concept development* (Chapter 6-8) and *Evaluation* (Chapter 9). The main body of the thesis, the case study, is then followed up by a

[1] A lot of the company's environmental work so far has been mitigation of emissions from fuel and this project was a way to focus on new areas.

discussion (Chapter 10); starting on a lower level, discussing the results and implementation and to be followed up with a meta-level discussion about the process and the project in the bigger picture. Finally, Chapter 11 presents the project conclusions, in relation to the aim.

Thereafter, the references are accounted for and complementary material is appended in the end of the report in APPENDIX amongst which the report over the conducted life cycle assessment is found.

2 AN INTRODUCTION TO CIRCULAR ECONOMY

As was mentioned in the introduction, circular economy is the suggested way of closing the flows of materials promoted by Ellen MacArthur foundation (Ellen MacArthur Foundation 2015). The foundation describes how the society of today is involved in a linear economy where goods are bought, used and disposed. Typically, purchasing decisions spring from different sources including new or altered needs, new models being released, a worn or broken product, or simply a hunger for a new item. The replaced products often end up in quite non-constructive end-of-life processes, such as landfills or in incineration. Ellen MacArthur foundation points out that nothing is disposed in nature; what is considered waste by one species is valuable matter for another. This is the idea the chemist Michael Braungart and the architect Bill McDonough used when they developed the concept cradle to cradle (C2C). C2C utilizes the same idea, but transfer it to materials in industrial processes which they argue, should be looked upon as nutrients, either biological or technical. The fundamental rules governing their idea are that: *waste equals food*, *processes should be powered with renewable energy* and *human and natural systems should be respected by celebrating diversity*. How the concept of cradle to cradle is used in circular economy principles is developed in Ellen MacArthur Foundation (2015) and illustrated in Figure 1, the system diagram of circular economy.

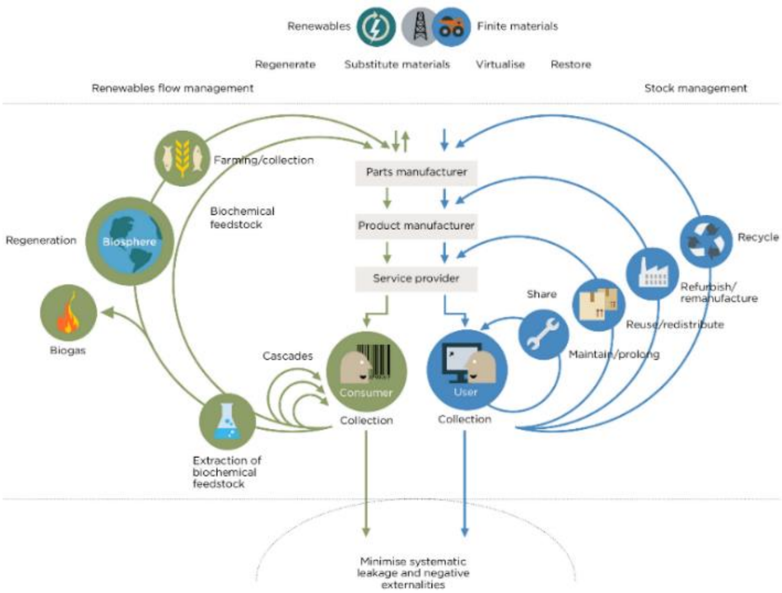

Figure 1: Circular economy system diagram, showing examples of how products can be used longer by actions in the use phase by both user and producer. (EllenMacArthurFoundation 2015)

It is crucial in circular economy that materials circulate, in one biological and one technical circle, to become new products. Another principle in circular economy is that resource yields should be optimized, meaning that the use of extracted materials should be maximized before recycling. Figure 1, the circular economy system diagram, suggests ways of doing so. A rule of thumb in the system diagram is that products should be used in the inner circles for as long as possible, to reduce the amount of resources required per use (Ellen MacArthur Foundation 2015). Since the product of concern in this project was mainly consisting of technical materials, principles on the right side of the diagram were applied.

The linear business model has made our society expert at delivering products and services to customers. Supply chains are in place and materials are efficiently shipped, one way, from extraction to the user and further to disposed. In a circular economy, *reversed cycles* are suggested; the flow of materials needs to be expanded with a take back system simultaneously with that we start looking at disposed products as raw material for new products. However, more knowledge is needed on how to get the materials back into the factories in the most useful and efficient way (Ellen MacArthur Foundation 2015).

A product, machine or component often contains multiple parts and even if the life is over for the entity the different parts might still have lots of potential left. One suggested way not to lose this potential is to reuse parts, hence saving material and energy. Another way is to repurpose parts, which means that a component changes contexts after its first use and serve another, or similar, purpose in another context. Ideally, the entire functionality of the product is still utilized in the new context; otherwise there is a risk that the product's value and material is not fully utilized. If no other option is available, or if there is no way the product can any longer meet the user needs, the product should be recycled. Recycling includes the in going materials being collected, treated and redistributed to manufactures of new products. According to the principles of circular economy, the recycling process must strive to maintain as much of the material value as possible; i.e. a minimum amount of resources should be required to retain the same material value as the initial product (Ellen MacArthur Foundation 2015, Bocken et al. 2016).

There are multiple ways for users and producers to keep or bring back the initial value of products. As mentioned earlier many of them are included in the circular economy diagram (Figure 1). One way for companies to do so, is through remanufacturing. Remanufacturing is a process where products are taken back from the market by the company instead of being disposed, and through a series of processes, the products are brought back to as-good-as new performance and sold again. The processes needed may involve cleaning, repairing, upgrading and exchange of worn out parts. The companies sometimes give the same warranty on remanufactured products as for new products (Sundin 2004). Remanufacturing is thought to be more environmentally friendly than new production, since up to 85 % of the weight of remanufactured products comes from used components and the process only require 20-50 % of the energy compared to conventional production. In addition, 20-80 % of costs can be saved (Sundin 2011).

Another opportunity for a company to utilize the materials better in their products is by providing their products as services in product service systems (PSS). A (PSS) is described by Baines et al. (2007) as: *"... an integrated product and service offering that delivers value in use. A PSS offers the opportunity to decouple economic success from material consumption and hence reduce the environmental impact of economic activity."* A PSS can range from selling access to the machine all the way to only sell the results of the use of the product (Tukker 2015). According to Baines et al. (2007) and Tukker (2015), the environmental benefit with the concept *product service system* is that a PSS, per definition, offers the opportunity to decouple economic success from material consumption. In addition, PSS facilitate product longevity activities and waste management.

The adaption of the wheel loader to circular economy in this project has been built around the concept of functional sales; which, in this project is defined as the company selling operable machine hours. Functional sales is based in theory about use-oriented PSS (Baines et al. 2007, Tukker 2015), since it focuses on selling the use of the product. The principle is tied to circular economy primarily in how it is aiming to reduce resource use. In the wheel loader case, the idea with functional sales is that the company receive payment per hour of operation, fuel and operator excluded. The company is responsible for keeping the machine in operable condition, including repairs, service and maintenance etc. Ideally, this has two positive implications for the environment. First, the company wants to maximize the income from one machine by keeping it on the market with high hours of operation per year, as long as possible (product utilization and durability). And since maintenance, which today is revenue, will turn into a cost for the company, the second implication would be optimized maintenance schemes; fewer occasions and less resource use, to maximize profit. However, a functional sales model is not per definition more sustainable than a linear business model (Tukker 2015). Therefore, this project has focused on design for closing loops and design for less material use in addition to the functional sales model.

3 A USE AND SUSTAINABILITY CENTRED PRODUCT DEVELOPMENT PROCESS

As stated in the introduction, the purpose of this project is: ”*to explore the potential behind a use and sustainability centred product development process*” and as mentioned in the introduction; no univocal such process seems to exist today. Instead there is a wide range of design for environment tools available, but the task of sorting out which of them are suitable for a certain problem formulation, is often perceived as difficult (Knight and Jenkins 2009). This fact states a lack of *working strategies* or defined *development processes* when designing for the environment. Therefore, a process was compiled which could give recommendations about the way forward in every step of the product development process. The user centred product development process described in seven steps by (Bligård 2015, Wallgren 2016) is used as the foundation for the framework. This process is selected since it promotes a holistic view and focus on the use and function rather than the tangible product itself; which according to Tingström (2007) are essential aspects also for sustainability centred product design. The seven steps in the process are:

1. Identification of target group and available users within the group who can contribute with valuable information.
2. Collect information.
3. Analyse information to reach understanding about the user's situation and needs.
4. Ideation with the goal to meet user needs through a new product, system or service design.
5. Requirements formulation as a concurrent process together with ideation to remember the user's situation. The requirements are gonging to transform throughout the development process and translate from user quotes to technical requirements that describe the solution.
6. Concept selection where the concept which best meet user needs is chosen.
7. Validation of concept. Where the concept is tested against user needs and requirements.

In each of the seven steps, the environmental sustainability aspect is acknowledged by emphasizing the concept *of ecodesign,* to form the use and sustainability centred process. Ecodesign *is described by* NRC (2003) as a strategy to systematically incorporate environmental consideration in the process of product and process design. However, since the concept has been developed, expanded and used for different applications it is now rather seen as a "way of thinking and analysing" rather than "…a specific method or tool" (Lindahl 2006).

As discussed in Chapter 2, circular economy suggests multiple ways of closing material loops and finding ways to more sustainable consumption. In order to ensure that the result will lead to resource savings, as stipulated by the project scope, the use and sustainability centred product development process is going to be the core of the project and, while working with the process, resource efficiency will to be the guiding strategy. The process is split up in three parts: prestudy, product development and evaluation where the prestudy is aiming to narrow down a problem statement to something manageable for the product development process to work with. The product development process aims to create a product with less environmental impact and the evaluation aims to assess if less impact was achieved.

3.1 PRESTUDY

To guide the prestudy towards not only a manageable product to design, but also a product with potentials in resource savings has Holmberg´s (1998) way of somewhat defining the problems, been helpful. He states that: *"In order for a society to be sustainable, nature's functions and diversity must not be to systematically subjected to…*

> *… increasing concentrations of substances extracted from the earth's crust.*
>
> *…increasing concentrations of substances produced by society."*

With those two recommendations as guides, the choice of methods for narrowing the project scope is helped to be tightly tied to material savings. However, to increase the efficiency of any change, Holmberg stresses the importance of being aware about on which level of the system a change is most efficiently implemented from a resource saving point of view. He suggests seven levels where a substitution can be done, here presented in increasing order of efficiency: the raw material level, the material level, the component level, the sub-system level, the system level, the strategic level or the value level (Holmberg 1998). Changes on all levels can be positive, although, more radical changes occur higher up in the system; hence, are potentially being more beneficial for the environment.

A system focus is also suggested by (Bligård 2015) in his description of the product development process. His focus is not primary environmental sustainability, but he concludes that a *system focus* during the development work facilitates the development of relevant requirements and criteria. It is chosen here to expand his view to include environmental sustainability and the importance of a system perspective is valid also in ecodesign to address environmental issues concerning the product. Such an expansion of the concept is promoted by several authors (Holmberg 1998, Tingström 2007, Ellen MacArthur Foundation 2015, Bocken et al. 2016).

By defining the system, the product is part of, both on a high level and on a zoomed in level, it can be ensured that most aspects and needs of the system are acknowledged and taken into account. However, if the system the product will be part of does not yet exist, a system model might be challenging to develop, which could have the consequences that not the right problems are addressed. The suggested way for the use and sustainability centred product development process to find relevant problem formulations is to use the backcasting methodology outlined by Robinson (1982). It should preferably start by describing the current situation through a system model; this will provide useful knowledge about existing products and systems, the system model should then function as the *baseline scenario* needed in the first step of the backcasting process. Secondly, a *future scenario* should be visualized, where the most desired future context and situation for the (future) product are described. The fundamental idea of backcasting, also used here, is to then work out ways to achieve the desired situation by starting from the future scenario and work backwards to connect the two scenarios; this reverse approach is used in order not to be locked-in to already existing solutions and systems. In the use and sustainability centred product development process the connections between the two scenarios could be considered key areas for development work. If the topic of each key area is compared to what resources and competences are available for a certain project, a suitable problem formulation or design opportunity can be identified.

A simplified system analysis described in Bligård (2015) can be used for developing the system model needed in the first step of the backcasting process. Information can be obtained by literature scanning, focusing on the overall strategies, structures and goals of the company which the product is produced by. The system model could be further developed with observation studies, interviews, literature studies and workshops. To gain more information about conducted environmental work within the company and the current strategy, the RDAP-scale, by Clarkson (1995), could be used. Depending on the nature of the action, the RDAP-scale sorts sustainability activities according to the categories: reactive, defensive, accommodative and pro-active. It is recommended to also use any existing life cycle assessments of existing products of similar characteristics to address the life cycle view and support the environmental problem identification in this stage. The end goal of developing a system model is thereby threefold: using it in the earlier described backcasting process, to help highlight connections and try to identify the seven levels where substitution could be done and define which level is most impactful and feasible for the actual project.

When visualizing the future situation, an environmental objective should be decided to help guide the development in the desirable direction. Ideally, the objective is outlined with support in theory and is aiming guide the development of the scenario and to work as a mindset throughout the project. When the future situation is visualized as a scenario, it fulfils two purposes; first, to be part of the backcasting process and secondly to be central in the product development process. The scenario will be the expected reality for which the product is going to be designed; hence, it must be well enough defined to serve the purpose as a system description. Such description will include a reasonable estimation of the context, user(s), task(s) and product(s); although, since part of the objective is to redesign some of these parameters, the scenario must be developed concurrently with the improvements as new information arise, and design parameters are set. The idea is supported by Holt (1989) and Carroll (2000), who both agrees on that a scenario helps a design team in their process. Erickson (1995), Carroll (2000) and BØDKER (2000) also state that a scenario facilitates discussions within the team, but also in the communication with stakeholders.

The developed environmental objective is suggested to be extended beyond the prestudy. Aspects learned could be formulated as guiding criteria for the decision of a suitable problem formulation. Furthermore, the criteria could also be used in the following product development process, to make sure the objective is acknowledged in every step of the product development.

3.2 PRODUCT DEVELOPMENT

As emphasized in previous sections; an important part in understanding the user needs is to examine the system. However, as the system only exists as a future scenario, much of the system description is based on the current situation; users, tasks, contexts and products; although, some changes in regards to these system components in a future circular scenario was done in the backcasting process.

In accordance with the statements from Gould (1995), Margolin (1997) and Preece (2002): the developers need to know the target group they are designing for if the developed product is going to be successful. The use and sustainability centred product development process has added a requirement for successful products; low environmental impact. The target group for this success could be described as *future users*[2] since they do not yet exist. However, from revisiting the user centred product development process in the beginning of the chapter, it is emphasized in step number 1 that users within the important target groups, who can contribute with information should be picked out. To contribute information is for obvious reasons impossible for the future users. However, they need to be taken into consideration, and the resource management act (New Zealand Parliament 1991) offers a version of what could function as their requirement on how a product should be produced by saying that it should be done in a way so it is: "*sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations*" (Part 2, purpose and principles, RMA). Since no one from the use group future generations can be interviewed for obvious reasons, instead they should be treated as silent stakeholders (Sharma and Starik 2004). The same goes for every part of the ecosystem that cannot communicate in a way sufficient for a product development process. Their stakes still must be accounted for as discussed by the same authors. A sustainability centred product development process should have the environment and future generations as part of the core, since these will have to take the future consequences of material extraction and dispose. The strategy when moving

[2] If the whole product life cycle is considered the future generation will be a user of the recycled materials in the product as well as the quarry where the metal is extracted from.

forward in this phase could be to pay attention to resource efficient solutions and be aware of all users and stakeholders in every part of the product life cycle. A concrete way of achieving this can be to use any kind of environmental impact screening method or tool.

Including the idea of resource efficiency in the product development process could probably be done in more than one way. For this process a product life cycle perspective is suggested for all stages of the use and sustainability centred product development process. The definition of the product´s life cycle by Sundin (2004), includes: raw material extraction, production, use and end of life can be used for the development process. Also in cases where the most resource efficient solutions can be obtained through a *product service system*, the life cycle perspective is a valuable contribution. Sundin (2004) continues by saying: *"Having a life-cycle perspective on combined services and goods means that lifecycle considerations must be considered for both physical products used in the PSS and the services used during and between the contract times".* This stresses the importance of that all impact, from every part of the product's life cycle, should be accounted for, in every stage of the product development process described in this chapter.

A life cycle perspective throughout the processes could make the way of analyzing and ideating slightly different in the use and sustainability centred product development process compared to the traditional process. The extended user group and the extended view on the product life cycle results in product requirements not only based on use and functionality, but are also extended to include manufacturing (process and material), distribution and recycling. To assist in the altered analysis and ideation processes, the following tools are suggested to be used as a complement to the common user centred methods and tools, to ensure the development process arrive at a solution with less environmental impact.

ECO STRATEGY WHEEL AND ECODESIGN CHECKLIST
The ecodesign checklist and eco strategy wheel, introduced by Brezet and van Hemel (1997) are life cycle based tools. The checklist consists of a number of different questions to be answered by the designer, addressing the environmental impact from the product during its different life cycle stages; whereas the wheel suggests aspects and new perspectives for the product system to consider.

TEN GOLDEN RULES
The ten golden rules of ecodesign presented in Luttropp et al. (2006) can be used to ensure that environmental aspects are considered:

1. Don't use toxic substances and arrange closed loops for necessary but toxic ones.
2. Minimize energy and resource consumption in production and transport through HOUSEKEEPING
3. MINIMISE energy and resource consumption in the usage phase, especially for products with most significant environmental aspects in the usage phase.
4. Promote repair and upgrading, especially for SYSTEM dependent products.
5. Promote LONG LIFE, especially for products with most significant environmental aspects OUT of usage phase
6. Use structural features and high quality materials to minimize WEIGHT not interfering with necessary flexibility, impact strength or functional priorities
7. Use better materials, surface treatments or structural arrangements to PROTECT products for dirt, corrosion and wear
8. PREARRANGE upgrading, repair and recycling through access ability, labelling, modules, breaking points, manuals

9. Promote upgrading, repair and recycling by using few, SIMPLE, recycled, not blended materials and no alloys
10. Use as FEW joining elements as possible and use screws, adhesives, welding, snap fits, geometric locking etc. according to the life cycle scenario.

DESIGN FOR RECYCLING CHECKLIST

In addition, a recycling company has established a guide of design guidelines for design engineers, which are supposed to favour recyclability (Domini 2001). The principles suggested for this process are summarized as in the following list.

Design for recycling principles:

- Reduce the number of different types of materials
- Use materials for which recycling is possible, and for which there is a demand for the recycled material.
- Different materials must be separable, preferably through disassembly. Otherwise through material fragmentation and material separation.
- Mark parts with material type.

Together, the methods create an environmental foundation for the analysis and generation of ideas in the different stages of the development process. However, to make sure that the product lives up to the requirements, continuous evaluations should be carried out during the process (Johannesson, Persson et al. 2004, Bligård 2015, Wikberg Nilsson, Ericson et al. 2015). When an evaluation is made and potentials for improvements are identified, ideally, designers should take a step back in the process and look for alternative solutions; the process is iterative with continuous evaluations and design improvements. A suggested way for continuous evaluation in the use and sustainability centred product development process is evaluation against a set of criteria; similar to what was mentioned in the framework described by Bligård and mentioned previously, when defining the prestudy process.

3.3 EVALUATION AND VALIDATION

To make sure that the end result lives up to the requirements and to assess the environmental sustainability, the following tools and methods are suggested to emphasize the sustainability focus and complement the more commonly used products development evaluation methods.

RAPID ECO ASSESSMENT

The eco strategy wheel (Brezet and van Hemel 1997) could be utilized as a rapid eco assessment tool as a qualitative complement to the quantitative LCA. It has similar characteristic as a checklist and it is quicker, less comprehensive, and partly covers other aspects than an LCA. Thus, it can be utilized multiple times during the process and in general earlier than quantitative analysis. In addition, rapid eco assessment is suggested as a good way of evaluating a reference product to identify existing problems for the product development process to resolve.

LIFE CYCLE ASSESSMENT (LCA)

Life cycle assessment is a way to describe what resources a product uses and what pollutions it causes during its life cycle. By deciding on which processes are part of the product lifecycle, and by modelling all in and outflows over the system boundary, the environmental impact of a product can be quantified. Different LCA's can have different approaches and the focus is decided by the functional unit, which is directing what is included in the LCA. LCA is a very quantitative and ambitious tool and might be more suitable for the later stages of the product development process, when specific product attributes such as material is decided. Ideally, the LCA can be conducted concurrently with the later stages of the product development process to also provide new insights.

USE AND USER EVALUATION

To ensure that the use and user aspect of the product development process are sufficiently acknowledged, user tests should be carried out. Verifying sufficiency in this area is important for the use and sustainability centred development process primarily in regards to two aspects. First, a product which is easy and effective to use could provide better preconditions for utilization. Secondly, a truly useful product is likely to promote product longevity effects. A design process with a use perspective should evaluate the use to verify improvements and for this, the following methods can be utilized.

Concept user evaluation, as described in Wallgren (2016), is a test for evaluating an early stage concept or, in later stage, a product prototype. It can be done by letting the user have opinions about the design and perceived functionality of a concept or let the user try a prototype. A prototype can be tested on site or in a laboratory by letting the user solve tasks with help of the product representation. The test is usually observed and can be supported by a, more or less, structured interview.

CONCEPT DEVELOPMENT CASE STUDY, L150

4 THE DEVELOPMENT PROCESS

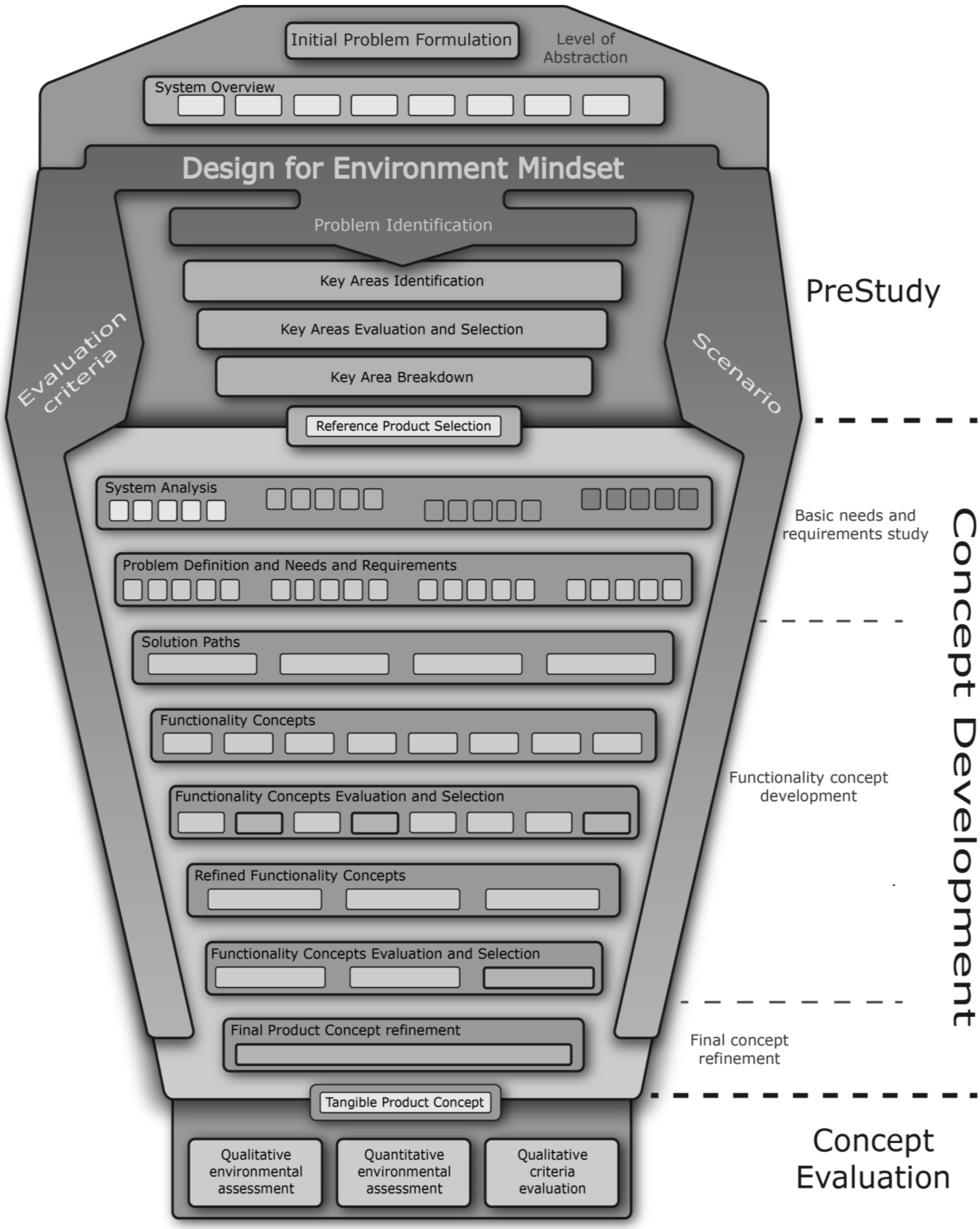

Figure 2: Illustration of what the use and sustainability centred process looked like when applied on the case L150. Each action and when it occurs is illustrated in the figure. It can also be seen how the evaluation criteria and the scenario helped narrowing the scope of the project.

Due to the limited scope and timeframe of the project, the product development process defined in the previous framework will not reach a *product* per definition, but rather a *product concept*; hence, the process is hereinafter referred to as the *concept development process.*

The product development case study is divided into three main processes described in Figure 2. A *prestudy*, aiming to gather knowledge and to narrow down the case to an appropriate reference, on which the use and sustainability centred design process could be applied. The outcome of the concept development, a tangible final concept, will then be evaluated in the *concept evaluation* stage, to assess the success of both the concepts and the process. As illustrated in Figure 2, the evaluation criteria and the scenario are utilized as tools for the design for environment mindset to force the level of abstraction towards the expected and predefined outcomes of the respective main processes. The individual main processes are described in the following paragraphs, which also refer to Figure 2.

4.1 PRESTUDY

Apart from supplying the project with a sufficient knowledge base, the goals of the initial prestudy were; first, to define a probable future scenario, including the business model and the system and then to identify potential problems in the current machine fleet. Also, the goal was to define a set of appropriate criteria for objective evaluation of key areas. The final goal of the research stage was to select a problem formulation related to a specific system of components, deemed appropriate for a product development process. The process used to arrive at the goal is described below.

4.1.1 SYSTEM

The prestudy started with a study of the company to learn more about the strategy, the sustainability goals and today's business model to create a baseline for the study. The study included scanning of Volvo Group documentation, conduction of interviews, and observations of the wheel loader and the system it is performing in. Within the Volvo documentation was the already conducted LCA for the wheel loader L150. It helped to point at which were the biggest challenges for the wheel loader in terms of environmental sustainability and materials. However, the focus of the LCA was different from the focus of this project and the LCA could be used less than what was first expected.

The interviews were carried out with respondents from different areas and on different levels of the company, with the primary focus on product development and sustainability engagements. The complete list of interviewees is supplied in Appendix I. To identify the nature of the conducted sustainability work, the RDAP scale (Hart 1995) was used to sort the identified sustainability actions into reactive, defensive, accommodative, and proactive actions. Focus was to understand the drives and obstacles for actively working with sustainability questions from the producing company's perspective and to briefly understand how the different company departments were connected, to create a good foundation to later, in the scenario, build the business model on. Interviews were carried out with the external service provider, to develop the understanding from the user's perspective.

The goals in the second step of the prestudy were to understand and get an overview of what is affecting the wheel loaders life; who owns and uses it, and in what context? For this, a system analysis as described in Bligård (2015) was used as foundation, but with a focus to identify and explain the parts of the system rather than understand how the parts interacted. The simplified system model also served as part of the baseline, or present scenario in the backcasting process. The information was primarily built on information provided in service, operations and recycling manuals etc. and from interviews.

4.1.2 Scenario

The product concept expected to come out of the concept development phase was required to be better for the environment and be part of a functional sales business model. To be able to design an appropriate solution for a future reality, a scenario was needed in which all the affecting factors from a functional sales model were included. The process for arriving at the scenario started with a brainstorming session where concepts of the future wheel loader product system were developed and concretized as various functionality concepts; including short product descriptions, accompanied with brief descriptions of the system it would perform in. The functionality concepts were placed on a timeline as an attempt to sort them by how far off into the future the realization of the concept could be expected. With concrete concepts for alternative functionality focused product systems, it was easier to decide on the aim of the case study in terms of compatibility with current technologies, concept readiness and other factors that together defined a reasonable time perspective. The timeline was used to communicate these aspects with the stakeholders, with the aim to agree on an appropriate level for the particular project. The scenario was used as the vision, or future scenario, in the backcasting process. When the work with outlining and concretizing the scenario continued three considerations guided the process:

- In order to benefit the company the most, a scenario that is not too far off in the future should be used as a base for the design process.
- The product concept should ideally be able to serve a purpose in today's context as well as in the future scenario.
- What is considered most valuable is a case study showing the potential of implementing a use and sustainability centred development process on a system with today's preconditions, rather than a utopic science fiction scenario, where everything is different.

The development of the scenario continued over the whole prestudy process, with new facts continuously refining the scenario definition, all the time guided by the environmental objective: reduce resource consumption and close loops. In the following concept development process, the scenario was concurrently evolved with the product design, since the scenario, and the product system, including user, use, product and context were shown to be highly dependent components.

4.1.3 Key areas

In a parallel process with the scenario development, interviews and literature studies were carried out to find out how different eco strategy wheel principles were used in the product development process in the company. The goal was to find areas where the environmental work could be developed. The results from the interviews were therefore compiled to areas with a Kawakita Jiro -analysis (KJ-analysis) and resulted in ten key areas. The key areas were identified in the analysis as important areas to address in a transition to a circular business model. The eco strategy principles aim to cover every change that can be made at all levels of Holmberg's (1998) levels of substitution. And since the interviews were based on the eco strategy principles, it resulted in that the key areas were addressed on different system levels.

4.1.4 Choice of component for development

To stay focused on what was important to consider in the project, a set of criteria was developed to help narrow the project (left side of figure 2), simultaneously with the scenario development and the identification of key areas. Some of the criteria followed naturally from the choice of business model, while others developed during the prestudy in dialogue with different stakeholders in the project. The stakeholders were allowed to communicate their prioritizing through a common weighting of the evaluation criteria. Ultimately, the criteria were used to decide about which key area to further develop. The decision was made through a weighted evaluation, similar to a concept selection method described in Wikberg Nilsson et al. (2015). Points were given to each key area, based on the estimated score for the respective evaluation criteria.

The key area which pointed out as having most potential, *repair and maintenance*, was analysed further; the interview results from the area were organized and expressed as a number of problems. As a complement to the interviews, an LCA, conducted on a similar wheel loader was consulted. Information about what activities had an impact in this key area was considered. The LCA offered a life cycle perspective in the aspect of resource consumption and emissions. These problems went through a similar evaluation process, using refined evaluation criteria, with the purpose to establish each problem's relative potential to be sufficiently solved during the project. To narrow down the area further, towards a tangible reference component, or system of components, the existing LCA and the supervisors were consulted; which in turn led to that an appropriate component could be selected for the following concept development. The selected component was the main fuel filter.

4.2 CONCEPT DEVELOPMENT

The primary goals of the second main process, the concept development, were; first, to define the specific system and identify relevant needs and requirements for the concept development, and also to further refine the evaluation criteria to suit the concept evaluation. Thereafter, to develop conceptual design solutions for alternative functionality through a use and sustainability focused and iterative design process. The iterative process also includes continuous evaluation against the previously defined criteria, in order to ensure the most appropriate concept is select for further refinement in the, final concept refinement stage. As can be seen in Figure 2, the concept development process was divided into the three parts: Basic needs and requirements study, functionality concept development and final concept refinement.

4.2.1 BASIC NEEDS AND REQUIREMENTS STUDY

The first part of the product development stage included a system analysis and a complementary problem analysis (see figure 2). With the base in the identified system and the problems, the outcome of the needs and requirements stage were initial needs and requirements and evaluation criteria for concept assessment in later stages. These outcomes were the foundation for the following concept development.

4.2.1.1 SYSTEM ANALYSIS

For the conceptual solutions to consider a significant part of relevant influencing factors, a holistic approach, obtained by system analysis was used. The system analysis considered the individual contributions from the four system components: *product/artefact*, *task*, *user* and the surrounding *context*; and described how the aspects influence each other and overall system performance (Bligård 2015). In the particular project, the system analysis again served as a baseline; defining a reference case which allows for the comparative evaluation in the end. The holistic system and life cycle perspective was important for the environmental impact screenings, since it allowed for connections between impact, system components and the different life cycle stages. The system analysis aimed to complement the system overview carried out in the prestudy; however, focusing on the selected reference product.

To obtain a general understanding of the system before moving into depth, a system overview was constructed. Conducted interviews seeking to find evidence of current problems helped refining the overview. The system boundaries helped ensure the problem was limited to a manageable level to keep solutions relevant for the system. Key factors, similar to what is described as “external factors” for sustained system performance in Bligård (2015) were identified and described for the respective sub-system.

ARTEFACT

The reference artefact was described in terms of its design and functions based on information from the company and manufacturer. However, the most important contribution to the understanding of the current artefact design came from a dissection of one new and several used filters of different models. To collect the information about the reference product, a table of the component content was made, and a representative CAD model was constructed to facilitate communication and development of graphics to explain new concepts. In addition, the collected information was used to conduct the LCA of the reference filter.

In order to identify and assess environmental impact from the product and to identify possible actions for improvement, the product's life was investigated and described from raw material production to disposal and evaluated with rapid eco assessment, as the tool is described in the development framework (Chapter 3.2). The life cycle overview was also aiming to support the product development, since it indicated where changes could be most efficiently implemented, and where the suggested improvements had potential to optimise the positive impact.

The functionality of the reference product was determined from interviews with in-house product engineers, from manufacturer information and from conducting market research of various corresponding solutions. The artefact functionality was structured with the help of a functions analysis; defining the reference object's primary, sub- and support functions according to the theories described by Österlin (2010). Procedures were assumed based on information from the company and complemented with data from similar manufacturing, presented in online video clips and in manufacturing techniques literature. The artefact could not be observed in use in this study due to project constraints.

TASK

Compared to the description of the user and the context, the task description is to a larger extent based on the service instructions; i.e. how the operations are supposed to work according to the company manuals. This data was then, if possible, verified and complemented with data from the interviews.

The task was specified with help from a hierarchical task analysis as presented by Bohgard (2011). The task was based on the entire service scenario, to cover all the relevant occasions where the product was handled by a person. Another reason to why it was deemed important to cover the entire service operation was to highlight other relevant product requirements and possible design solutions incorporating combinations of needs.

USER

Several complementary methods were used to describe the identified user of the chosen reference product. First, the different user types were addressed and categorized in terms of their influence over and the contact with the product; primary user, secondary user, side user and co-user were established, according to the theories and definitions presented in Janhager (2005). A simplified stakeholder analysis was performed in which the motives and the product design influence from the most important users were outlined.

The primary user was categorized according to the level of experience and skill described in Janhager's theories (2005). The primary user was further elaborated through a persona and a complementary scenario. The combination of the methods served as important tools in communicating the use and user profile.

The persona was constructed from the template referred to as "user character" in Janhager (2005) and the format for the scenario was also picked up from the same reference. The user analysis was based on data obtained through interviews and observations at the service provider and to some extent on information from within the company.

The reason to the quite extensive user analysis for a product with its main functionality entirely disconnected from a user, was that the situation was anticipated to change and the use to increase due to focus on redefining the functionality and extending the product life.

CONTEXT

The context description was also constructed from descriptions of the surroundings, communicated through interviews, literature review and to some extent observations. Another important source of information in defining and analysing the user and the context were reports describing previous work carried out in quarry environments from the department of product and production development at Chalmers (Wernberger Jonsson et al. 2011, Bergstrand et al. 2014). The context description presented in the system analysis of the machine, in the prestudy, was important also for the selected reference product and the related service operation. As a complement to the context description, the external factors which were deemed relevant for each sub-system were addressed according to what is prescribed by Bligård (2015).

4.2.1.2 PROBLEM AND NEEDS IDENTIFICATION

Problems connected to the studied system were compiled in problem identification documents and categorized according to area of relevance. In addition, aspects in the current system which might cause problems in a future functional sales business model were addressed. At this stage the learnings from the rapid eco assessment were used and complemented with a recyclability screening.

Needs and requirements engineering, described in Bligård (2015), was used to define relevant needs and requirements in the areas: *functionality* and *use requirements*. In addition to these traditional requirements, the silent stakeholder, the environment, was also considered through the requirements category: *sustainability*. Thereto, a set of desired concept properties were defined; i.e. aspects which were considered positive if the concept could fulfil. The purpose of the requirements list was to focus the solution generation process on only relevant aspects for the particular system and the case study scope; without being very explicitly defined. The requirements were then continuously updated and more explicitly defined when the level of abstraction was further narrowed. To communicate that the level of abstraction had been narrowed down further, the overall process effect goal was redefined.

Criteria for the evaluation of the concept solutions were considered necessary for a structured selection process with many, and to some extent contradictory, demands. The criteria had to be a mix of objective and subjective criteria in order to cover all the relevant aspects. The criteria used in this stage evolved from the criteria used in the prestudy; though, compared to the previous criteria, they could now be more explicitly defined due to the more explicitly defined problem. This fact also made the evaluation more accurate. The old criteria from the prestudy, had an important role by acknowledging the different project stakeholders' priorities in a new weighting process. The expanded set of criteria was weighted by a pairwise criteria comparison, inspired by Johannesson et al. (2004).

4.2.2 Functionality concept development

4.2.2.1 INITIAL CONCEPT DEVELOPMENT

The purpose of the first concept development was to generate several conceptual designs for the main functionality. The idea of producing several concepts was to maintain a broad solution spectrum. In this first development stage, the concepts were described quite inexplicitly and in terms of their functions rather than product attributes. This was because it was believed that a change in system or functionality level would have a much bigger positive environmental impact than product design changes alone; an assumption based on the levels of substitution presented in (Holmberg 1998).

The ideation process described in the suggested sustainability centred design process (Chapter 3.2), was used to explore how the effect goal: ***"Reduce environmental impact from main fuel filter",*** could be attacked. The different strategies presented in the ecodesign ideation methodology, compiled by Okala (2012), were assessed according to their appropriateness for the particular problem. The most relevant strategies were combined, resulting in the four solution categories; "reduce basic need", "extend useful life", "reduce impact from materials" and "reduce indirect use of resources". The different categories were used for ideation of conceptual solutions together with the needs and requirements list with the goal to achieve the effect goal. Mind maps were used to develop solutions to the identified problems. The technical solutions and the solution paths were combined to form eight independent, self-supporting concepts.

It was considered important to clearly separate the concepts in order to make the evaluation explicit. For the same reason, the aim was also to present the concepts on the same level of detail. The separation was obtained by focusing the descriptions on the differences within the concept range and by stressing the unique features of each individual concept. To facilitate communication, the concept description and analysis were complemented with a concept illustration and a numeric, weighted evaluation for each of the eight concepts.

The criteria which were defined and weighted in the previous needs and requirements study were used in a concept selection matrix, as described in Wikberg Nilsson et al. (2015), to assess the eight concepts. In addition to evaluating the concepts against each other, a comparison against the reference with a Pugh's comparison matrix (Wikberg Nilsson et al. 2015) was conducted. However, since Pugh's evaluation method is different from the evaluation matrix, the criteria had to be revised and the criteria were weighted slightly differently. The reason to the alterations is connected to the fact that Pugh's evaluation method compares concepts to the reference; hence factors such as technological feasibility, company compliance and completion level were obviously not considered relevant for comparison against an already existing solution.

4.2.2.2 SECOND CONCEPT DEVELOPMENT

Three concepts were selected for further refinement, however all concepts served the process with valuable learning outcomes and sub-solutions which were brought to the next development stage. In this stage of the process, it was deemed necessary to also include technical solutions in order to assess feasibility; although, still concentrated to the functionality and the principles of the technical solutions rather than tangible product concept properties.

After the refinement process, the three concepts were described in detail. Additional research regarding each of them was outlined and the tasks were described in more detail. In addition, a SWOT analysis (Johannesson et al. 2004) was carried out; in which the assumed strengths, weaknesses, opportunities and potential threats, were identified and addressed. In addition, remaining problems and uncertainties were outlined, as important complements to the descriptions, in order to understand the concepts and as brief indications to what further development of the respective concept could mean.

The three concepts went through a final evaluation to decide which concept had most potential for the project. Thereto, strengths and technical solutions from the less successful concepts were picked up and implemented in the final solution.

4.2.2.3 SPECIFIC NEEDS AND REQUIREMENTS

To facilitate the concept refinement, the needs and requirements together with the overall effect goal and the identified problems and uncertainties were first expanded, evaluated and compiled and then broken down into a set of desired effect goals. Effect goals are concrete design objectives, concerning the desired effect from a design decision. The effect goals are used to support the arrival at a product which is sufficiently fulfilling the needs and requirements (Bligård 2015). Solutions were then generated for each of the effect goals. Complementary effect goals were added to the list.

In order to communicate the expression requirements, an expression board according to Wikberg Nilsson et al. (2015) was created. Five areas were considered important to cover; form and material, general expression, metaphor and functionality. For the individual areas, a set of images and adjectives were collected; and the ones which represented the desired expression in the most satisfactory way were selected for the final expression board.

4.2.3 FINAL CONCEPT REFINEMENT

The final concept refinement process was aiming to develop the winning concept to a level, explicit and tangible enough to allow for communication of the ideas and for final evaluations to be carried out.

The final concept solution generation was a very iterative process, where solutions and effect goals were developed concurrently; suggested solution for one effect goal created new problems, which in turn required new solutions. Problems and effects goals were listed and a solution ideation process, documented with mind maps, similar to the various brainstorming techniques described in Wikberg Nilsson et al. (2015), was carried out. The solution mind maps are presented in Appendix XII.

Different topological and typological form features were evaluated before a form was selected for the filter. The previously introduced expression board was used when evaluating the form and the surface properties of the product, to ensure the desired expression was obtained.

Concept credibility was obtained by a final concept evaluation and in order to allow for the quite detailed final evaluation, solutions were presented both in text and with complementary concept renderings from CAD models. A representative from the service provider with good technical understanding supported the selection of attachment solution.

The concept solutions were motivated in relation to each individual effect goal; which means that instead of assessing the degree of goal fulfilment, the actions which were implemented to resolve each effect goal were explained. The concept was also motivated in relation to the expression board images and adjectives to complement the effect goal fulfilment evaluation. The product was assessed not only in terms of the visual expression but also by considering the previous functionality descriptions. A final product rendering was placed in the expression board, facilitating the visual assessment.

4.3 FINAL CONCEPT EVALUATION

4.3.1 QUALITATIVE EVALUATION

The final concept was qualitatively assessed in relation to the predefined evaluation criteria. The reason to why the requirements list was not used for evaluation of the concept, as would have been customary, was due to that the requirements were considered too explicit in relation to the concept readiness. Instead a Pugh's evaluation matrix-inspired evaluation was carried out to determine the final concept successfulness in relation to the reference case. In this evaluation, the concept was assessed for an extended and more explicit version of the evaluation criteria than previously used.

In order to complement the criteria evaluation, a qualitative eco assessment was carried out with the same tool, based on eco strategy wheel principles, as used for problem detection in the previous basic needs and requirements study. The result of the assessment was compared to the analysis of the reference product to assess improvements.

4.3.2 QUANTITATIVE EVALUATION WITH LIFE CYCLE ASSESSMENT

Life cycle assessment was used to quantify the change in environmental impact between the existing reference product and the new concept. The method was considered a good way to discover trade-off effects and less intuitive effects from the concept's entire life cycle. An LCA was made for the reference product before it was carried out for the concept, to allow for the comparison. To cover most aspects of both the reference's and the concept's possible impacts, cradle-to-grave LCAs were made; meaning that all production processes, use situations, transports and end-of-life treatments were included. Information about these processes for the reference product was collected from the company and after dissecting the component and measuring its parts, materials and weights could be decided.

The process of conducting the LCA for the concept started with deciding crucial parameters of the concept; some of which had not yet been defined in the development process, such as materials and weights. Some of the system parameters also needed to be set early, in order to determine transportation and handling processes, which were considered important to include in the LCA. Both assessments were made in the software GaBi, by Thinkstep and the entire LCA procedure was reported as suggested by ISO_14040 (2006) and is included as an appendix to this report (Appendix XX).

I. CASE L150 - PRESTUDY

The prestudy chapter is aiming to narrow down the project to a manageable level for the development process. Apart from a solid knowledge base regarding the system, the chapter also includes the definition of a scenario to design for. Thereto, the evaluation criteria are presented, which will be used to steer the project in the desired direction. And finally, the chapter will present a specific product, to be used as a reference in the following redesign process.

5 PRESTUDY

In the following chapter, the result from the prestudy is presented. From the initial system to an unambiguously defined problem formulation for the use and sustainability centred process to work with in the following chapters.

5.1 WHEEL LOADERS

Rather than being specialized for a certain application the wheel loader, seen in Figure 3, is a very flexible machine, used in a wide range of different environments and purposes. Wheel loaders come in many sizes and with an array of customization equipment and attachments, to allow versatility and fit each individual customer's needs.

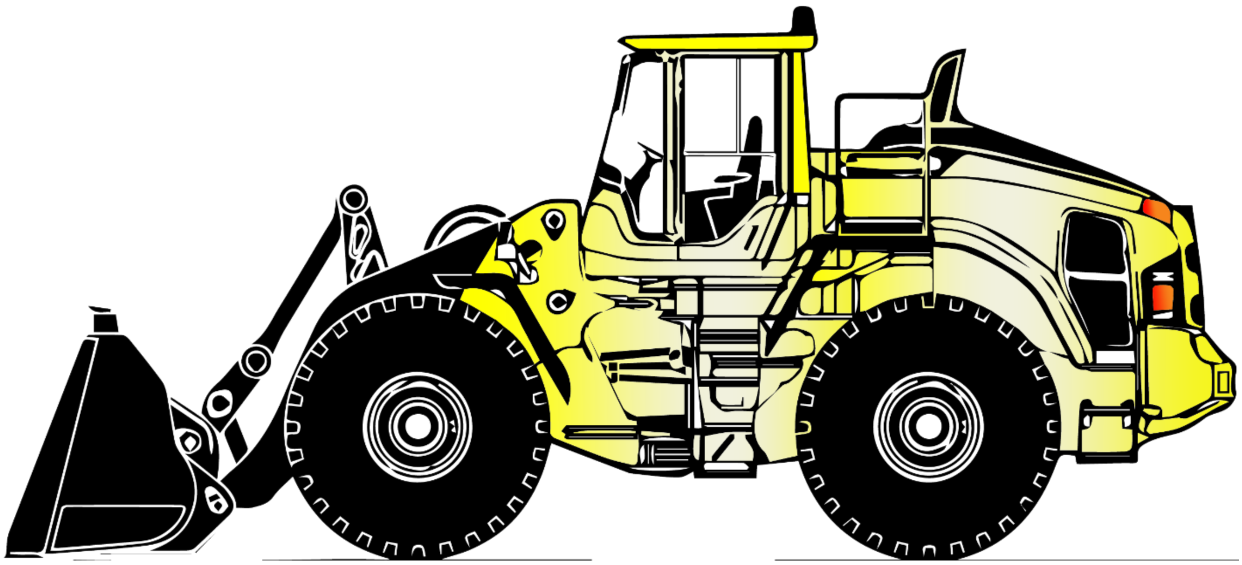

Figure 3: Wheel loader L150, schematic image (Prosis 2016)

The operational weight of Volvo construction equipment's wheel loaders (compact wheel loaders excluded) varies between 11 tons for the smallest L60 model, up to 50 tons for the largest L350 model. The initial price varies greatly with customizations and special equipment; general estimations however, suggest a basic price somewhere around 100 SEK per kilogram. A wide range of special equipment and attachments are offered by Volvo construction equipment, while others are provided by the dealers' suppliers and mounted on the new machine according to the customers' requests. By default, the machine comes with a one year producer's warranty, which sometimes can be extended by the dealer. When new, the machine is most frequently sold with additional service arrangements (Interviewee 3 2016). The service arrangements include preventive maintenance according to intervals prescribed in the service manual. An overview of the estimated general target groups can be viewed in Figure 4.

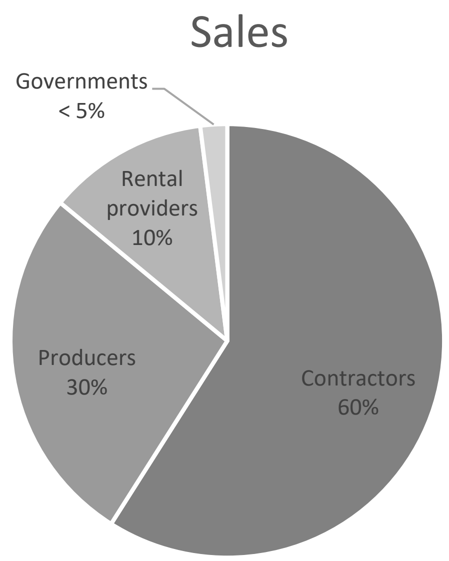

Figure 4: Approximate image of general customer groups for the L150. Reference: Interviewee 3.

Customers and applications for the wheel loaders vary greatly between countries and regions and over time, due to the variation of industrial and societal demands. Although, a rule of thumb is that the larger and more expensive the machine is, the more likely is it to be used for more specialized applications (Interviewee 2 2016). An estimated distribution of the applications can be seen in Figure 5.

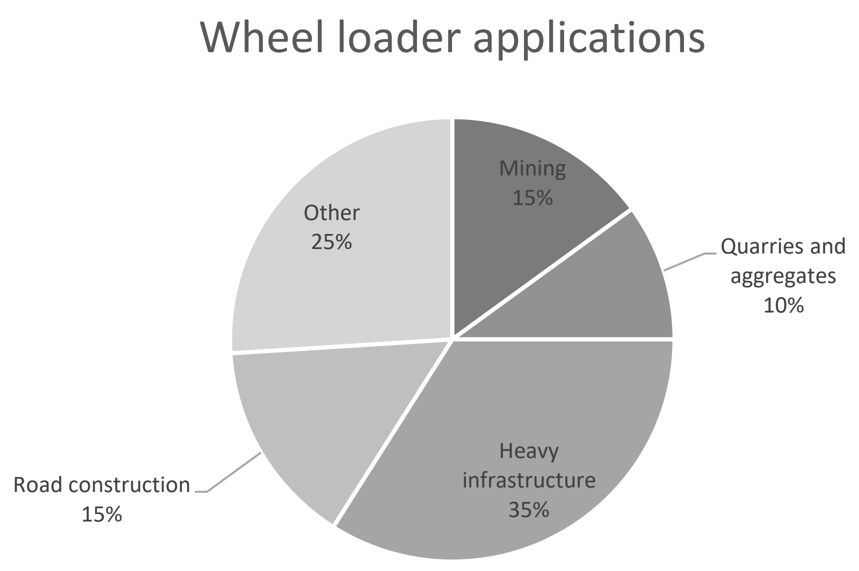

Figure 5: Estimated distribution of sold wheel loaders over different applications. Reference: Interviewee 3

5.2 SIMPLIFIED SYSTEM DESCRIPTION

Figure 6 shows a simplified system model of L150. The successfulness of the machine's daily operations is decided by a combination of the system components, represented on different levels in the model. The model's inner circle illustrates the fact that the wheel loader is actually a set of products that forms an entity, more valuable than the individual parts alone. The machine is in turn affected by other products and information in *the context*, captured by the second circle. The model also shows that there are external factors affecting the system performance on the different levels. These factors can be governed by for example business plan, policies, the market etc. and are not direct relevant to the object; though, will still have a major impact on the system performance and the machine design. The system components which were identified as extra important for the system performance and the result of this project are described more in detail in the following sections.

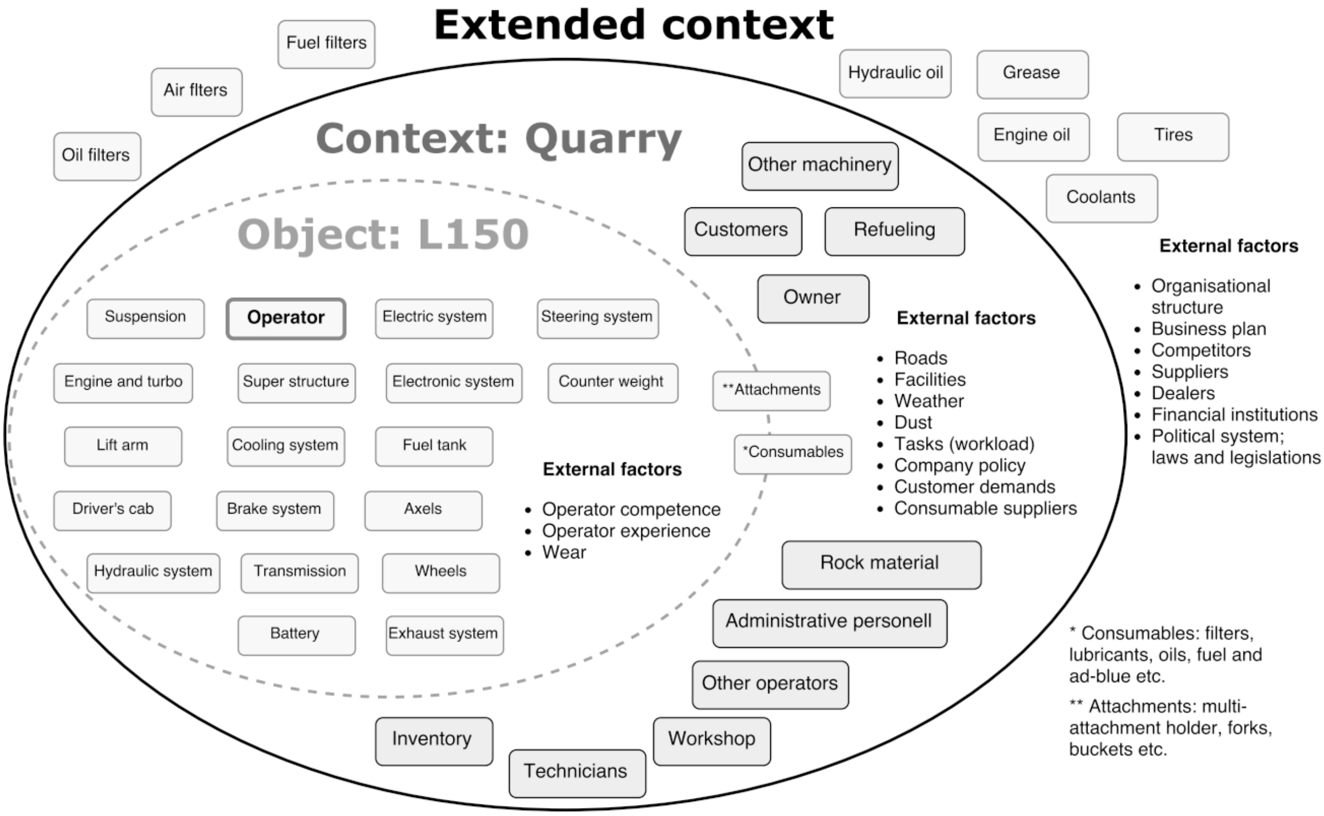

Figure 6: Simplified System Model for L150, as used in a quarry. The inner circle contains the systems of components needed for the machine to function. The bigger circle contains factors important for the operation of the wheel loader in the quarry. Outside the circles are factors which affects the wheel loader, but are not specific for the machine or the context. Boxes on the borders of the circles indicates the factors can be influential in both systems.

5.2.1 VOLVO CONSTRUCTION EQUIPMENT (VCE)

The manufacturer of the L150 wheel loader, Volvo construction equipment is part of Volvo Group and delivers under three brands: Volvo, SDLG and Terex Trucks. The brands compile a broad range of products including excavators, wheel loaders and other heavy duty machinery. The company employs about 15 000 people worldwide, with a majority in EU and Asia. The headquarter is located in Gothenburg.

Since VCE is part of Volvo group and thereby also part of their achievements and investments, the main focus of environmental work has been to reduce CO_2 and NO_X. But VCE has also worked to make their production sites more energy efficiently and to educate operators to use their equipment more energy efficient. Volvo CE is also parts of the construction climate challenge (CCC) program, which is aiming to increase knowledge about how construction equipment can reduce its environmental impact.

According to Hart (1995), two of the three environmental activities could be classified as pollution prevention, rather than sustainable development or product stewardship. The CCC endeavour however, shows signs of the latter.

Table 1: Reactive, Defensive, Accommodative, Proactive-Evaluation of actions. Table shows most actions carried out by the company are either defensive or accommodative.

Reactive	*Defensive*	*Accommodative*	*Proactive*
Lower CO_2 emissions Lower NO_X emissions	Constructed an excavator on diesel with lower emission levels than hybrids.	Hybrid and electric. Lowering energy consumptions at sites. Remanufacturing.	CCC initiative. CO_2-neutral site initiative.

Looking at the Reactive Defensive Accommodative Proactive scale, Table 1, the sustainability activities are somewhat spread over the entire scale. However, the activities which are applied on the products in present time are more to the reactive and defensive side. The pro-active and accommodative technologies are all still in the research phase. The dominating strategy however, is a mix of defensive and accommodative actions.

The interviews revealed that capital and energy has been focused on reducing emissions from diesel so intensively that other initiatives have been put aside due to lack of time and resources. Here might a lot of possibilities to improve the sustainability work be found, in areas such as materials choice, weight reduction, utilization and more.

5.2.2 PRODUCT SYSTEM: L150

The L150 is among the smaller wheel loaders in the large loader platform category, with an operational weight of approximately 25 tonnes. Buckets of size 3.4 - 14 m^3 can be attached to the loader and the static tipping load at full turn is almost 16 tonnes. The machine has a 13-liter, 6-cylinder diesel engine, engineered to live up to the emission standards in the close future. The company is aiming to be a premium brand and deliver wheel loaders of high quality, with high operator comfort and good serviceability. Some of the features are a cabin that is tiltable, to facilitate maintenance and service. In addition, design changes have been made to the machine to achieve better access to frequently used service points (Equipment. 2015, Interviewee 2 2016). Figure 6 shows some of the ingoing components of the system and in which level of the system they are found.

The selling of the machines is done through a dealer. The salesman tries to understand the need of the customer to find a machine that can help satisfying it in the best possible way. A mismatch can lead to the machine being used incorrectly, which in turn reduces up-time and in the end, gives the company a reputation of poor quality products (Interviewee 9 2016). The dealer orders the machine from to the producing company and additional equipment is mounted in the dealer workshop before the machine is delivered. The extra equipment might come from the producing company; however, sometimes also from competitors (Interviewee 3 2016).

Due to its size, the L150 rarely comes to a workshop for service; instead, the technician comes to the machine. Every machine is connected to a data system which tells the technician when a certain machine requires service. The technician then calls the operator and decide on a suitable date and time. Prior to the service, the technician loads his car with the required equipment and drive out to the site where the machine is operating. A build-in GPS in the machine tells the technician where it can be found. That might be in a static location as a quarry, or at a more dynamic site as a road construction site. Often the operator is not present when the service takes place, since that conflicts operating efficiency. An interviewee told that, sometimes a note is left from the operator in the wheel loader with more instructions to the technician about what needs to be done in addition to the standard service (Interviewee 3 2016).

A L150 wheel loader require certain service components to be replaced at every 500 hours (Interviewee 4 2016, Prosis 2016). The components are often disposables and include for instance oils and filters which are replaced to guarantee that the machine will run for another 500 hours. Over the lifetime, service and maintenance results in a consumption of materials weighing more than the machine itself. Most this weight comes from tire replacement, although liquids and filters make an extensive contribution too. Service and maintenance also generates additional costs, adding to the cost of operator, fuel and the initial investment. The service parts are an important source of income for the producing company.

Basically, the technician has two main assignments: planned, preventive maintenance and unplanned operations (Interviewee 9 2016). For planned service, the technician conducts service according to set intervals, whereas unplanned operation is when something fails and must be repaired or replaced. The latter can happen during operating hours and since the wheel loader can be crucial in a production line, a break down quickly leads to loss of income for the customer (Interviewee 2 2016). The replacement parts can be bought in three different qualities and price classes. New parts are, as the name indicates, factory new parts. A remanufactured part on the other hand is a part for which company has developed a process to take back and remanufacture them to become as-good-as-new, and the to sell them with a warranty; although as a cheaper option compared to new parts. The cheapest alternative though, is used parts bought from disassembled machines. In the latter case, the guarantee is limited (Interviewee 4 2016). To make it possible to have a working supply chain with reused and remanufactured parts, certain actions need to be done already at the development stage of the wheel loader. Components needs to be easy to remove and remanufacture, so that the procedure can be both profitable and doable (Interviewee 7 2016).

Also, there are some aspects to consider in a wheel loader's end of life phase. First, the dealer and the company often lose track of the machine already after the first or second change of ownership. In this way, it is difficult to make the customers continue buying certified company parts, which is lost income for the company. For the same reason, it is also difficult to make sure that hazardous matter and components are taken care of in a proper way.

Instead of investing in a new machine, the owner can choose to make a *certified rebuild*. This is a relatively new program meaning that parts are refurbished or exchanged, so that the machine can be brought back to its original condition in terms of performance. This process is quite long today, including interviews and investigations to be sure about what needs to be replaced. Then, parts are remanufactured or ordered as new or used. Through certified rebuild, the company manages to build machines that are as good as new, with a large percentage of already used parts. Today the objectives for the process is not to save the environment, but to get the machine back in the loop of consuming service parts. (Interviewee 7 2016). However, it is identified as a good way for the company to use less virgin materials and the method has good potential for expansion.

In the end, depending on if a certified rebuild was made or not, the wheel loader is often sold abroad. Due to this, components and materials are getting completely out of reach for the company and the machine might end up in a context where it cannot be recycled properly. This in turn means that not only materials are lost, but also that the wheel loader might contaminate the environment in its end of life phase.

5.2.3 Context

The L150 handles mostly virgin materials such as hard virgin bank, shot rock and lose virgin bank. However, those tasks can be found in a range of environments and contexts as can be seen in Figure 7. For the case of this study, the focus has been on an environment similar to the bottom right image in Figure 7 (Equipment 2015); a quarry or similar site where the wheel loader handles dirt, gravel or rocks. This is a very dusty and dirty environment, where machines are exposed to weather and heavy wear.

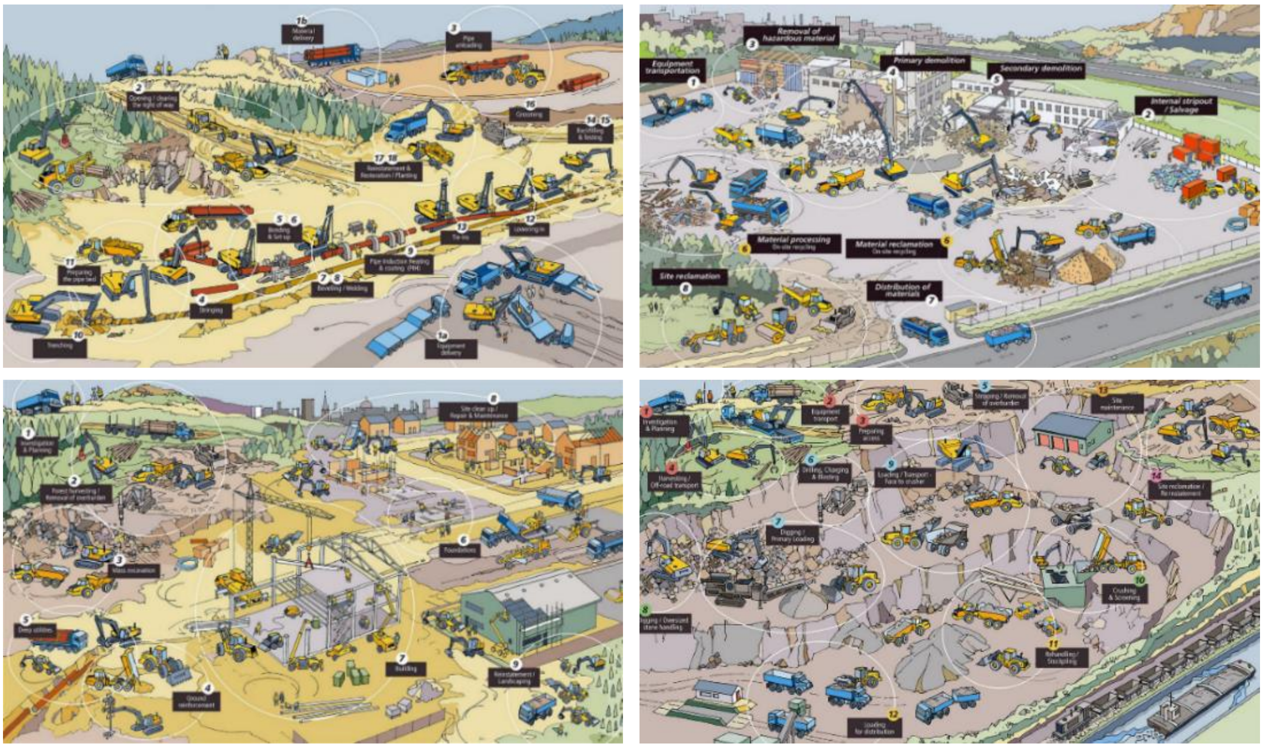

Figure 7: Examples of contexts in which the wheel loaders operate, forestry, infrastructure, construction and quarry

5.2.4 Business model

Generally, a company buys a wheel loader to be used in the everyday business operations. The ownership of the machine lies with this customer. As mentioned, it is very common that a service agreement is signed along with the purchase. A service agreement might look slightly different, depending on by how much of the responsibility for the machine's reliability will be on the service provider. Generally, a service agreement guarantees up-time and gives a possibility for the customers to pay smaller amounts more frequently for this service. Even though not very common, leasing agreements exists; these are however signed between the customer and today's dealer, and thus means little difference for the equipment manufacturer compared to normal purchase.

When the price of the machine is discussed, it is often discussed in terms of "*total cost of ownership*" (TCO) and it aims to help the buyer to compare the machine with other options. TCO includes all the costs per hour it takes to keep the machine running, including fuel, operator, initial investment, service and expected repair and spare parts. Since TCO is calculated per operating hour, it gives the investor a possibility to compare the cost of the machine with what profit is possible to make hourly; and thereby assist in determining whether if the machine is a good investment or not (Interviewee 2 2016).

In general, machines which are operating in high performing production lines stay with its first owner until the cost for maintenance and the level of unreliability reaches a point where the machine is no longer profitable. At that point, the machine is sold to an application with lower requirements, and where a new machine is not affordable. The procedure is repeated as long as there is remaining value in the machine to be extracted.

Three kinds of users were identified in the case of the wheel loader, each with a different connection to the product. The users identified through interviews were: owner, operator and technician. All three users are interested in different part of the machine and its performance and at different times. The owner is obviously the company owning the machine. It is in the owner´s interest that the machine is reliable.

The operator uses the machine as a tool for performing the tasks in the production. Important factors for the operator are that the machine has the right characteristics for the job and provides a good workplace. To facilitate the work, the operator must be able to monitor what goes on around and in the machine. Information from the surrounding is presented through the windows with support from the displays in the cabin, whereas machine information is presented on displays and through interpreting movement and sounds from the machine and the controls. Based on that information, the operator makes decisions and executes tasks through the controls in close proximity.

The service technician interacts with the wheel loader when performing the service. It is important that the technician can conduct the service in the different contexts without being constrained by the machine design. The technician gets information about what service needs to be done from multiple sources. By monitoring how many hours the machine has been running, the right kind of service can be provided and the right parts changed. In addition, information from the operator or owner is an important complement for the technician to learn if the wheel loader shows any abnormalities in its everyday performance, to help assessing possible issues. Finally, the technician can receive information through a visual scanning of the machine. The technician interacts with the machine through the different service points, mainly in or around the engine compartment.

5.3 FUTURE SCENARIO

In Figure 8, the result of the first concept generation is presented in the form of a timeline. The idea was to have a blue-sky ideation concerning what the future of a wheel loader could look like and then try to sort the ideas based on how far off in the future the idea could be expected to be (if ever) realized. The ideas, which are partly a result of a screening of trends and the company’s current commitments, aim to find a reasonable time span for when the scenario should take place, the scenario to design for. A time for the scenario was sought, which was not too close, nor too far away from the present state. The ellipse, to some extent symbolizes an estimation of where in time the

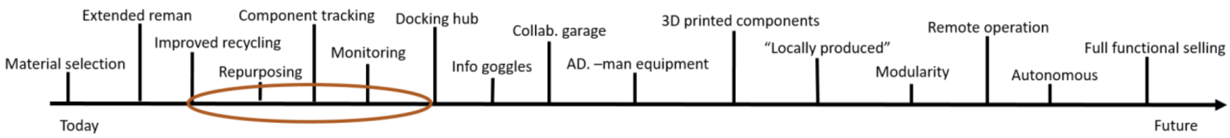

Figure 8: Results from an ideation session, in the form of concepts, presented on a constructed timeline based on estimated technological readiness and feasibility.

scenario takes place, in terms of technical and technological reediness based on the ideas that came out of the ideation.

In this section, a description of the scenario used for this project is presented. As can be seen in the time line, it is not a scenario representing the ultimate goal of circular economy, but is rather a leap towards it. It is reasonable to expect that the use of wheel loaders will not change much over the next 10 to 15 years. Partly because a lot of infrastructure projects are planned for which wheel loaders are used today and partly because it is a machine with a lot of different applications; hence quite hard to replace. Infrastructure projects require material from quarries which too is a context where wheel loaders successfully perform today. Both contexts accounted for in this project are thereby thought to be running in the next ten to fifteen years; even though some changes are of course expected to occur.

5.3.1 PRODUCT: L 150

The average life length of L150 before major rebuilds is approximately 20 000 hours, which corresponds to approximately 10 years if the machine runs 8 hours a day. This means that it is not reasonable to believe that VCE will rely on a wheel loader that is completely different from today's machine within next decade.

A lot of investment has been done to adapt the engine to tough regulations concerning low emissions of particulate matter and carbon dioxide. The adaptations made are thought to be sufficient for the machine to stay within the regulated limits for the next 8 years (Interviewee 3 2016). This gives the company time to explore other alternatives, but also less incitements to release new models. In addition, the machine is built on common platforms which might make alterations slower; which is yet another argument in favour for the assumption that the machine in the future scenario will look quite similar to today's machine.

5.3.2 BUSINESS MODEL

As previously mentioned, the business model in the future scenario will be a functional sales model, in which the ownership of the machine stays with the producer and the access to an operable machine is sold to the customers. In PSS terminology, the company will take the role as both enabler and provider (Tukker 2015). The customer (previously the owner) and the operator only need to worry about planning the tasks and operating the wheel loader, since all service and maintenance is included in the contract. This will require that a close dialogue is kept between customer and the service provider and that monitoring of the machine is done to avoid unnecessary down-time. Down-time will be compensated for by the provider, and thus will induce major costs in the case of breakdowns.

Figure 10 shows an estimation of how the revenue is split on the areas machine sales, spare parts and soft offers in today's model whereas Figure 9 shows the estimated, anticipated sources of income in the circular business model. The diagrams are principle figures to illustrate the difference between the different business models and emphasize that the idea of a functional sales model is that the cost of repair and maintenance is carried by the producing company, and profit can be increased by designing better products to decrease this expenditure post. This implies that the rent should cover investment costs, spare parts, maintenance, service technicians, repairs, soft offers etc. Despite the pressure to cover all these cost, there is quite an opportunity minimize costs by using remanufacturing, rebuild, optimizing procedures and designing longer lasting machines and consumables etc.

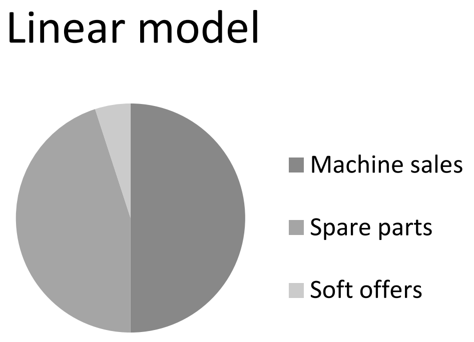

Figure 10: A principle distribution of revenue in a linear business model of a wheel loader.

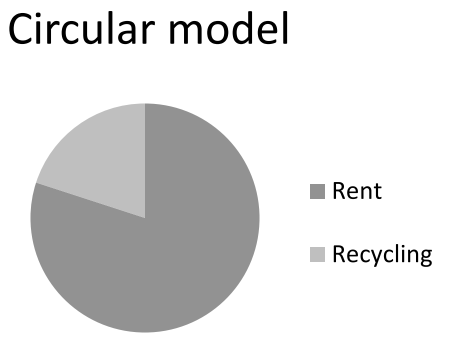

Figure 9: A principle view of how the revenue sources are expected to change if the wheel loader is in a circular, functional sales model.

Another possible, new source of income is to sell recycled material for production of new products. One advantage is that when the wheel loader does not change owner, knowledge about the materials is available, which will facilitate recovery of pure materials in the recycling process. In some cases, the company might even be able to take components and materials back into their own production line and in that way, contribute to a reduction in production costs.

A complete stakeholder analysis for both business models can be viewed in Appendix II. The analysis showed that the change of business model lead to a transfer of risk, from the customer to the company. This is connected to that the company has to make sure the product can deliver what is promised and in their interest is also to lower all costs for doing so. Whereas the customer no longer must carry the risk of investing in a product that might fail or require excessive service.

In the stakeholder analysis, the silent stakeholder "*environment*" was also included. In today's system, the environment is not considered to a high extent. However, in case of a more sustainability focused product development process, the environment will suddenly have more influence on the process and the result, hence its strength as a stakeholder increase.

The service technicians will have an even more important role in the new business model, being responsible for the up-time. The technicians must be at the site quickly in case of a breakdown, to avoid high compensation rates. In addition, they are also in close contact with the customers, hence very much responsible for maintaining a good relation.

As this very brief analysis shows, most changes are on the company side. The risk of a machine breakdown and expensive repair and maintenance costs is on the company and initially it must lead to changes, since what was previously an income now will turn into a cost. However, the customer will have to bear the cost of taking a lower risk. Material and organizational changes could be needed on the company side meanwhile increased cost could be expected on the customer side.

5.3.3 Service

The company will be in charge of service of the machines and the deal can be compared to today's gold level service agreement. It can advantageously be performed by the current service provider, since it already holds a lot of knowledge about the machines and have a good relation to the customers. As mentioned, when the service is paid for by the company, there are incentives to lower the cost for service. In 10 - 15 years, it is reasonable to believe, with the knowledge gathered during the 10 years of increasing levels of functional sales, that service has been optimized and thereby require less parts and service occasions.

5.3.4 Research and product development

Research and development will focus on decreasing the number of consumables, and the amount of service the machine require. A focus will also be on machine modularity, allowing for easier repair, service and remanufacturing to promote product longevity. Thereto, the business model is going to need further development. A new question to answer is how to involve innovation and updates in the machines, to allow it to stay attractive for the customer over a longer period of years. Part of the development will also be to educate employees about environmental issues and make sure they understand what impact their products have.

In addition, the process of additive remanufacturing can be explored to allow for a higher number of parts to be suitable for remanufacturing, and even on-site remanufacturing. This, together with the development of design for remanufacturing practices, will make sure that the majority of parts will come from remanufacturing. Consumables can be designed for the machine life length or for reuse, to limit waste and costs.

Product development is focused on design for extended life and all projects could start with three questions: Which cores already in production can we use? How can innovation be applied? How do we remanufacture/recycle the component? All new design solutions are carefully compared to, and evaluated against, the data gathered by the machines on site. Engineers are not only measured on cost, but also on environmental impact performance to increase the importance of an environmentally friendly product development process.

5.4 IDENTIFIED KEY AREAS

In the following chapter identified key areas are presented. A *key area,* is a certain subject which is identified to require consideration, if the circular business model, as described in the scenario, is to be implemented. The areas can be a mix of methods, actions, theories etc., clustered together and categorized according to common aspects.

5.4.1 Reuse

The producing company does not commonly reuse components today. Sometimes, as described previously, used parts are sold by the dealer to fill the demand from owners not wanting to invest in new parts. A suggested reason to why reuse is not utilized to the maximum of its capacity could be that the company has no possibility to warehouse or keep track of possible components to reuse (Interviewee 6 2016). In the scenario, this is different since the company stays owner of the product, thus a range of possibilities opens to reuse parts from the wheel loader.

What has been identified as a challenge is that it must be acknowledged that parts are going to be used in different machines and adapt both the machine and the part for this already in the development stage. Designing for reuse includes the aspects of durability, adaptivity and possibility to detach from the machine, and more.

Reuse is not necessarily the ultimate solution in all situations; some problems and possible obstacles were identified. Reuse might hinder radical improvements; old and potentially inefficient components and technology is preserved to allow for the reuse. Another problem is to ensure the quality of a used component; which in turn might lead to either expensive quality testing, or the risk for premature breakdowns. Another criticism towards reuse in this case is that it might induce large costs for warehousing, administration and logistic chain, since parts and customers are widely dispersed, geographically.

Another obstacle for the company's reused parts business seem to be that the company structure is designed for developing, producing and selling machines; while the reuse business also requires the purchasing department to be in close contact with the market. Today, this contact is primarily maintained by dealers. For the company to take part of potential revenue from reuse, establishing such relationships and developing the required knowledge within the own organization is seemingly essential actions.

5.4.2 Remanufacturing

Remanufacturing is usually labour intensive, but on the other hand, it saves virgin materials to a high extent. The logistics and system around the process is still under development within the company and representatives from remanufacturing strives to give design for remanufacturing higher importance in the product development process (Interviewee 7 2016). Remanufacturing is already good business today, generating income on used products. In the future scenario, remanufacturing will not be a source of income, but rather a way to reduce costs, since components required for repair, rebuild and maintenance can be remanufactured instead of replaced with a new one.

Today, only parts which are profitable in small numbers are involved in the remanufacturing schemes. In the future, the number of remanufactured parts might need to be higher. This can probably be achieved by using design for remanufacturing principles more frequently in the product development process. Another problem today is that the company does not always own the rights to remanufacture the components in their machines.

Whether a component is remanufactured today or not, is decided based on the economic value of the product; i.e. expensive products such as the engine and the transmission are included in remanufacturing schemes whereas, some products are designed as disposable components or consumables, such as filters, oils and other liquids. In a circular business model, every consumable is a cost and hence needs to be reduced. Another aspect is that by extending the product's life with design, the component might get more expensive, which in turn gives an incentive for remanufacturing.

5.4.3 Repair and maintenance

It can be concluded that a lot of research is required to find the best way of handling repair and maintenance in a circular business model. But what was found after a brief literature review, including the existing LCA, was that repair and maintenance consumes a lot of parts and materials, which contributes to the exhaustion of resources on Earth.

As mentioned in the system analysis, most services are made on site, which means all equipment needed for the service must be transported to the site by the technician. If a more environmentally friendly approach is desired, it might be of interest to reduce the amount of service occasions.

A lot of environmental benefits comes with reducing service; and in a functional sales model, many benefits are also economical. Ways of reducing service can be to develop better solutions from the beginning, construct systems that do not need service, or design a condition based service model, preferably together with longer lasting solutions.

5.4.4 Recycling

Another identified key area is recycling; since the company today take little responsibility for the recycling of their wheel loaders, since the machines are often sold to countries outside Europe in the later stages of their life. On top of that, the country where the wheel loader ends its life might not have a good system for handling scrap or materials for recycling (Interviewee 10 2016).

In the case of consumables and service parts, such as oils, fuel and lube filters, the situation looks a bit different. In Sweden, filters are classified as hazardous waste and thus needs to be taken care of properly. Service stations have agreements with recycling firms such as Stena, which take care of, and recycle, filters (Interviewee 9 2016).

Wheel loaders, as many other products, are getting more complex and rely on more computer governed processes. Often, components that can control processes contain scarce metals, which further stresses the need for recycling. If the producing company stays owner of the wheel loader, it will mean that knowledge exists about what materials the machine contains and will be available in the end of life phase. This fact implies a good opportunity to turn used materials into revenue. Recycling methods and strategies are system problems; although, a lot can probably be done about the wheel loader design to promote recycling. Action which can be done is to investigate if all design for recycling principles are used for each component and to make sure that only materials are used, for which there is an actual demand.

5.4.5 Repurposing

A replaced component is in general replaced for a reason, but it has not necessarily lost its entire value. Parts of the machine might be unharmed and sometimes even in the same condition as when it was put in place. There is today no system in place to track and take care of most of these components. It is possible that new and innovative applications can be found to elongate the life of components in new applications, within or outside the organization. This sums up the key area: repurposing.

Few case studies on repurposing could be identified during the research phase. However, one identified case was about repurposing of car, bus and truck batteries, by using them as energy storage units in factories or apartment complexes (BMW-Group 2015). To make repurposing successful, it should be considered already in in the design process in the future, since the early phase of a design process is most suitable and less costly to make changes to a component (Österlin 2010). If the area is considered early in the design process, repurposing is believed to have potential to offer an alternative approach to problems of wasted capacity.

5.4.6 Utilization

Another identified key area is utilization, especially for wheel loaders since the tasks that the machines perform many times involve waiting. Also, the owner might have a fluctuating demand, which is preventing maximum utilization. Service and reparation are actions which require the machine to stand still and thus prevent maximum utilization. In a function sales model, a wheel loader will be paid for when it is utilized, which could work as an incentive for the company to increase utilization of their products through design. One interviewee mentioned that many wheel loaders are used 12 hours a day and then the operator takes Fridays off, which would mean the wheel loader stays still for 3 days (Interviewee 3 2016). Shared use can be one solution; although, L150 is a big machine and is not easy to move around between users. The problem in the future scenario is that the customer, who has the real influence over utilization, will no longer be accountable for wasted capacity. Clever solutions and user studies are probably needed to increase utilization. Possible soft offers to affect customers to maximize utilization can include combined fixed and floating rates in the contracts, or guaranteed operating hours, or bonus systems for high utilization rates etc.

5.4.7 Use efficiency

Interviews showed that the behaviour of the driver and the application in which the wheel loader is used greatly affect the life length of the wheel loader (Interviewee 2 2016). Every hour of use is an hour of wear and reduction of life length; thus, use efficiency appears to be another key area. To get the most out of the invested knowledge, material and capital, every hour should be used to its maximum. Since the service provider offers education in operation efficiency, it can be concluded that improvements are considered necessary in that field (Interviewee 3 2016). More studies and observations are required to understand where most can be done to optimize the use of wheel loaders.

In a circular economy, with a functional sales model, it is in the interest of the provider and owner of the machines that they are operated in the best possible way, and are effectively protected against excessive wear. The draw-back on the other hand, is that customers have less economic incentive to treat the machine well. An optimization of those factors would increase the life length and the hours possible to sell, and at the same time, potentially decrease maintenance. A challenge is to find the right actions for saving resources; not only adding technology, hence risk to make the operator's task more demanding. Suggested ways are monitoring technology to help the operator improve the driving habits. Another improvement is applications to help plan tasks in an effective way. Thereto, autonomous driving will probably make a very important contribution to this area. However, the most important objective will be to analyse what operating behaviour has negative impact and work the way from there.

5.4.8 Material selection

Another key area is material selection, which has major impact on a variety of factors tied to functional sales. The choice of material affects recycling rates, reusability, weight and hence fuel consumption, remanufacturability as well as impact on ecosystems. So obviously, material selection is part of all other key areas presented; despite that, the area is presented as a stand-alone to stress the challenges and advantages.

Today, the company works with a red list of materials, forbidden to use in any of their products for different reasons. A suggestion could be to develop a list of preferred materials that should actively be used in products due to better recycling options and therefore less environmental impact.

5.4.9 Business model

Today, the whole organization, the goals and the visions are built around delivering wheel loaders to customers. The employees are measured on efficiency indicators connected to the amount of sales (Interviewee 2 2016, Interviewee 5 2016). The business model key area contains a broad set of challenges over an equally broad set of areas. Some aspects related to design are to keep the feeling of a premium and quality product, even if it is used for longer and multiple times. Another aspect is to keep up the customers' interest for the machine and make it possible to incorporate new technology and user benefits in the older machines. Related to this is to keep the machine within regulatory boundaries over a longer time period. Until now, regulations have been focusing on emissions; though, what demands will need to be stressed in the future might be hard to anticipate. Having machines that run for longer, will mean that they must be able to adapt to new regulation during the period.

The company has not yet developed a concrete plan for what a circular business model would look like. It will require time and competence to come up with a model that is profitable and suits customers, users and the company (Interviewee 2 2016). If a transition towards a functional sales business model is done, in simple terms, it could mean that the focus ultimately shifts from: "*manufacturing a wheel loader*" to "*solve the customers*' tasks more efficiently". A use centred development process will be a key to meet the demands of a functional sales business model, with an inherent user focus.

5.4.10 Organizational structure

The last key area concerns the organizational structure and strategies of the company. During interviews at product development departments, sales departments, at site with dealers, remanufacturing representatives and with advanced technology department it was concluded that information sometimes has trouble to find its way between departments. In some cases, there seems to be a shortage of communication between sales, remanufacturing and product development, which leads to that some possible opportunities for the company, the customers and the environment might be overlooked.

Making important information easier to share between departments would benefit the company and make it easier for new ideas to grow. If the environmental issues were better recognized, they could be developed and lead the way into a more environmentally sustainable product. An improved structure to facilitate communication and cooperation can have huge innovation potential and be beneficial for most stakeholders.

5.5 Key area evaluation

Table 2 presents the evaluation criteria which evolved during the prestudy, and worked as sounding board to stress the relevant aspects in the project. The first two criteria are based in the thoughts from circular economy resource efficiency. Other aspects are relevant for the project to stay within the scope, time limit and make best use of competences. Other aspects assisted in the communication with the company, about how close to current work the final concept should end up.

Table 2: Evaluation criteria with explanation

Evaluation criteria	***Explanation***
Material resource efficiency	*The concept's potential to offer a reduction of environmental impact compared to the existing solution; in regards to extraction of new raw material according to Volvo's internal "sustainable materials report". If applicable, quantitative figures from LCA should be used to back up the result.*
Energy efficiency	*The concept's potential to offer a reduction of environmental impact compared to the existing solution; in regards to fuel efficiency and energy consumption in production etc. If applicable, quantitative figures from LCA should be used to back up the result.*
Innovation potential	*How much the concept is expected to allow for, stimulate, and/or require innovative solutions.*
Volvo benefit	*The suggested concept's expected ability to generate revenue, goodwill and developed customer relations for the Volvo company.*
Customer benefit	*The extent to which the concept is expected to create customer value by offering a reasonable price over the life span (TCO) and/or satisfying customer needs to a higher extent than current solutions. For instance, equipment efficiency, reliability, employee work environment etc.*
User benefit	*To what extent the suggested concept is expected to satisfy user needs; ergonomically (physical and cognitive), manoeuvrability, overall impression (quality, esthetical), maintainability etc.*

Societal benefit	*The concept's potential to generate benefits/value for the society by for instance creating work, reducing transportation, decreasing noise and pollution in the immediate surroundings of sites etc.*
Volvo capability/ competency	*To what extent Volvo (CE) currently has the capability and/or the required competency to exploit/further develop a solution within the suggested field.*
Competency	*To what extent an expected solution is considered doable with our competences and the extent of the thesis.*

All evaluation criteria are important, but some more so than others, as can be seen in Table 3, showing how the criteria were weighted. The highest rated criteria are *resource efficiency* and *competency;* to ensure that those criteria guided the project to the desired end-result, dictated by the project aim. *Energy efficiency* comes next, since that is of big environmental importance, also in line with the project aim. *Customer, user* and *Volvo benefit* came next to make sure those three stakeholders were acknowledged in the new concept development.

The *societal benefit* is another important aspect, since it one of the main pillars for a sustainable solution. *Innovation potential* is rated quite low, since the focus of the solution was to be implementable rather than induce system change. More impact can be done if entirely new solutions are developed, but part of the aim was to show that much can be done for the environment also in the existing system. Lastly, the solution should be compatible with the wheel loader and the business model; however, if that solution is built on in-house knowledge or not, is not considered very important.

Table 3: Weighted criteria

Criteria	***Weight***
Volvo competency	1
Societal benefit	2
User benefit	3
Customer benefit	3
Volvo benefit	3
Innovation potential	2
Competency	5
Material resource efficiency	5
Energy efficiency	4

From the weighted evaluation, *repair and maintenance* stood out as the criteria with most potential for this redesign process, as can be viewed in full in Appendix III, after receiving high scores in every category. The area is especially interesting, since it becomes a very important aspect to consider in a functional sales scheme. Thereto, the area is closer connected to users than most other areas, in this case the service technicians, which is deemed positive for the exploration of the use and sustainability centred development process. Another factor that made repair and maintenance interesting to work with, was the fact that disposable parts from the repair and maintenance category stood out in the conducted LCA as a major source of impact (Salman and Chen 2012).

5.6 FINAL PROBLEM FORMULATION

In a functional sales business model, the revenue from consumables shifts to instead become a cost for the company. The change in revenue stream implies that there might be a potential for design solutions to decrease the need for, and make the use of, consumables more environmentally and cost efficient. The objective will be to reduce the life cycle environmental impact from consumables, which has been identified as a quite substantial impact contributor in the current LCA. The problem formulation is defined as follows:

"There is an extensive environmental life cycle impact during the product's use phase connected to the consumables used for maintenance, such as filters, oils, coolants, tires etc."

Consumables in the case of this study are defined as: "*a part, or component that is added to the machine with certain intervals for maintained performance and extended machine life*". The consumable is often replaced, sometimes based on wear, and sometimes based on a set interval. When replaced, a brand-new piece is installed and the used part is disposed. Examples of consumables on a wheel loader are tires, hydraulic oil-, oil- and fuel filters, batteries, lamps and additives (Prosis 2016).

5.7 SELECTION OF REFERENCE COMPONENT

The *main fuel filter* was selected among the consumables as an appropriate reference product to focus the development process on. The decision to continue to work with the main fuel filter was based on aspects ranging from substantial environmental impact to project practical issues. The main fuel filter is a disposable, which is replaced at almost every preventive service occasions, and is disposed as hazardous material after use. Other aspects making the filter a good component to redesign and try out the development process on, is the fact that it is a component with an unnecessarily high environmental impact, and which allows for proper product investigation prior to redesign, remotely from Gothenburg. Ideally, an appropriate product should have a mechanical function rather than a process or chemical function. It was also important that the rights to the product better belongs to the company for it to work as the reference product. Such product fulfils the competency criteria and is possible to redesign without changing too much of the surrounding system. The main fuel filter lives up to all these criteria and is therefore used as the reference product in the second stage of the L150 case study.

II. CASE L150 - CONCEPT DEVELOPMENT

The concept development stage of the case study is aiming to take the learning outcomes from the pre-study, and by using the use and sustainability centred development process, ultimately come up with a final product concept. The concept is supposed to be relevant in a well-defined and credible future scenario, which is realistic and explicit enough to allow for a quite detailed environmental impact assessment. Furthermore, the suggested solutions ought to sufficiently respond to the pre-defined effect goal defined as:

"To reduce environmental impact from fuel filtration (corresponding to the task of today's main fuel filter) and ensuring that the solution fulfils the adequate requirements from a functional sales business model"

The concept development is made up by a structured process which can be described in three parts; the first part aiming to establish the theoretical foundation for the development process through a holistic system understanding; whereas the second and third parts, respectively, are aiming to generate and refine adequate solutions to the problem, by considering the different aspects of the project foundation described in the prestudy.

The use and sustainability centred development process aims to ensure that the final result can be considered better from an environmental perspective and for the specified user. The credibility of the final concept relies on the solution to be relevant for the defined system and the scope, which is obtained by a structured process and verified by a final concept evaluation in the last step of the case study.

6 BASIC NEEDS AND REQUIREMENTS STUDY

6.1 PRODUCT SPECIFIC SYSTEM ANALYSIS

The structure which is used to obtain the development baseline was system analysis. The existing reference system; the reference context, product, task, the user(s) are all described for in the following sections.

6.1.1 SYSTEM OVERVIEW

The Artefact, also known as the reference object for the study: the main fuel filter, is considered a replacement article or consumable by the company (Interviewee 1 2016). During the fuel filter's useful life, it is static on the machine, filtering fuel with very little human contact. In fact, the filter is only handled by the specified user(s) for a very short period, during mounting and dismounting and when transported and disposed. A consequence of this fact is that the focus of the system analysis will be shifted slightly away from the user and the task and focus more on the context and the product's lifecycle. However, since a part of the objective is to extend the product's life, tasks and users are likely to have a more central role in the suggested concepts, hence are still included in the system analysis.

The main fuel filter is attached to the machine's fuel system. The main fuel filter's objective is to prevent particles to reach the sensitive fuel injectors. Even small particles can cause damage to the injectors, due to the high flow rates in the fuel system. Replacement of injectors is very expensive and tedious (Interviewee 1 2016, Prosis 2016).

When the machine is started, the fuel pump (marked as 1 in Figure 11), feeds diesel with high pressure from the machine's fuel tank up in the fuel system. Before the diesel reaches the main fuel filter (2) it passes through the primary fuel filter (3), for removal of larger particles and water. The primary fuel filter is similar to the main filter, however equipped with an additional water trap screwed on to the bottom of the primary fuel filter canister (4). Both filters are screwed on to a separate fuel filter housing unit (5). The housing is feeding the filters with fuel through several inlets spread around the edge of the filter and the housing then receives the filtered fuel through a hole in its centre. After the diesel has been filtered by the main fuel filter, it is pumped onwards to the six fuel injectors (6) where it is sprayed into the engine cylinders with high accuracy (Prosis 2016).

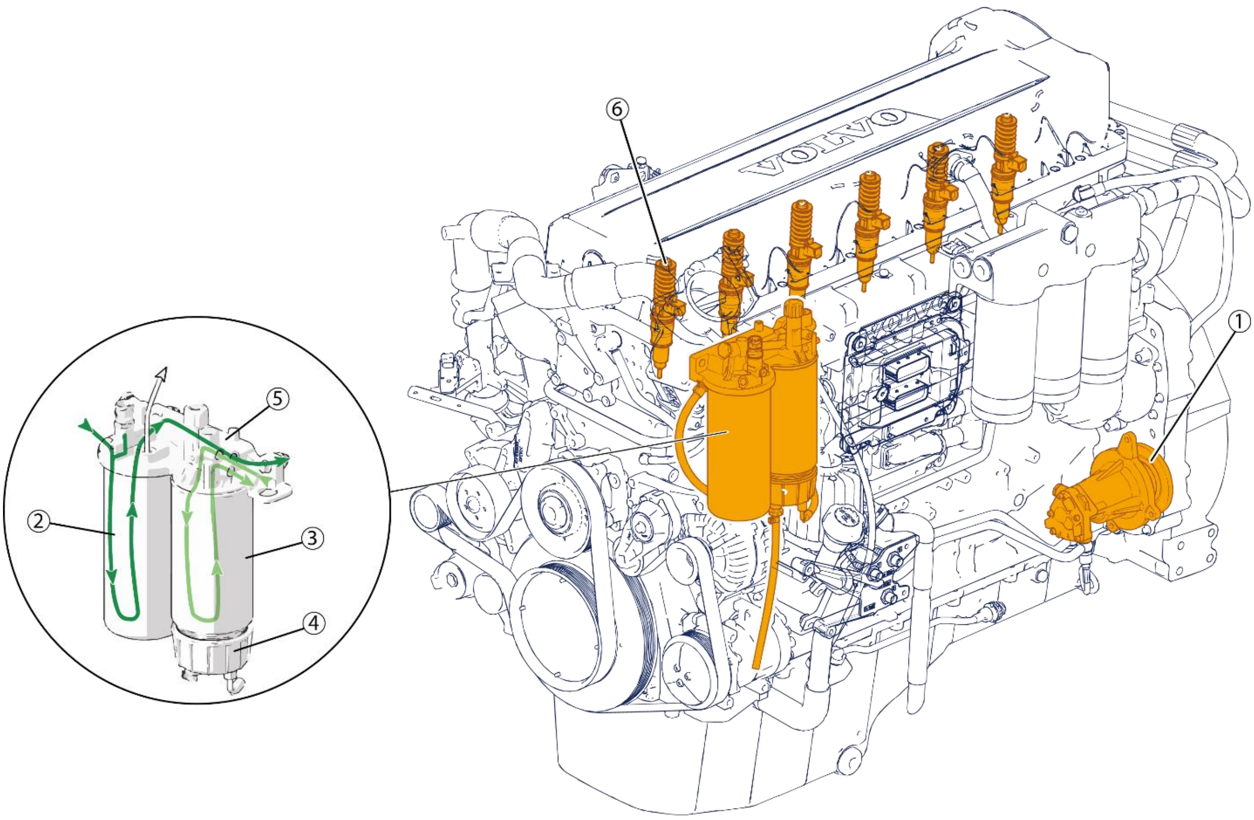

Figure 11: Fuel system overview (Prosis 2016). (1) Fuel pump, (2) Pre-filter, (3) Main filter, (4) Water trap, (5) Filter housing, (6) Fuel injector(s).

Particles enter the fuel system mainly through contaminated diesel, however possibly also due to fuel tank corrosions and during service and repair operations on the system. Contamination of diesel outside the fuel tank is often caused by “poor fuel hygiene”, i.e. deficient diesel storage at the local sites or careless refuelling (Interviewee 1 2016). In some countries, insufficient diesel quality with elevated levels of particles and water in the fuel, is believed to be a consequence of less serious providers, suppliers or distributors (Interviewee 11 2016). Water in the fuel can cause internal corrosion and less efficient combustion (Interviewee 1 2016). Water in the fuel is due to many of the same factors as for particle contamination; however, water in the diesel can also be a consequence of condensate air in storage tanks or the machine’s fuel tank (Interviewee 11 2016). Particles can be both organic and inorganic matter; metal residue from corrosion, sand and dust from the environment etc. (Interviewee 1 2016). In trucks, clogging due to build-up of organic matter on the filter surface is a known phenomenon, caused by bacteria thriving in fuels with high water content (Interviewee 11 2016).

For trucks, the company researchers also have determined that the filter contamination rate is primarily dependent on the mileage, and to some extent also the fuel quality (Interviewee 11 2016). However, a wheel loader, in comparison to a car or truck, consumes diesel for other tasks than only moving forward. Actual diesel consumption is detached from how may kilometres the machine runs; hence, a better indicator for filter change is hours of operation rather than mileage. It is also reasonable to assume that construction equipment in general have more problems with insufficient diesel quality than on road equipment, since these machines are more commonly refuelled from local storage tanks, sometimes of lower quality and with less circulation of fuel. These aspects might in turn cause organic matter to grow and the storage tank to corrode etc. (Interviewee 1 2016). The filters have been developed through empirical testing and the filter life is ensured by ISO-standard specified quality tests (Interviewee 1 2016). The very same filter model is used on machines up to the biggest machine in the company product portfolio, the L350 (Prosis 2016). These facts indicate that today's preventive maintenance concept, based on operable hours might not be optimal, if the fuel filters alone were to decide the service system design.

6.1.2 System model

The overall system goal is to filter fuel in order to reduce the risk of particles reaching and inflicting damage on the engine fuel injectors. To understand how this goal is fulfilled, the system is broken down into sub-systems and system components and illustrated in the system models in Figure 12 . The system model describes the connections between the system components within the system and sub-system boundaries. The model also describes how the subsystems interact over the system boundaries. Furthermore, the model illustrates some system entities which might affect the system from outside the system boundaries, and in which ways. The focus is on flow of matter, information and energy; however, it also includes the different external factors for the different sub-systems which are thought to have impact on the system performance in some way. The most important system components: *user* and *artefact* are marked out in the illustration. The flow of energy and matter in the artefact sub-system is quite complex, however it is a quite good illustration of how the components are attached and interact.

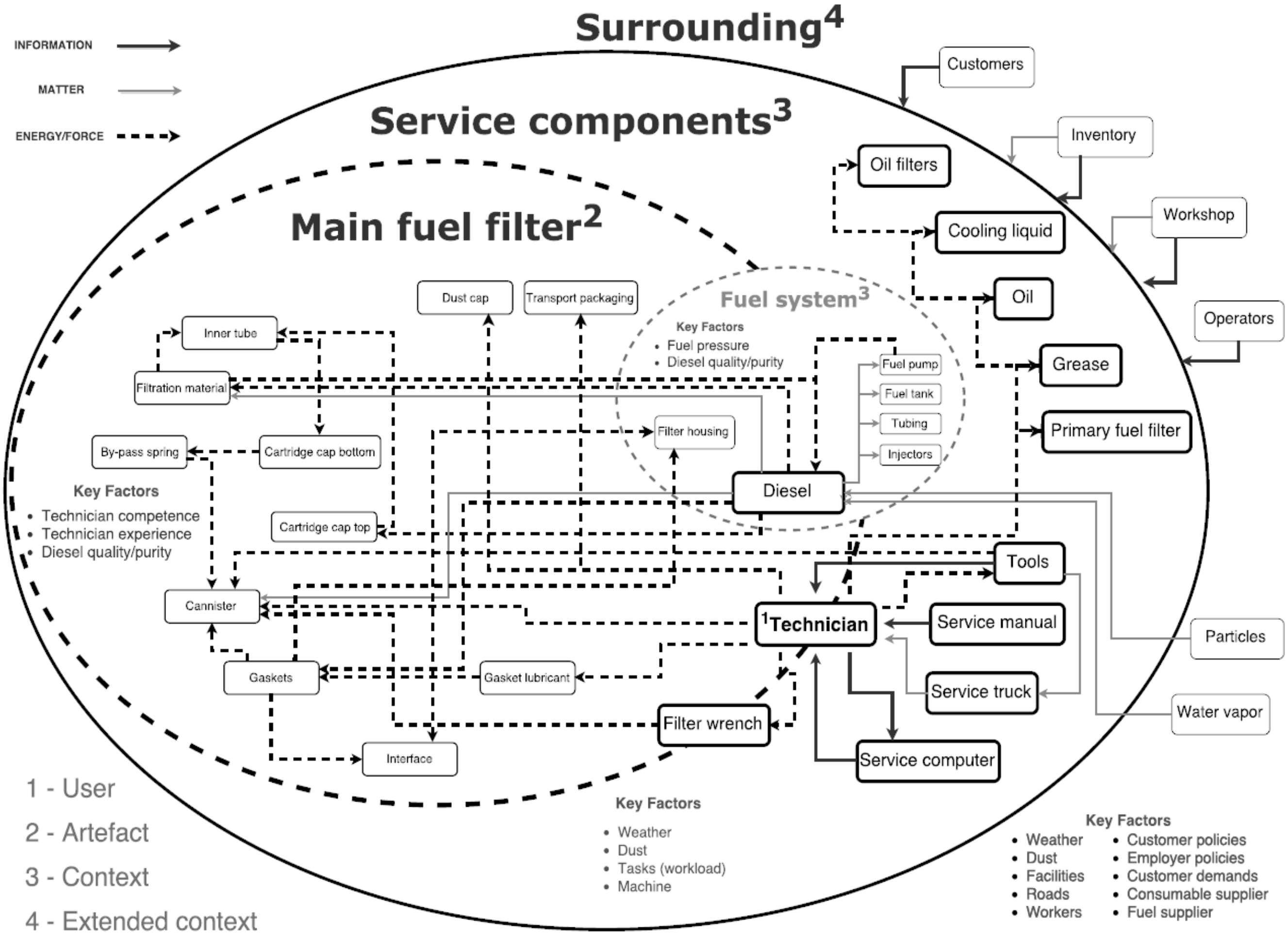

Figure 12: System model for the main fuel filter. Illustrating connections and flows between system components and over the system boundaries.

The main system boundaries, marked with s black dashed line in Figure 12, is framing the system elements which make up the fuel filter and contribute to its function. The elements which are enclosed by the sub-system boundaries (dashed grey) are considered to have a strong connection to the artefact and influences its function to a high extent. The outer system boundaries contain the *service elements*; these are considered to influence the main task, i.e. the filter exchange. From outside the system boundaries, contextual factors contribute to the system performance; these are further elaborated in the *context description* in the following chapter.

6.1.3 CONTEXT

Much of the environment description in the *context* paragraph from the *system analysis* of the wheel loader, presented in the *prestudy* (Chapter 5.2), is also relevant for the fuel filter system described in this chapter. In addition, with the complementary *scenario* description in later chapter (6.1.6.3), the overall context and related problems is believed to be covered on a general level. Although, a complementary description of the influencing factors from the context, which are identified to influence the system performance follows in this section. The *key factors*, visible in the system model in Figure 12, are presented according to the different sub-systems: *fuel filter*, *service components*, *surrounding* and the subsystem, *fuel system*. The most important aspect from the individual system layers are presented next.

SUBSYSTEM: MAIN FUEL FILTER

Within the inner system boundaries, the filter replacement is dependent on the technician's skills and expertise. These aspects are assumed to be related to the background and training of the technician. However, the replacement hygiene can also be connected to the user personality. The replacement aside, the main fuel filter performance is as previously mentioned affected by diesel quality; which in turn is dependent on suppliers, storage tanks and refuelling hygiene.

MAIN SYSTEM: SERVICE COMPONENTS

The success of the service and the possibility for the technician to ensure a high level of replacement hygiene, is believed to be affected by external factors such as the weather, light conditions and dust. The user's ability to perform the designated task, is also affected by the character of the different tasks (type and workload), the machine's serviceability and the service policy and instructions from the machine manufacturer.

EXTENDED CONTEXT: SURROUNDING

In the extended context or the surrounding, several different aspects have been identified to influence the service operation. It might be quite static factors such as roads and facilities, the quality of replacement parts, the customer's demands and policies and the employer's equipment, policies, procedures and schedule. However, it can also be more dynamic factors such as the weather again, workers in the site, client location, and unexpected additional repair etc.

6.1.4 ARTEFACT

As a support to understand the system, challenges and potential problems in the existing artefact, the existing main fuel filter is described in this chapter. The described artefact is also the subject of comparison in future concept evaluation. For the sake of the sustainability focus, a complementary description/analysis of the reference artefact's life cycle is also presented in this chapter.

6.1.4.1 MAIN FUEL FILTER DESCRIPTION

The main fuel filter, seen in Figure 13, is classified as a static product from a human factors perspective, since it is not actively used by a person throughout most of its operable life. From an environmental perspective, the filter is classified as a passive product, since a very small part of the product's environmental impact can be attributed to its use-phase (no direct consumption of resources); but is rather connected to the production and end-of-life stages. Also, within the scope of this analysis, the filter is not sold as a shelf product, but is included in a service package, which implies it is rather an industrial product than a consumer product. This fact might have implications on what information needs to be presented, packaging design, product appearance etc. (Kotler et al. 2011).

Figure 13: CAD rendering, representing the main fuel filter

The exploded view in Figure 14 illustrates how the various components are put together to form the filter. After the primary filter, diesel enters the main fuel filter housing as described earlier and further through eight holes in the filter interface plate (3) and into the filter canister (9). The interface is held in place with the retainer sheet (2), which is also encapsulating the entire construction. The bypass spring (8) in the bottom of the canister prevent dangerous pressure build-ups caused by for instance unexpected filter clogging. The cellulose cartridge (6) in the canister is supported by an inner tube (5) and capping discs on the bottom (7) and top (4). The diesel pass through the cellulose filter media of the cartridge at a specified nominal flow rate and particles larger than a specified size are filtered out. Filtered fuel continues through the threaded hole in the interface plate (3), back up in the housing and onwards to the engine's diesel injectors. To prevent diesel leakage and mixing of filtered and unfiltered fuel, the main fuel filter is equipped with a rubber gasket (1). The filter comes with a plastic dust cap to prevent contamination of the filter prior to assembly. The filter canister is coated with a protective layer of powder paint.

Figure 14: Main fuel filter, exploded view. (1) Gasket (2) Retainer sheet (3) Interface plate (4) Filter element cap (5) Inner tube (6). Filter element (7) Filter element cap (8) Bypass spring (9) Canister

Component information, as well as instructions for appropriate handling and assembly is printed on the canister in blue print (Figure 15) A breakdown of the filter into the separate components, with functions and material content specified, is supplied in Appendix IV (Interviewee 1 2016, Prosis 2016).

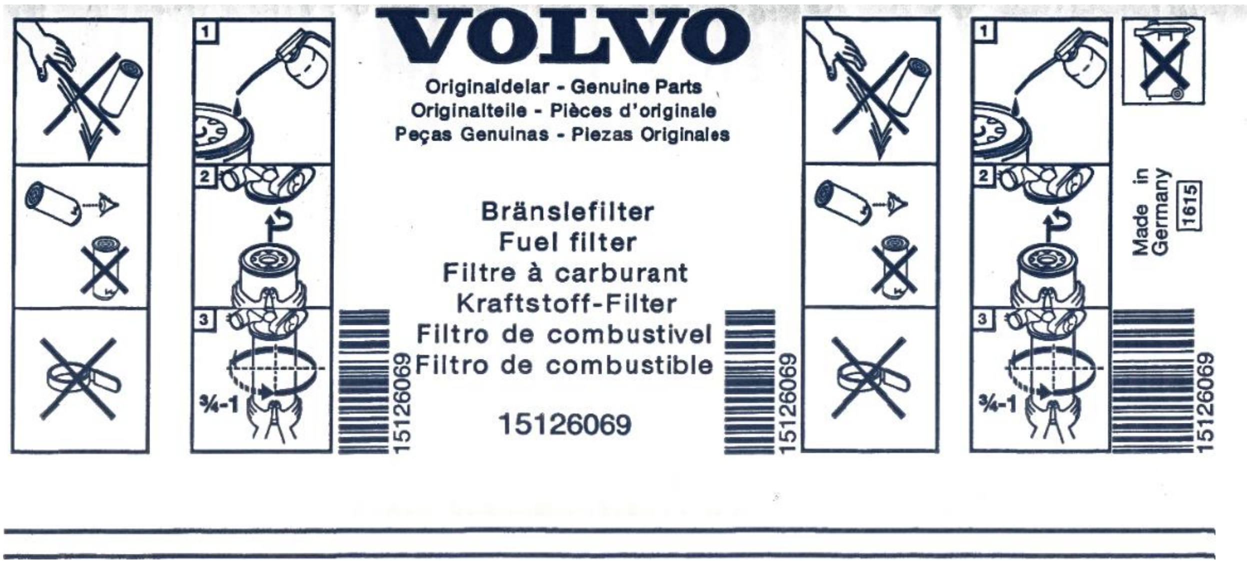

Figure 15: Main fuel filter decal, showing product information and use instructions to the left and right.

As a part of the analysis of the existing system, the functions are identified and explicitly defined in this section. The current functionality is important both for system understanding and for deciding which functions are essential for the main functionality, hence necessary to keep in future concepts. In the previous artefact dissection (Appendix IV), the functions are combined with the respective fuel filter parts to further enhance the understanding.

PRIMARY FUNCTION:
The primary function of the main fuel filter is to prevent particles in the fuel, larger than a specific size measured in micrometres, to reach and damage the engine fuel injectors.

SUB-FUNCTIONS:
- Enable attachment to machine
- Resist fluid pressure
- Separate clean and contaminated diesel
- Ensure downstream side remain uncontaminated
- Contain diesel
- Prevent diesel spill
- Allow diesel to flow without pressure to drop more than a specific MPa.

SUPPORT FUNCTIONS:
- Provide user with product information
- Provide user with use instructions
- Prevent pirate copying of product
- Express company genuine product.

6.1.4.2 PRODUCT LIFE STAGES OVERVIEW
An overview of the different life stages for the reference product is illustrated in Figure 16 and the stages are elaborated in the following sections.

PRODUCT REQUIREMENTS ENGINEERING
The company has no own development or manufacturing of filters, but instead have suppliers that provide them with fuel and oil filters. Hence, the initiating stage in the fuel filter life cycle is to define the product requirements, and an important part in this process is the communication between company and supplier. The company and the suppliers have a close cooperation during the filter's development process. The company receive guiding requirements from the injector manufacturer, which are translated to filter performance (technical) requirements and passed on to the fuel filter supplier. The sensitive injectors are the primary dimensioning factor for the fuel filter design; thus, the injector requirements specify nominal values for filtration capacity, pressure and flow rate. Additional filter requirements come from housing specifics, standards and legislations, transportation and the serviceability area (Interviewee 1 2016).

DESIGN
The filter producer design the fuel filter according to the company performance requirements. Thereto, manufacturing details are probably specified in this stage.

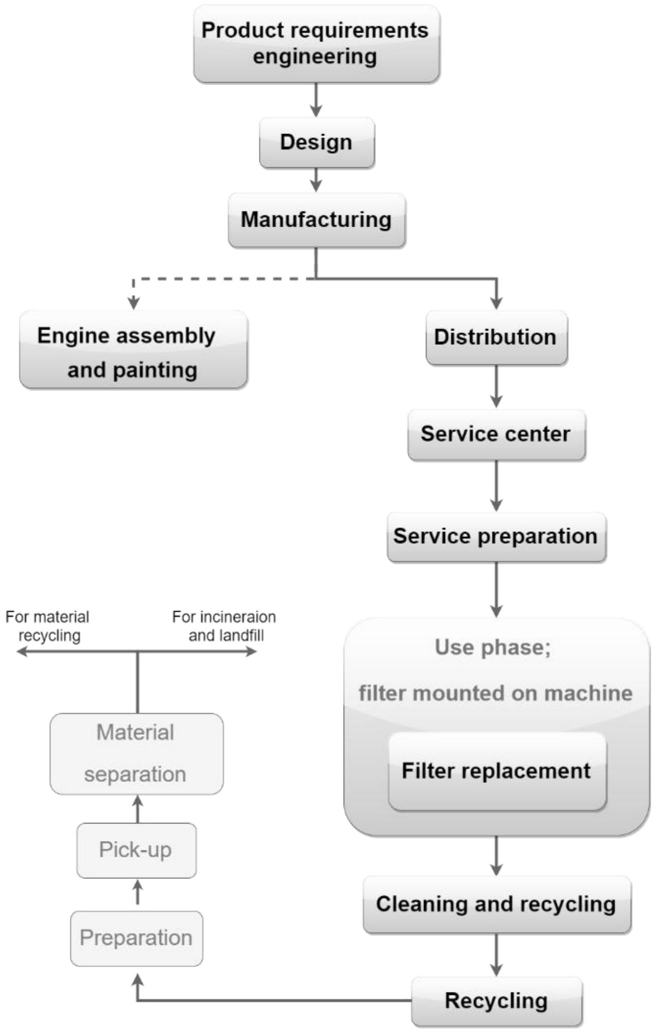

Figure 16: Filter life stages overview

MANUFACTURING
The filter is manufactured at the filter supplier's manufacturing facility in Germany. It is assumed that some components arrive ready-made or as bulk material to the manufacturing facility, where filters are assembled and packed. Detailed manufacturing procedures for the different filter components are presented in in LCA, Appendix XX (Chapter 4.2).

DISTRIBUTION
Most the filters are shipped off to central storage facilities for redistribution to local service centres, whereas a small number of filters are sent to the vehicle engine assembly line, where they are mounted on the new engines before painting.

ENGINE ASSEMBLY
The filters which are sent to the engine assembly line are mounted on the assembled engines in order to prevent contamination of the fuel system and also to allow for performance testing of engines before shipping. Today, engines (maybe not all) are painted with mounted fuel filters which lead to the decals being painted over (Interviewee 3 2016).

SERVICE CENTER

Filters arrive on-demand to the service centres, where they are packed in designated service boxes for the particular service, together with other service products (Interviewee 3 2016).

SERVICE PREPARATION

Service technician receive information about the service and pick up the corresponding service box and required equipment at the local service centre. Some services are performed in-house, but for most services the technician will have to pack his service truck and drive to the customers (Interviewee 3 2016).

FILTER REPLACEMENT

At arrival, the technician unloads the service box and the equipment and perform the service operation according to the procedure which will be described in detail in the task analysis (Chapter 0). Used filters are placed in the box, in order to prevent diesel from contaminating surrounding and the technician. The box is then loaded onto the service car (Interviewee 3 2016, Prosis 2016).

CLEANING AND RECYCLING

When the technician returns to the service centre/workshop, used filters are placed in the designated recycling container, together with oil and diesel filters of various types and sizes. Packaging materials etc. are thrown away in designated containers and if necessary, the service car is cleaned (Interviewee 3 2016).

FILTER RECYCLING

When the recycling container is full, the recycling company is contacted. The recycling company pick up the container at the service centre and transport the filters to their local recycling facility in Gothenburg (Interviewee 3 2016). Thereafter, filters are again collected, now by a specialized recycling company.

At the recycling facility in Halmstad, the container is emptied onto a conveyor and the filters are transported to a shredder together with oil and fuel filters from other applications, such as cars, trucks, busses and other heavy machinery etc. (RagnSells 2016).

Oils and fuels are separated from the mix in a centrifuge and the oils regenerated if there are economic incentives to do so. Steel is separated with magnets and sent to materials recycling and the remains are sent to incineration and energy recovery (RagnSells 2016).

USE-PHASE

The filters are dimensioned for 500 hours of machine use. The diesel flow, hence the filter wear/contamination vary with the tasks and to a high extent also the purity level of the incoming diesel (Interviewee 1 2016).

6.1.5 TASK

The specified task in the hierarchical task analysis, presented in Appendix V, is based on the entire standard service scenario carried out every 500 hours. The task is defined as: "*the standard service operation with focus on the filter replacement*". The stages which are considered being of most concern for the main fuel filter are highlighted in the figure and the essential steps of the process are explained in the following paragraph.

The replacing procedure starts with the service technician bringing the right filters to the machine on site, turn the machine in service mode, detaches the existing filters with a filter wrench and put the used filter in a container to bring back to the workshop. Three oil filters and two fuel filters are replaced at this interval (Prosis 2016). The new filter is unpacked and the dust cap is removed, the rubber gasket is greased with motor oil, the filter is screwed on and tightened. It needs to be screwed until the gasket is against the machine interface and then another three quarters to a full lap, according to instructions on the filter. The technician needs to bleed the filter, which is done with a hand pump, it requires 2-300 strokes to build up the pressure and get rid of air in the system. The entire procedure takes about 0.7 hours (Prosis 2016). The used filter is sorted in a container for hazardous waste together with other fuel and lube filters. It is picked up when full by a recycling company (Interviewee 3 2016).

6.1.6 USER(S)

As been identified before, the existing reference object is exposed to very little user contact during its entire operating life of approximately 3 months[3]. Identified direct contact is more or less only made at two occasions; at mounting and dismounting (Interviewee 3 2016). However, since one of the main objectives was to extend the filter life, it has been deemed important to still maintain a user perspective, including the identification of the potential user characteristics, special considerations and the actual user needs.

The identified users are described with support in user description and classification theory and the primary user description is then complemented with a persona and a scenario in the following paragraphs.

6.1.6.1 USER CLASSIFICATION

The identified user types are divided according to their relation to the artefact.

PRIMARY USER(S)

Since the task in this analysis has been defined as "*the standard service operation with focus on the filter replacement*" the primary user is identified as the *service technician;* the person who will perform the service hence the filter replacement.

SECONDARY USER(S)

Secondary users of the reference object are service centre personnel (order filter, plan service, pack service boxes etc.), waste treatment personnel (collect filters), recycling personnel (collect filters and manage the recycling procedure) and possibly also the after-market retail personnel (selling the service and service components).

SIDE USER(S)

Side users are consumer (indirectly pays for filter), machine operator (rely on filter functionality), product designer, service designer (design procedure and overall service system in which filters are a part), manufacturing personnel (assemble and pack filters) and possibly performance testing engineers (test filters in protected environment). Side users are in different ways in contact with the products, but for different reasons than the main functionality. Amongst the examples, the manufacturing personnel is in most physical contact with the product and hence needs to be considered.

CO-USER(S)

Co-users might be other service technicians and workshop personnel; performing similar service tasks and using the same tools, or performing other mechanic work on the machine.

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[3] 500-hour interval/40 h a week = 12,5

6.1.6.2 USER INFLUENCE ON PRODUCT

The users or stakeholders which have been deemed to affect the needs and requirement for the fuel filter are outlined in this section. The influence from these four users has also led to the decision to have them represented in the following concept development criteria. The different stakeholders use and motives are outlined.

OWNER

According to our study, the customer or owner is primarily concerned about two aspects in regards to fuel filter: high up-time and low cost (Interviewee 2 2016, Interviewee 5 2016). Up-time is in turn dependent on two aspects: mitigating the risk for unplanned stops and designing efficient service (few and short). The customer often buy the filter as part of a service agreement, thus the cost in this case rather refer to the total cost of ownership (TCO) than the individual filter price. The owner might also affect the fuel filter design and performance through the diesel quality put in the machine; through the selection of diesel providers and maintenance of storage tanks etc.

OPERATOR

The operator seems to have little influence over the product design and whether it is bought in the first place. However, the operator may be concerned by the up-time of the machine and especially the avoidance of unplanned stops. The operator influences the filter design and performance through the refuelling hygiene.

SERVICE TECHNICIAN

The technician has some influence over the filter design and later requirement will be focused on responding to this person's needs. It is in the technician's interest that the filter handling is somewhat streamlined and clean, connected to what is referred to as the serviceability. This might include the filter being easy to replace, the procedure does not include additional physical strain (ergonomic handling) and that leakage and spill is prevented during handling etc. (Interviewee 3 2016, Interviewee 4 2016) The technician also influence the filter performance through the replacement hygiene.

SILENT STAKEHOLDERS

The objectives for the silent stakeholders: *the environment* and *future generations,* are not as closely connected directly to the fuel filter; although, the fuel filter system has important indirect implications for these stakeholders. The stakeholder's possibility for prosperity will be negatively affected if natural resources and sinks are exhausted. The environment could be changed beyond recognition if to many ecosystems are exploited in the hunt for more materials leaving difficult life conditions for surviving spices. This will impact future generations and their possibility to live acceptable lives. But the material extraction itself can impact them as well, by exhausting resources today that might be crucial in the future, we leave them in an unfavourable situation for being able to satisfy their basic needs. Both silent stakeholders obviously need help to influence product design and today they are given voices on a couple of different levels in the industry; first, through laws and legislation governing manufacturing emissions, use-phase emissions and end of life treatment. Thereto, the company's own environmental policies give the environment a voice trough sustainability strategies and research; primarily run by the environmental department in this case. A last, but very important, influence is obtained from individuals; designers seeking sustainable solutions and customers choosing responsible alternatives.

VOLVO

Volvo, as a stakeholder is primarily concerned about two closely tied aspects: profit and customer satisfaction (Interviewee 2 2016, Interviewee 5 2016). The first aspect can also include quantities, prizing, manufacturing cost and more. The latter is about sufficiently responding to the previously described customer motivators. However, they are also interested in offering customer security and availability. Volvo influences the filter design and performance through the requirements from the fuel system and overall machine design.

FILTER SUPPLIER

The supplier has high influence over the filter design, though limited by the performance requirements provided by the company (Interviewee 1 2016). The supplier's primary concerns are believed to include fulfilling the performance requirements, maintaining the business relation with the machine manufacturer to generate revenue. The latter from cost efficient production, selling large quantities and to the right price.

6.1.6.3 PRIMARY USER DESCRIPTION

User variations might occur for filter replacement on machines without a service agreement, i.e. non-licensed service technicians or machine owners performing the service on their own; these users are however considered outside the project scope, hence not taken into consideration for future design suggestions. The user described in this section is a version of today's service technician. This user is believed to correspond quite well a hypothetic company hired technician performing the service in the future functional sales business model.

USE PROFILE

The user expertise and experience have been identified as important factors, affecting the concept design. The primary user is an *expert user,* in regards to how the product is used. Thereto, the technician has a high level of knowledge about the domain, the product itself and how it works in the system. The user has very high experience in using the product; although, the direct use situation is short (Interviewee 3 2016, Interviewee 4 2016). The high level of expertise and experience means that, for instance the need for instructions will be quite limited.

PERSONA AND SCENARIO

To communicate the user preferences, considerations and the user needs, a persona is developed. The persona is based on interviews with technicians and the company and on field observations. One single persona has been considered enough for these purposes, since compared to many consumer product users, the reference object user group is quite homogenous for the stated case and the possible variations within the group has been deemed unlikely to affect the filter design. As a complement to the previous task description, a scenario has been incorporated with the persona, to communicate the user's subjective experience from performing the task and to highlight the potential problems in today's use situation. The scenario-type addition, which is placing the user in the actual environment is also thought to emphasize the previously presented contextual descriptions and how the contexts will have different consequences for the user, task and artefact. The complete persona and scenario is presented in Appendix VI and a persona summary is supplied below in Figure 17.

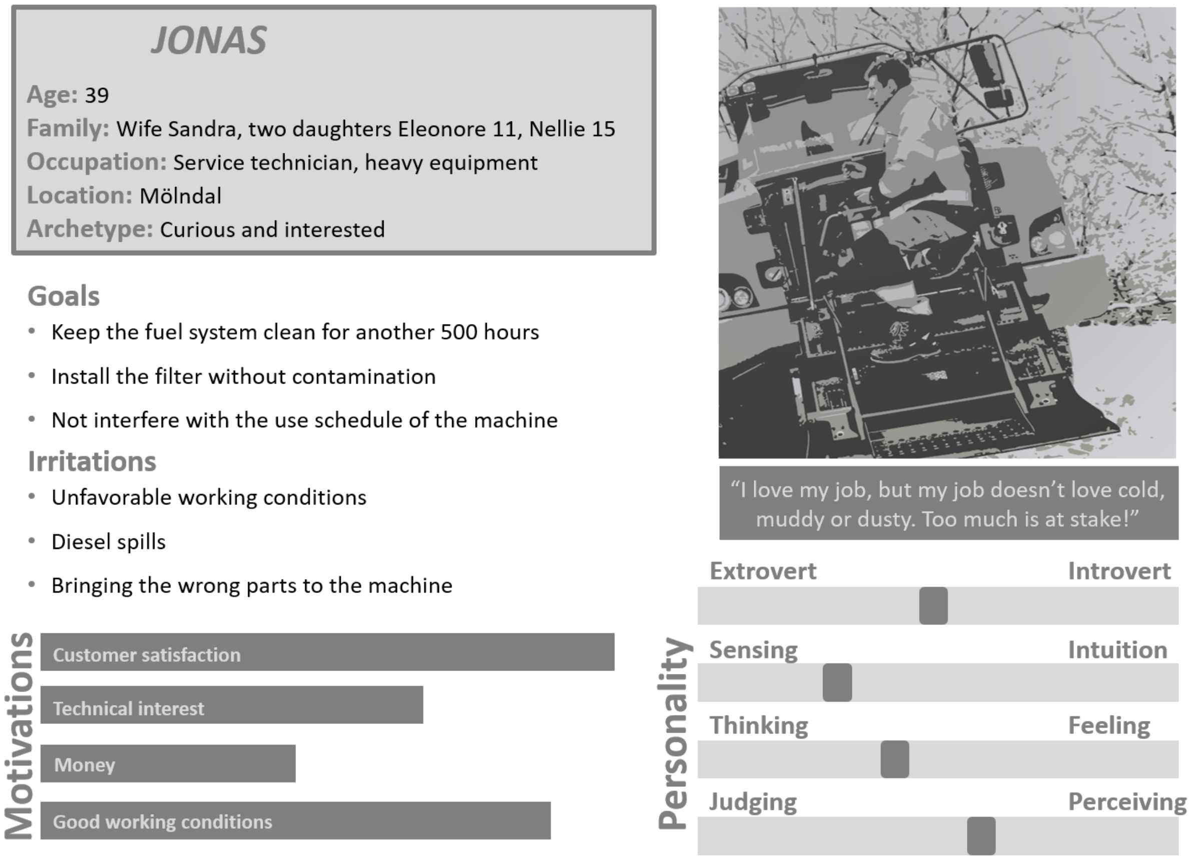


Figure 17: Persona summary, Jonas. Used in the product development process to obtain and communicate a uniform understanding of the user

6.2 PROBLEM IDENTIFICATION AND ANALYSIS

The system analysis of the fuel filter has led to several conclusions regarding actual and potential problems, which all must be considered for the conceptual solution to achieve the desired effects. In this section, problems are identified and together with the system analysis result translated into the relevant product needs and requirements. The main problem areas, which have also been the primary subjects for the screening are the sustainability and user related issues. The problems are sorted per theme and presented in the following paragraphs.

6.2.1 SYSTEM DESIGN PROBLEMS

The first and what seems to be the most prominent problem regarding the fuel filters is the fact that the entire filter is considered a disposable, even though a major part of the materials in the filter is not consumed when disposed, according to our filter dissection. As can be seen in Figure 18, the metal and plastic does not seem to be worn when disposed. The filter cartridge on the other hand has some visible contamination after use. The recycling procedure of filters in general is quite inefficient in terms of material recovery (Interviewee 13 2016) and the number of scrapped filters[4] are high (Interviewee 3 2016, Interviewee 4 2016, Prosis 2016), which indicates there is potential to benefit from, by considering design for recycling principles to a higher extent.

[4] Fuel and oil filter together is about 20 units per machine and year

There are indications that the preventive maintenance scheme is not ideal for the Swedish market and leads to premature disposing of the filters. Some of the indicators pointing in this direction are: the lack of incentive to change maintenance system due to the high profitability from today's system, the fact that few fuel filter breakdowns or quality issues have been reported and lastly, from the drive to coincide replacement of fuel, oil and breather filters and other service articles. According to the company fuel filter specialist, the filters could be designed more robust to last longer if the need was expressed (Interviewee 1 2016).

The fact that the filters are dimensioned to work for several machines in several different applications and for different sizes suggests that the filters are not optimized to the various applications; hence, contributes to a loss in potential resource utilisation. The particular main fuel filter is for instance used in wheel loaders up to the largest machine in the range, the L350; in addition, a range of larger excavators and articulated haulers share the exact same filter. This indicates that the fuel filter life could benefit from individual design, condition based replacement or individualized replacement schemes etc. (Interviewee 4 2016, Prosis 2016).

6.2.2 Filter design problems

Design for recycling principles are not included in the filter requirements to the manufacturer (Interviewee 1 2016). The dissection of the filter also reveals that such principles are not sufficiently considered from the manufacturer's side either. This conclusion is based on the observations presented in Table 4, and supported by the images of a dissected, clean filter in Figure 18. The dissection also concluded that non-destructive disassembly for reuse or functional recycling was quite problematic and for some parts, separation was impossible.

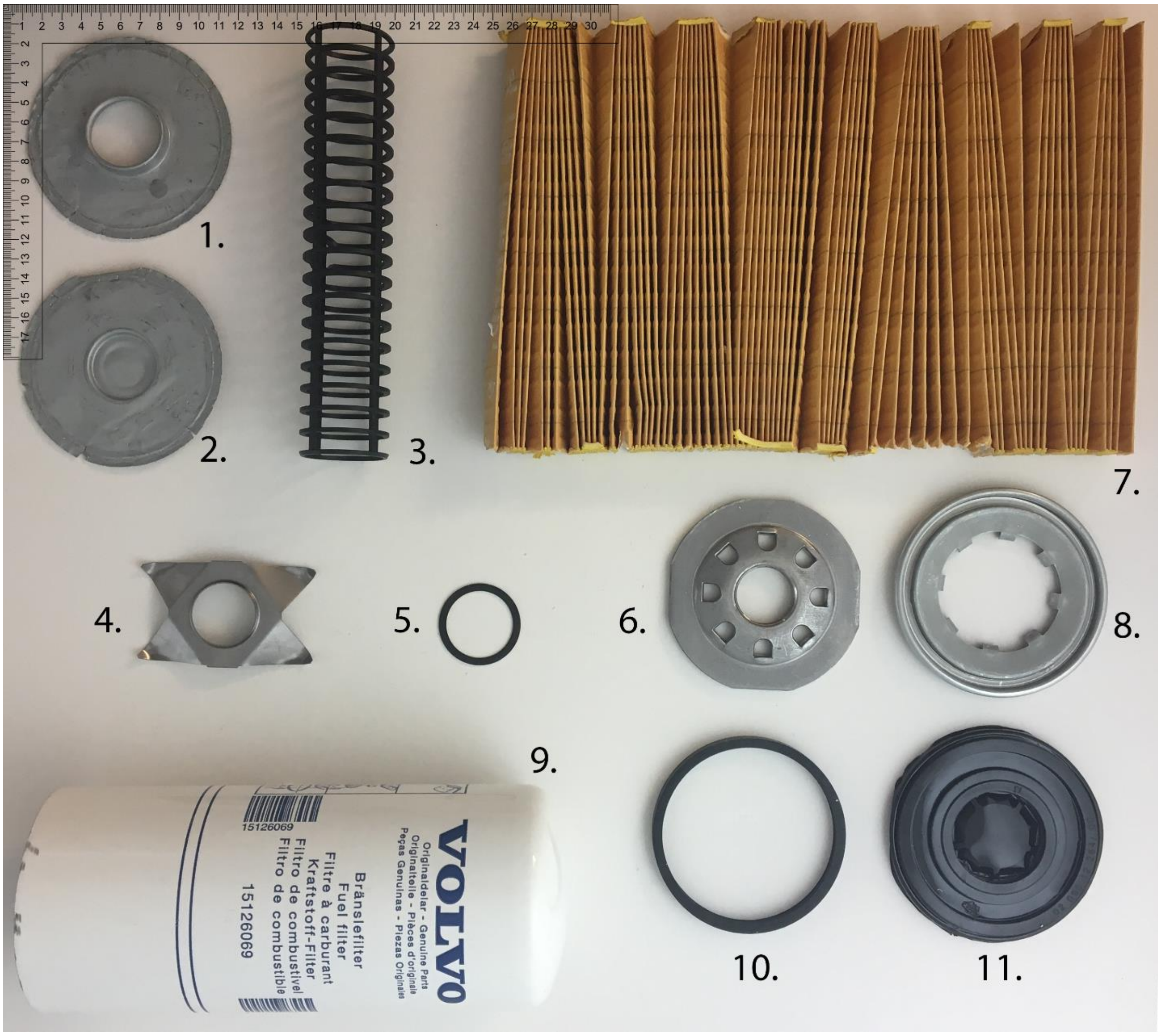


Figure 18: Reference filter dissection. (1) Cartridge cap, top (2) Cartridge cap, bottom (3) Inner tube (4) Bypass spring (5) Rubber gasket (6) Interface plate (7) Filter media (8) Retainer cap/sheet (9) Canister (10) Rubber gasket (11) Dust cap

Table 4: Design for recycling deficiencies identified during dissection and interviews

Design for Recycling principle	Example from reference filter
"Reduce the number of different types of materials"	- A large number of different materials are used in the existing design; NBR, different alloy steel, paint, Different types of plastics and cellulose. (See material content in Appendix IV)
"Different materials must be separable, preferably through disassembly. Otherwise through material fragmentation and material separation."	- The steel caps are glued to the cellulose filter media - The filter media is soaked in diesel and contaminated with particles without the possibility to drain or clean it. - The filter media is a composite of cellulose and various plastics. - The canister is encapsulating the other components through a fold sealing along the top edge
"Use materials for which recycling is possible, and for which there is a demand for the recycled material."	- The filter media does not allow for value recycling (incineration and heat recovery). - The glue and gaskets does not allow for value recycling (incineration and heat recovery). - The sheet steel is downcycled; i.e. used for lower quality applications.
"Mark parts with material type"	- Not all of the individual components are marked according to material content. (some are) - Insufficient recycling instructions comes with the filters.

A conclusion of the findings in the table is that different materials are mixed without the possibility to disassemble the units; which does not comply with the design for recycling principle. Another plausible reason to why filters are not designed to allow for disassembly might be to prevent competitors to design pirate versions of the filter (Interviewee 6 2016). However, in the circular business model, where the company has total control over the selection of service components, the risk for competition from non-genuine products or pirate copies is eliminated.

For a product which is considered a consumable, these deficiencies must be considered somewhat problematic, since the possibility for reuse of components, functional recycling and material separation will be limited. As mentioned, the environmental impact from consumables will be substantial in total, due to high quantities of products, and which are poorly adapted to today's reuse and recycling systems.

6.2.3 Handling and transportation

Since today's filters are considered consumables, they are handled accordingly. During field observations, dents and scratches were observed on the collected, used filters as can be seen in Figure 19 below. As indicated by the same images, the filters were also smeared in diesel and oil.

The machines operate in dirty environments and even though the procedures are well established and the clean filters come with a dust cap, there is still an imminent risk of contamination from particles in the surrounding, either the downstream side of the filter or to the exposed fuel system. Such

Figure 19: Filters collected from recycling dumpster at the service provider. Note the dents from the filter wrench in the left image and the grease and dirt on both filters

contamination could be a serious problem considering the sensitive fuel injectors (Interviewee 1 2016).

Since manual labour is expensive and excessive down-time is highly undesirable from a costumer's perspective (Interviewee 2 2016, Interviewee 5 2016), considerations affecting the serviceability were also included in the problem identification. First, since the filter is "spin-on", the filter gasket needs to be smeared with engine oil to enable tightening (Interviewee 4 2016, Prosis 2016). A different mounting solution has the opportunity to streamline the service procedure. Another potential problem is that there is no real feedback when filters are screwed on tightly, which might cause undesirable uncertainty and variance. Insufficient tightening might also cause additional stress on the components, with excessive wear as a result. In addition, releasing an overtightened filter requires tools, which in turn will inflict damage to the filters, as can be seen in Figure 19.

The way the filter attaches to the machine results in the filter canister to be filled to the edge with diesel (Interviewee 11 2016). This has been identified as a possible cause for diesel spill, hence contamination of the surrounding, equipment and the technician. It is suggested that this fact might also lead to a more difficult dismounting procedure, since the filters must be kept vertical when handled.

Another aspect which needs to be considered for suggested solutions is the fact that in the engine assembly line, the filters are mounted to the engine prior to painting; which means that the first set of filters are painted over with the engine paint (Interviewee 4 2016). This fact needs to be considered for an extended life solution, since instructions are painted over and the appearance is affected. In addition, it can also be argued that the information decals are to a little extent considering design for usability principles; in terms of relevancy to the user.

6.2.4 Rapid Eco Assessment

The reference concept has been screened for sustainability related problems against the Eco strategy wheel principles. Thea summary of the result is presented in the below section and the complete evaluation is presented in Appendix VII.

As been touched upon before, the main fuel filter can be classified as a passive product. This suggests that the filter has its most important environmental impact during the production phase and from end-of-life. Hence these are the phases improvements should be focused towards. However, it can be argued that the weight of the filter contributes to the fuel consumption of the machine on which is mounted and therefore the use phase impact also requires some consideration. However, the allocated contribution[5] from the filter alone is obviously very small.

Although, as the rapid eco assessment indicates, little is done in any of the filter's life cycle stages to reduce environmental impact. There are only a few aspects for which there are clear and conscious initiatives to do so. One is material selection; where the company's internal material selection process seems to have been considered in the supplier requirements. The manufacturing and detailed design related aspects have not been possible to assess to the full extent, due to limited access to information from the filter supplier.

6.2.5 ADDITIONAL CONSIDERATIONS

Additional aspects believed to be contributing to the complete understanding of the problem picture are presented in the following paragraphs.

FUTURE PROBLEMS AND THREATS

There are constantly increasing demands on companies to consider their sustainability work (Interviewee 5 2016, Interviewee 8 2016, Interviewee 9 2016, Interviewee 10 2016) and it is only a matter of time before customers pay attention to the wasted material and demand more sustainable solutions. It is also reasonable to believe that the system of today induce extensive costs for disposal of hazardous waste.

Fuel filters are most likely to be needed as long as today's diesel combustion technology is used, due to the need for protection of the injectors. However, new powertrain technologies are emerging as for the truck and car sectors. For hybrid solutions, a much smaller engine is required and in turn, smaller fuel filters (Interviewee 1 2016, Interviewee 5 2016). And for electrical engines, no fuel filters are needed. Although, companies anticipating the shift to alternative technologies is not a valid excuse of not doing anything about the 6 000 000 filters (RagnSells 2016) that are disposed in Sweden every year; and even less of an excuse for the enormous numbers globally.

Another challenge which involves fuel filters, is the demand for up-time and the cost of manual labour. These facts open the possibilities for service robots, which might be able to perform full services in the future (Interviewee 11 2016), and thereby new kinds of requirements are enforced on the filters.

STRENGTHS AND BENEFITS

Along with the problems regarding the existing fuel filtration system, the analysis has also revealed many of the benefits and strengths of the current solution, which just as well needs to be considered in future concept development.

First of all, the filters work very well; fulfilling the specified performance requirements with few reported quality issues (Interviewee 1 2016). Secondly, filters are good business for the company today and a lot of effort has been put into convincing the customers that the genuine filters are superior. As a result, many customers are prone to choose the genuine filters (Interviewee 5 2016, Interviewee 9 2016). The consumables business opportunity has also a lot to thank the service agreements; since almost all new machines today are sold together with a service agreement

[5] Considering a 1.5 kg fuel filter on a + 20 000 kg wheel loader.

(Interviewee 3 2016), the company remains in control over which service products are used; and genuine filters are used as standard in all service agreements.

A strength connected to the current design, is that the filters are encapsulated, which help maintain cleanliness and avoid contamination. Also, the closed filter design is thought to prevent pirate copying. Lastly, the filters are produced in a controlled manufacturing environment, which ensures sufficient cleanliness (Interviewee 1 2016).

Another strength is that the service procedure in which the filter has a significant role is quite well established among technicians and customers. Also, the service design department has done much to improve the serviceability of the machines and has also improved customer satisfaction by making the service operation as efficient as possible, thus cutting downtime (Interviewee 1 2016, Interviewee 3 2016, Prosis 2016)

6.2.6 Problem definition summary

In order to facilitate the understanding, the problem picture, as identified, is summarized in this section.

MAIN PROBLEM

The main problem, driving the need for the development of a new solution is defined as:

"Environmental impact from fuel filtration seem to be higher than necessary"

PROBLEM BREAKDOWN

The overall problem is broken down in different levels, presented under in the following bullets.

HIGHER LEVEL PROBLEMS

- The filters are considered consumables
- The filters are not reusable
- The filters are not adapted for functional recycling
- Most of the material in the filters still have major remaining capacity after disposal

LOWER LEVEL PROBLEMS

- There is no feedback when the filter is tightened.
- The sealing gasket needs to be greased with motor oil
- To prevent fuel spill during replacement, a container is put underneath the filter during replacement today
- The filter needs to be entirely clean downstream
- Tools might be required for loosening of filter – it is sometimes stuck
- It is quite messy for the service technician to change the filters

6.3 Concept needs and requirement definition

6.3.1 Needs and requirements list

From system analysis and problem picture, together with the project scope a list of initial requirements were created. The needs and requirements are divided in the different areas of: *sustainability*, *functionality* and *use* as seen in Table 5 below. The list is also complemented with additional consideration, under the header: *other.*

Table 5: Initial needs and requirements list

	Category	Need/Requirement	Specifications
1	**Sustainability**	***The solution...***	
1.1		...**must** be less material demanding	over the life cycle, compared to the reference
1.2		...**must** be reusable or recyclable	functionally recyclable and allowing for 100 % material recycling
1.3		...**must not** lead to human exposure from hazardous substances	liquid, fumes
1.4		...**must** consider distribution optimizations	
1.5		...**must not** contain scarce or hazardous materials	according to Volvo's Sustainable materials report
1.6		...**must not** lead to contamination of the environment by hazardous substances	
2	**Functionality**	***The solution...***	
2.1		...**must** prevent particles to reach injectors	larger than XX micrometre
2.2		...**must** comply with existing standards	ISO XXX
2.3		...**must not** induce additional risk of contamination of the fuel system.	
2.4		...**must** resist the relevant mechanical demands	pressure, flow, vibrations and external force
2.5		...**must** resist the relevant contextual demands	corrosive liquids, diesel, oil, dust
2.6		...**must** resist the relevant external contextual demands	cold, humidity etc.
2.7		...**must** be possible to use without major changes of the existing system	today's fuel system and housing
3	**Use**	***The solution...***	
3.1		...**must** be possible to use by one person	
3.2		...**must** be possible to use by the specified user	experienced technician
4	**Other**	***It is considered positive if the solution...***	
4.1		...contributes to decreased total down-time	
4.2		...contributes to a more time efficient service procedure	
4.3		...contributes to a less demanding procedure for the user	in terms of physical and mental load
4.4		...contributes to less transports	
4.5		...allows tracking of component	
4.6		…expresses quality and company genuine equipment	according to expression board

6.3.2 Effect goal

The effect goal for the Concept development process to work with is defined as follows:

"Reduce environmental impact from main fuel filter"

6.3.3 Weighted criteria for concept development and evaluation

The criteria are presented and explained in Table 6 below. User considerations are primary lifted through the task-related *serviceability* criteria and the environmental concerns are stressed through three complementary criteria, to highlight possible environmental contradictions and trade-offs.

Table 6: Evaluation criteria with explanation

Criteria	The criteria consider to what extent a suggested solution...
Serviceability	*...influences the technician's work. Serviceability factors include for instance the number of tasks, time expenditure, difficulty, risk for contamination and ergonomic postures etc.*
Customer benefit	*...responds to the customer satisfaction parameters, such as product reliability, profitability and whether it is compliant with the customer's business.*
Technical and technological feasibility	*...complies with current technical and technological advances, i.e. how the advances support and allow for the suggested solution.*
Concept completion level	*... is going to be described in technical detail; considering the students' educational background, available information and the project extent.*
Company compliance	*...considers and takes advantage of the company's current strengths and abilities; such as current technological engagements, existing business-to-business collaborations and current organizational structure etc.*
Material selection	*...avoids the use of scarce and energy demanding materials, according to the Volvo sustainable materials documentation, and whether it uses recycled materials.*
Energy consumption	*...contributes to reduced fuel consumption over the useful life of the wheel loader. The criteria include the combined effects from transportations, the use phase and possible additional processes.*
Material usage	*...contributes to reduced use of materials in total, over the useful life of the wheel loader.*

The criteria weighting is presented in Appendix VIII and the result (Table 7) is commented on in the below section. Even though the low scores of some of the criteria after the weighting suggest otherwise, it is important to realize that *all* criteria have been considered valuable in the process.

Table 7: Weighted criteria

Criteria	***Weight***
Serviceability	5
Customer benefit	2
Technological feasibility	4
Concept completion level	3
Company compliance	0
Material selection	6
Material selection	1
Energy consumption	7

Material usage and *material selection* turned out to be the highest prioritized factors, which is a natural consequence of the material efficiency focus, from the project scope and the core values of circular economy. The use perspective was considered important for a future solution, which is the main reason to why the *serviceability* criteria ended up on third place. The risk of limiting the concept development made factors such as *completion level* and *feasibility,* as well as *company compliance* all end in the bottom of the prioritization list. After the weighting, *company compliance* was eliminated from the criteria, since it, after discussions was not considered as important as the rest of the factors.

7 CONCEPT DEVELOPMENT

7.1 SOLUTION PATHS

The first step in the concept generation process: the solution path definition, is presented in the following paragraph.

BASIC NEED MANAGING

Amongst the solution categories, this one is located on the highest system level, thus solutions within this category are assumed to have the biggest positive influence on the system's environmental impact. The category is mainly derived from the ecodesign strategy: "*Design for innovation*". Primarily two design related actions are considered adequate for the category and the system as defined; these are:

System/product redesign to…

- Eliminate the basic need
- Reduce the basic need

EXTEND USEFUL LIFE

The category is a derivate of the Eco wheel strategy "*Design for system longevity*". It focuses on either prolonging the product life and/or sub-components. Maintenance programs, refurbishing, reused products are strategies mentioned to prolong product life and remanufacturing and reused components are strategies to accomplish a longer sub-component life. Relevant design related actions which have been identified for this category are:

System/product redesign to…

- Last longer; robust design, durable materials, more efficient (optimize)
- Foster connection with user.
- Allow for reuse of product or components
- Allow for repurposing of product or components
- Allow for refurbish and remanufacturing of product or components
- Incorporate maintenance program to avoid premature scrapping, through monitoring wear and service/repair.

REDUCE IMPACT FROM MATERIALS

The category is a combination of the aspects presented under the ecodesign strategy: "*Design for reduced material impact*" and "*Design for optimized End of Life*". The category includes focus areas such as design for recycling and recycling systems design etc.; and also, responsible materials selection. Design related actions to reduce environmental impact from materials which have been deemed relevant are:

System/product redesign…

- For maintained material value; design for recycling
- For increased product/material return rate
- Of efficient recycling system; labour and energy efficient.
- To become more material efficient; optimize design in relation to performance/structural requirements.
- Responsible material selection

REDUCE INDIRECT USE OF RESOURCES

Compared to the other categories, this category is considered to have the least influence on the system's environmental impact. However, solutions evolved from this category are believed to be quite easily implemented. The category is a combination of the eco strategies: "*Design for reduced distribution impact*", "*Design for manufacturing innovation*" and "*Design for reduced behaviour and use impacts*". Adequate design related actions include:

System/product redesign…

- To reduce impact from transportations; fewer, shorter, lighter
- For shared functions or combined products to reduce overall impact
- To become more resource efficient during use phase; optimize functionality, reduced weight for decreased fuel usage.
- To eliminate/reduce production waste; design for manufacturing and production quality management.
- For production to become more energy efficient.

7.2 INITIAL CONCEPT GENERATION

Eight self-supported functionality concepts are generated and described in detail in Appendix IX. The concepts' relation to the solution paths can be seen in Figure 20. The boxes underneath each solution path represents a path breakdown; where the most relevant aspects for the particular project are highlighted. As the figure illustrates, some concepts are related to several aspects.

The concepts vary primarily in two aspects. First, in how much of an impact they are believed to have on system sustainability improvements; and secondly, in their relative distance in time to implementation, considering technical and economic feasibility.

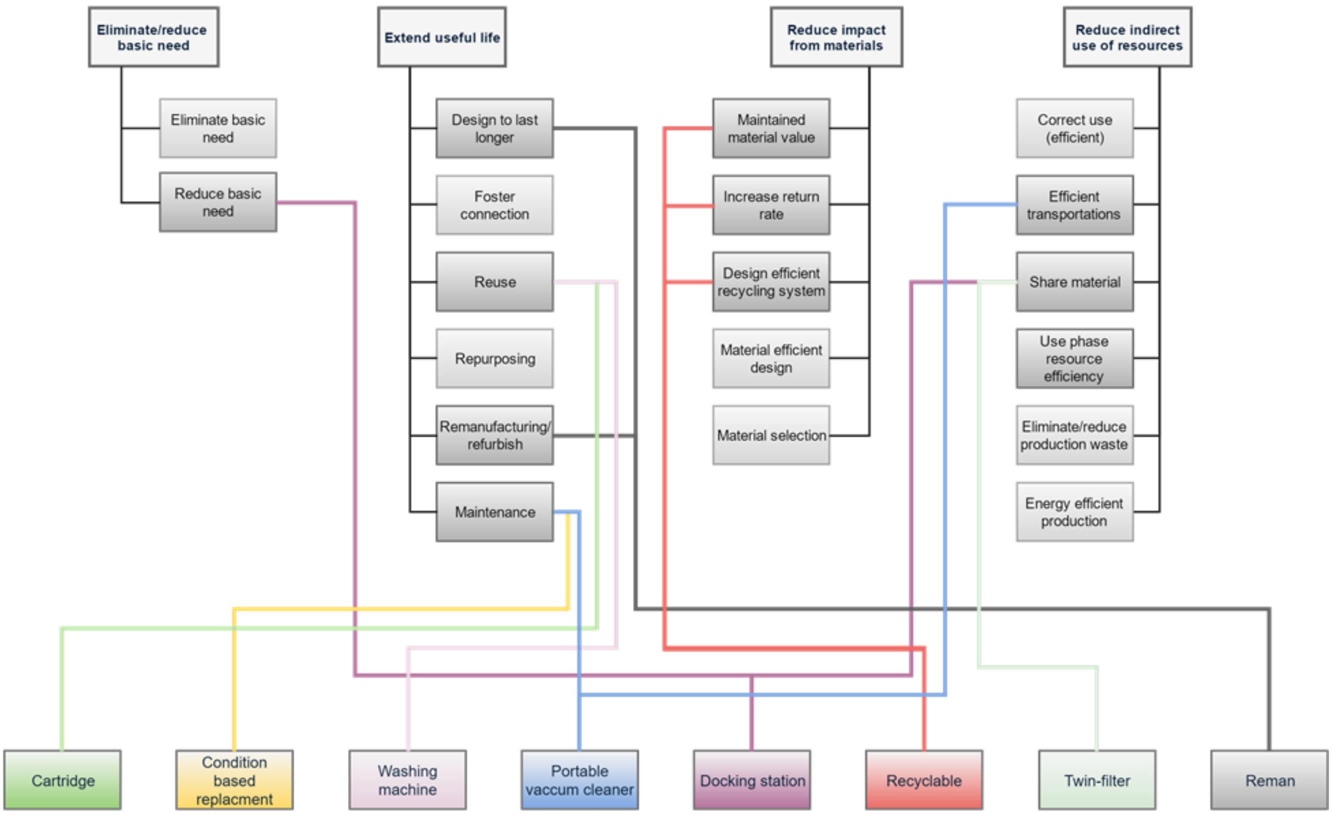


Figure 20: Concept generation overview. The colored lines connect the solution paths with the corresponding concept in the colored boxes. The eight concepts in the colored boxes are described in detail in Appendix IX

7.3 INITIAL CONCEPT EVALUATION AND SELECTION

The eight concepts are evaluated in relation to how well they are assumed to perform in relation to the predefined evaluation criteria, as defined in the previous concept criteria description and weighting (Chapter 6.3.3). The result of the evaluation is presented in Table 8 below and the complete weighted evaluation can be retrieved from Appendix X.

Table 8: Weighted evaluation result. Three concepts stand out: Replaceable cartridge, Filter remanufacturing and Local filter cleaning. These proceed to the next development stage.

			Weighted Average	Compared to average
Concepts	1	Replacable cartridge	17,4	15%
	2	Twin-filters	13,4	-12%
	3	Docking station	13,3	-12%
	4	Recyclable design	15,3	1%
	5	Filter Remanufacturing	17,6	16%
	6	Condition based replacement	13,1	-13%
	7	Local filter cleaning	17,1	13%
	8	Portable cleaning device	14,1	-7%

As can be seen in the table, the result is quite conclusive; three concepts seem to stand out among the rest, all well above the all concept weighted average, as can be seen in the right column. *Local filter cleaning*, *Replaceable cartridge* and *Filter remanufacturing* are selected for further development in the next chapter.

7.4 SECOND CONCEPT DEVELOPMENT

In the following chapter, the three selected concepts are refined to an equal level of abstraction and are then evaluated with the ultimate goal to select the concept which seems to have the most potential, considering the project scope and pre-defined criteria. The focus is still maintained on functionality, rather than product attributes, even though technical solutions will be considered in this stage of the process.

The problems and functionalities which were of most relevance to the effect goal, and the corresponding array of solutions, are presented as the complete mind maps in Appendix XII and elaborated on in the concept descriptions.

In the following chapter, the three remaining concepts are described at an equal level of abstraction; including a background, a process description, a specification of the environmental benefits and a SWOT-analysis, altered for the particular purpose. Thereto, remaining uncertainties and problems are outlined.

7.4.1 Replaceable cartridge

Traditionally, in most filter solution, only the cellulose filter media has been considered a disposable, since this is the only part which is actually consumed. Usually the canister, the bypass spring and interface etc. remain intact. This concept takes advantage of the principle of reusing the full functionally of the intact metal and plastic components. The concept represented in Figure 21 shows how the product solution could look like; a replaceable filter cartridge made entirely in cellulose material. Compared to how cartridge solutions worked in the past, this solution is also adapted for the studied application, use situation and users to counteract the reasons to why the cartridge replacement nowadays has been discarded as an alternative in many applications.

Figure 21: Replaceable cartridge concept, second concept development stage. The used filter to the left is replaced with a new cellulose filter, seen to the right in the figure.

THE PROCESS

How the designed process is anticipated to work is represented in Figure 22 and described as follows: The filter casing is opened and the cellulose insert is removed, the housing is cleaned and the insert is replaced with a new one and the filter house is then sealed and reattached to the machine. The used insert is brought back by the technician and disposed in a certain bin, which can then be sent to a recycling process were the cartridges are centrifuged to extract remaining diesel, and the cellulose fibre is then energy recovered at a district heating facility or possibly sent to a biogas production facility.

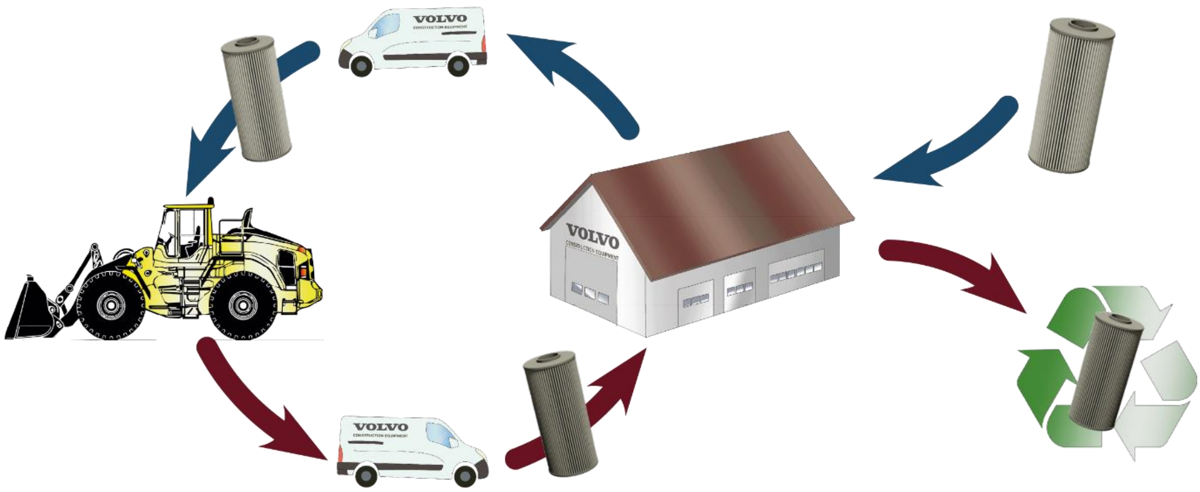


Figure 22: Cartridge concept, schematic overview. Showing the replaceable cartridge's life stages in the service loop, from arriving to the workshop to the recycling.

THE ENVIRONMENTAL BENEFIT

The cartridge solution is sprung out of the circular economy theories concerning how materials should not be disposed if they are not consumed, which in turn will lead to less material use over the life-time. Since the outer casing and the supporting structure can be reused, less material is disposed every filter change and less material is transported. Another benefit regarding the solution is that the materials will be separable, hence also better for recycling purposes in the whole product's end of life phase. Also, the suggested solution includes a disposable which is mainly made from bio-based material (the cellulose cartridge).

SWOT ANALYSIS

The result of the concept SWOT-analysis is presented in Appendix XI. The analysis pointed out the material savings, due to only the cartridge being disposed, as a main strength together with the promising outlook in regards to implementability; since the concept builds on existing and working technology. The primary weaknesses stem from that the solution builds on disposing principles rather than reuse and the fact that the replacement on site induces additional work by the technician. Possible opportunities can be related to the fact that major investments are not required and neither does the solution require big volumes to still gain environmental benefits. There is hence little risk to build a system around a solution which might not be relevant for future business scenarios. Expansion opportunities are also evident, with a solution which could be expanded to oil filters and fuel filters on all construction equipment (and trucks and busses etc.). On the other hand, threats arise with the difficulties to ensure cleanliness during change in the challenging work environment and the related risk of harmful diesel and grease contamination of equipment, tools and people.

REMAINING PROBLEMS AND UNCERTAINTIES AND NEXT STEP

The realization level of a cartridge solution is considered high, since it has been proven to work earlier. However, obtaining the absolute cleanliness in field, despite shifting working conditions, will be the biggest challenge to face if such a concept were to become a successful market alternative. The second major disadvantage of this concept is the additional amount of work required from the service technicians; especially since the extra work also includes exposure to fumes and toxic material. Solving these problems must be a main prioritization if this concept is chosen for further development. Other important potential problems and uncertainties include how to make the canister durable enough to last the entire machine life, and also, how to design the disposable cartridge for an efficient possible recycling. The complete list of identified problems and uncertainties are sorted according to the life cycle stage they are related to and presented in Appendix XIV.

7.4.2 Filter remanufacturing

The second concept, filter remanufacturing build on the principle of bringing the filters back to the company's own facilities to be restored to "as good as new" functional performance, through the appropriate measures. The company's remanufacturing business (also referred to as reman), and the remanufacturing trend in general has expanded during the last decade, as a response to the current depletion of materials resources, causing a raw material costs increase, hence posing a threat to many producing companies. The traditional idea of repairing or refurbishing components, or parts of a component which have been exposed to wear has returned as a strong alternative today. The boom of the reman business can probably be explained by companies identifying remanufacturing as a possibility to generate additional revenue from their already produced components. However, today's technical, technological and logistic advancements have been an absolute necessity for providing an efficient enough reman procedure to make investments economically justifiable. The changing trend has also made product development aware of the benefits of reman, and by incorporating principles of design for remanufacturing, contributed to further extend the reman product range and improve efficiency and profitability.

Although the benefits from reman are many, there are some typical weaknesses. For instance, major investments are necessary for most producing companies; since remanufacturing often require individual treatment of components, as opposed to the linear production line. Also, remanufacturing requires tracking, warehousing, and economic transformation; with the latter including reman components to be considered inventory, rather than sales articles. Another problem lies in how to remain in control of the components over the product's useful life, to ensure they return for remanufacturing. One of the main issues in this lies in motivating the customers, which is especially challenging when the value of the product is decreasing and when the product is leaving the primary customer and possibly ending up on more remote markets. Another limitation with reman is that it is often not considered profitable for smaller and less expensive products, even though quantities are big; this is because of the individual and often manual treatment that is necessary. Furthermore, companies seem to experience problems regarding how to set up the logistic chains (Interviewee 7 2016). Many of the identified issues are resolved in a circular business model, where incentives are created to increase the products' and the individual components' life.

The company has experience in setting up new remanufacturing facilities. Obviously major investments are necessary to set up an automated remanufacturing line. However, the large amount of quite undamaged filters, which end up in recycling facilities today offers an opportunity, just waiting to be exploited. In addition, a disposed filter equals hazardous waste, which needs to be handled accordingly, through costly procedures. For the concept to be economically and environmentally justifiable, the idea is to expand the filter remanufacturing to include all filters which are changed with the same intervals, i.e. the primary fuel filter and the three oil filters.

THE PROCESS

The suggested reman procedure illustrated in Figure 23Figure 23 is aiming to bring the filter back to as good as new standard. First, the contaminated filter is removed from the machine and exchanged for a remanufactured filter. Used filters are placed in the sealed transport container in which the remanufactured filters came. The container is brought back to the workshop and placed on a pallet, which is sent to a reman facility regularly in return for a pallet of remanufactured filters. In the reman facility, the filters are opened and brought back to as good as new standard (depending on filter media the filtering cartridge is replaced with a new one, or washed.) The filter is then resealed and put back in the transport container waiting to be returned to the service centre. The controlled environment in the reman facility guarantees a clean product. The disposed filter material and/or washing liquids are taken care of at the remanufacturing facility and treated in an, for hazardous waste, appropriate way.

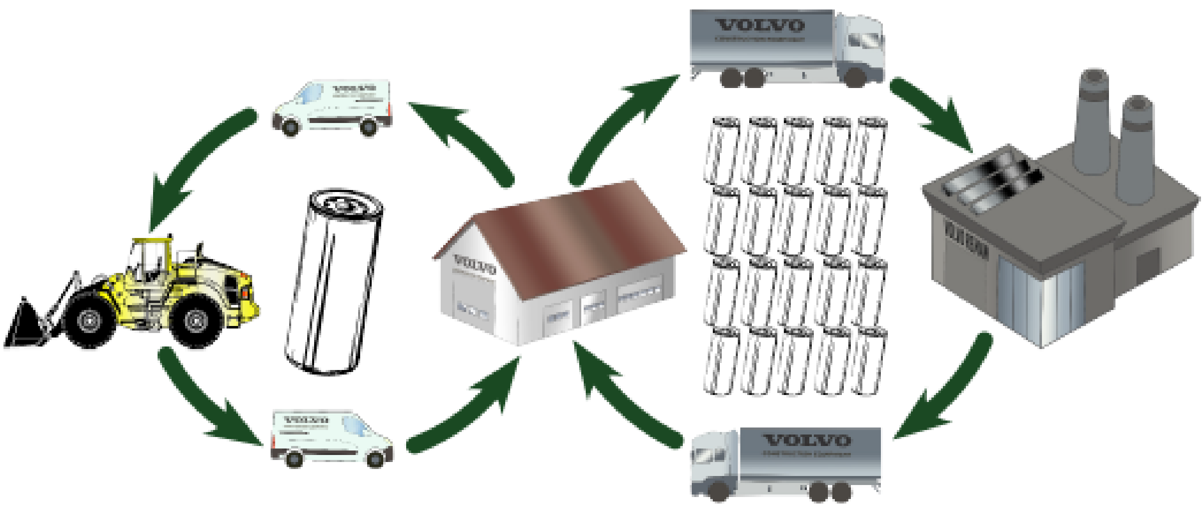


Figure 23: Remanufacturing process, schematic overview. Illustrating how the washable filters are moving within the service loop between the wheel loader, the workshop and the remanufacturing facility.

THE ENVIRONMENTAL BENEFIT

Materials are used more efficiently, since they stay in the technical loop due to remanufacturing. Only materials used in the remanufacturing process, such as the waste water and damaged/worn out components, are consumed and should be recycled. All metal is reused or recycled if replacement is needed. A circular business model favours a successful implementation of a reman concept. Volvo is making money by selling consumables in today's business model, but in a circular model it is important to cut any cost of ownership to make the equipment profitable. Compared to the other concepts, remanufacturing seems to rely on transportation to a quite high extent; which needs to be a prioritized aspect for optimizations if the concept is selected.

SWOT ANALYSIS

The complete SWOT for the concept is presented in Appendix XI. The analysis stresses the main principle behind remanufacturing as the major strength; materials being reused in *the first cycle* and multiple uses leads to major material savings over the wheel loader's life cycle. Also, the exchange process is known to the technician and requires no additional procedures. A weakness with the concept is additional transportations; with the location of the reman facility determining the extent of the environmental benefits. Another weakness is the need for investments to build up the reman chain (competencies, facility and equipment, logistics etc.) The SWOT analysis also identified a couple of opportunities for the remanufacturing concept; first, the possibility to guarantee cleanliness since a centralized facility might allow for testing. The centralized facility and the maintained ownership also come with other benefits. First, it is possible to incorporate an automated process, which in turn may increase profitability. Second, the possibility for high value recycling, due to the facts that materials are washed before disposal and the alloys are known. Threats include the uncertainties about the remanufacturing system; the volumes of filters required to be profitable and environmentally sustainable and that the energy consumption from the procedure risk to limit the environmental benefits. Another identified threat is that the solution might contribute to the risk of a technology lock-in; since electric powertrain requires no fuel filters, hybrid technologies require less filtration and alternative fuels might require entirely different solutions.

REMAINING PROBLEMS, UNCERTAINTIES AND NEXT STEP

The solution involves an initial investment in an automated production line, a logistic structure and a filter re-design. For the environmental benefits to be substantial, the distribution chain needs to be optimized. Also, for environmental and profitability reasons, the remanufacturing process requires a high level of efficiency. Another identified uncertainty is whether it is possible to design a casing which is appealing, durable and ensure high performance during the entire life length of the filter. Another major uncertainty is connected to the fact that the future outlook seems to be turning towards hybrids with smaller diesel engines, hence a reduced need for fuel filters. Such forecast obviously points at the risks involved when investing in remanufacturing facilities. The complete list of identified problems and uncertainties are categorized and presented in Appendix XIV.

7.4.3 LOCAL FILTER CLEANING

The third, and last, concept is also built on the principle to reuse non-consumed components. This time, it is obtained by using a washing machine placed in the local service centres, to wash the filters. The local filter cleaning concept in Figure 24 is described in detail in the following paragraphs. The idea is that if the solution is designed more robust and slightly more material demanding, it might be possible to develop much better and more environmentally friendly filters, considering the entire life cycle. Benchmarking showed that there are washable filters in aluminium or stainless steel, which can be washed instead of being replaced. Also, according to the specifications, these filters seem to last longer before clogging than the cellulose based alternatives used today.

Figure 24: Local filter cleaning, second concept development stage. Concept visualized together with an idea about what the washing machine could look like.

THE PROCEDURE/PROCESS

An overview of the concept process is shown in Figure 25. The technician removes the used filter and replaces it with a clean filter. The contaminated filter is disassembled and the parts are stacked in the sealed transport container in which the clean filter was transported. The container is brought back to the workshop where it is placed in the dishwasher. When the machine is filled with filter containers it is started. After the filters have been washed and dried, they are reassembled and put back in the clean transportation container and stored until needed.

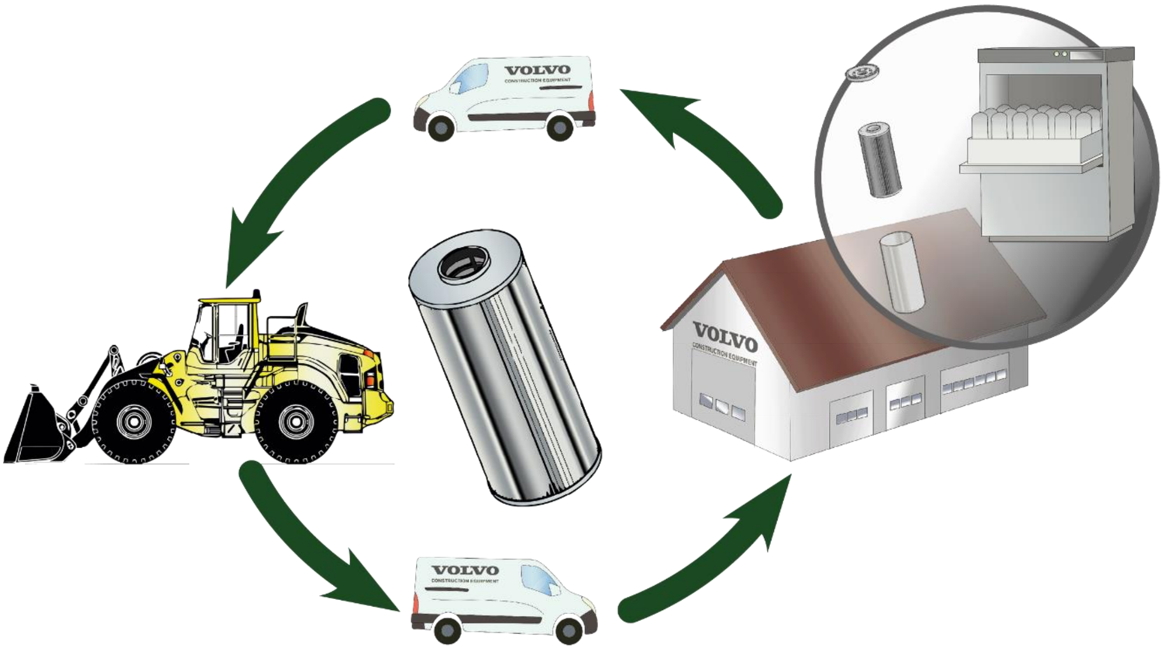


Figure 25: Local filter cleaning, schematic overview. Illustration how the filter never leaves the loop, it just travels between the workshop and the wheel loader.

THE ENVIRONMENTAL BENEFIT

The only weaknesses about the concept from an environmental point of view is that a buffer of filters is required and the potentially hazardous wastewater. Wash and reusing rather than disposing the consumed unit respond very well to what the eco strategy wheel suggest. The concept relies entirely on a circular business model, where Volvo maintains total control over the machines on the market, the processes and supply chain for the quantities of washable filters in operation to be high enough to justify a washing machine, both from an environmental and economic point of view.

SWOT ANALYSIS

From the SWOT-analysis of the concept presented in Appendix XI, the major strengths were identified as the major environmental gains due to the filters being reused multiple times and the washing carried out locally; hence reduction of heavy transportations. Inherent weaknesses are that every facility needs washing equipment, local storage space for buffer filters and additional work for technician/workshop personnel will be required. Opportunities identified in the SWOT includes the fact that the type of existing industrial washing machine that is in use in the workshops today might be possible to use to wash the filters. Furthermore, the solution has the potential to be expanded to oil and fuel filters on all construction equipment, maintained by the existing service provider today. Major threats again stem from the cleanliness requirements; including the difficulty to guarantee cleanliness and that it might be hard to ensure quality of the process, since there are many local sites with varying ability, regarding equipment, personnel, knowledge etc. The local cleaning concept also has a weakness in the fact that there are quite small quantities at every local unit and it is uncertain what quantities of filters are required for the solution to be profitable and environmentally justifiable.

REMAINING PROBLEMS AND UNCERTAINTIES AND NEXT STEP

As previously mentioned, the workshops in the service centres already have industrial washing machines, used for cleaning dirty and greasy equipment. These machines are equipped with the appropriate filtration systems to separate hazardous matter. In addition, the suggested type of stainless steel insert can be ordered today. These two aspects indicate a high level of feasibility for implementation of the solution in a near future. However, there is one substantial technical issue yet to be resolved; whether the dishwasher in the workshop can clean the filters good enough to live up to the filter requirements or whether complementary equipment is required. Other, issues concern transportation and separation of the individual components. The solution requires more work from the personnel in workshop, to disassemble, operate washing machine, dry and reassemble the filters. The solution also might also require additional space in the workshop for equipment and warehousing of the extra cartridges for buffer. A complete list of identified problems and uncertainties is presented in Appendix XIV.

7.5 SECOND CONCEPT EVALUATION AND SELECTION

7.5.1 CONCEPT EVALUATION

The result of the evaluation is visualized in Figure 26 and the results are commented on in the following section.

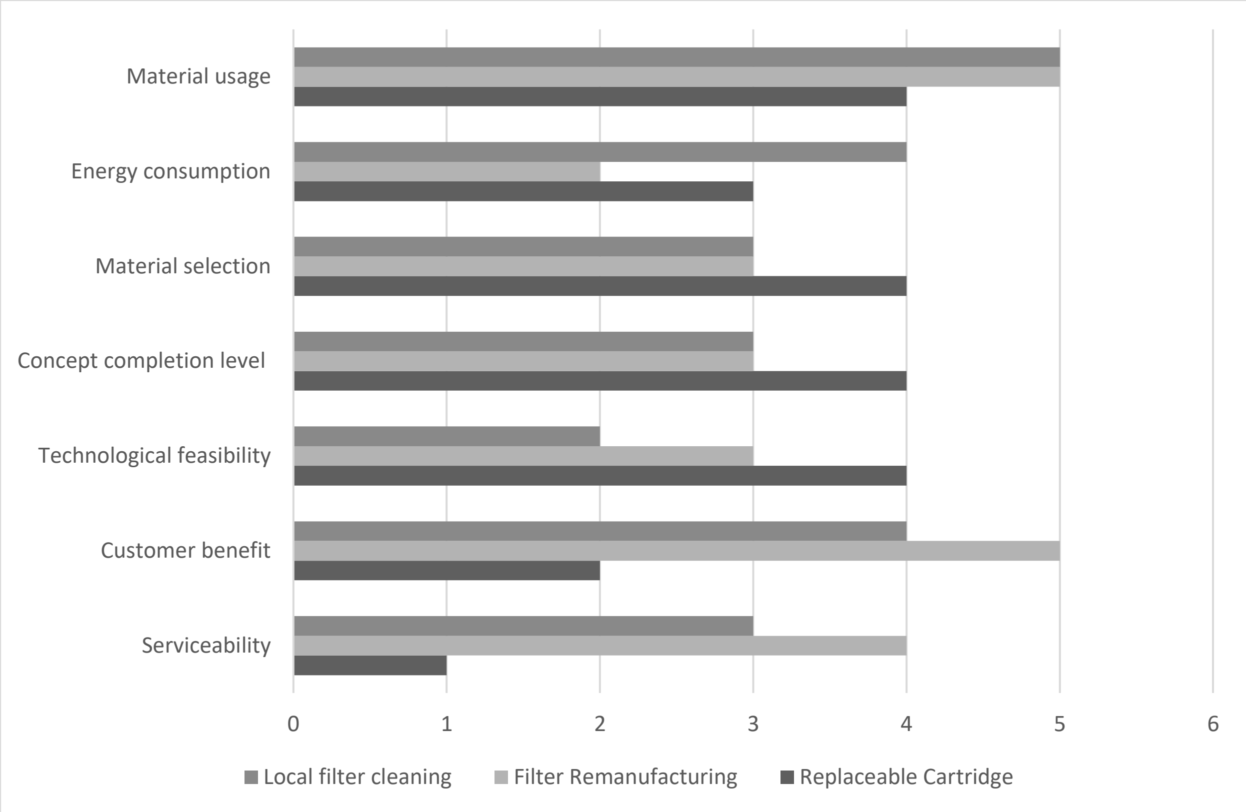


Figure 26: Unweighted concept comparison. The three concepts pick scores from different areas. The Filter remanufacturing concept receive the highest unweighted average (3.6), compared to Local filter cleaning (3.4) and Replaceable cartridge (3.1)

MATERIAL USAGE

Material usage was rated the most important aspect, hence had a major contribution to the concepts' final, weighted result. Due to the very low amounts of disposed material per use cycle in the two reuse concepts, these two came out as clear winners in this category.

CUSTOMER BENEFIT

Since the idea for all solutions was that they should to be used in a functional sales business model, the customers will be in little contact with the solution hence the *customer benefit* was weighted low. The most important aspects for the customers will be uptime, and the performance of each solution will not be compromised, hence the quite small differences between the solutions for this criterion.

SERVICEABILITY

As prioritized as the third most important criteria, serviceability has quite an impact for the overall result. The cartridge scored low in this category since it requires additional work, however even more so due to the higher risk for the technician to be contaminated by diesel during cartridge replacement. The other two concepts are considered better due to their similarities with the reference solution, which has been optimized to minimize manual labour and which can also be considered quite safe.

TECHNOLOGICAL FEASIBILITY

The score for each concept under *technological feasibility* is quite similar. However, the differences are a consequence of the uncertainty regarding the possibility to produce a technically and economically feasible washing solution for each service facility, or in large scale at a centralized remanufacturing facility.

CONCEPT COMPLETION LEVEL

The result for *concept completion* level differs little between concepts. However, the completion level concerns the filter solution. Less attention will be paid to the system design. Thus, the first concept would seem more ready since the system is already in place and can be described in more detail.

MATERIAL SELECTION

Material selection was considered the second most important factor. The reason to the differences between the concepts is due to that the two reusable material concepts are believed to require high alloy canisters, which might include scarce materials, to endure the performance requirements from multiple refurbish/washing and a substantial amount of handling and transportations.

ENERGY CONSUMPTION

The *energy consumption* was considered of less relative importance at this stage, due to the focus on materials. The differences between the concepts in this category are due to estimated variances in concepts weight and transportation distances.

7.5.2 CONCEPT SELECTION

Considering the predefined criteria, the *filter remanufacturing* concept came out of the evaluation as the one with the highest potential, as can be seen in Table 9; hence was selected as the final concept for further refinement and a final evaluation against the reference case.

Table 9: Weighted concept evaluation. The remanufacturing concept outscore the other two concepts, hence proceeds to the final concept refinement stage.

		Serviceability	Customer benefit	Technological feasibility	Concept completion level	Material selection	Energy consumption	Material usage	
	Criteria weight	5	2	4	3	6	1	7	Weighted Average
Concepts	Replaceable Cartridge	5	4	16	12	24	3	28	13,1
	Filter Remanufacturing	20	10	12	9	18	2	35	15,1
	Local filter cleaning	15	8	8	9	18	4	35	13,9

A very important learning from the second phase of the product development process was the washable stainless steel filter material which came up when researching the “local filter cleaning” concept. This stainless-steel cartridge was considered appropriate to use for the final version of the remanufacturing concept for substantial material saving over the product life.

7.6 SPECIFIC NEEDS AND REQUIREMENTS

Before the final concept refinement, the baseline for the following development process was established through a more specific version of the basic needs and requirements which were presented earlier. The specific needs and requirements also contain product requirements from the established remanufacturing procedure.

7.6.1 List of specific needs and requirements

The needs and requirement for the final concept is presented in Table 10[6] below.

Table 10: Final concept, needs and requirements list

	Category	Need/Requirement	Specifications
1	**Sustainability**	***The solution...***	
1.1		...**must** be less material demanding	over the life cycle, compared to the reference
1.2		...**must** be reusable	> 40 use cycles, which is corresponding to the useful life of one machine.
		...**must** be recyclable	100 % material recycling possible after useful life
1.3		...**must not** lead to human exposure from hazardous substances	liquid, fumes
1.4		...**must** consider distribution optimizations	
1.5		...**must not** contain scarce or hazardous materials	according to Volvo's Sustainable materials report
1.6		...**must not** lead to contamination of the environment	by hazardous substances
2	**Functionality**	***The solution...***	
2.1		...**must** prevent particles to reach injectors	larger than XX micrometre[6]
2.2		...**must** comply with existing standards	ISO XXX[6]
2.3		...**must not** induce additional risk of contamination of the fuel system.	
2.4		...**must** resist the relevant mechanical demands	pressure, flow, vibrations and external force
2.5		...**must** resist the relevant contextual demands	corrosive liquids, diesel, oil, dust
2.6		...**must** resist the relevant external contextual demands	cold, humidity etc.
2.7		...**must** be comply with the relevant filter performance requirements	specified in classified filter requirements[6]
2.8		**…must** resist (exchange) disconnections/connections	> 40 of each
2.9		**…must** resist disassembly/assembly	> 40 times
2.10		**…must** resist washing, filter	> 40 times
2.11		**…must** resist washing, canister	> 40 times
2.12		**…must** resist transportation (2 way)	> 40 times
2.13		**…must** allow for inspection and testing	pressure drop testing
2.14		**…must** prevent downstream contamination during disconnection/connection	water and particles
2.15		**…must** prevent downstream contamination during transportation	water and particles
3	**Use**	***The solution...***	
3.1		**...must** be possible to use by one person	
3.2		**...must** be possible to use by the specified user	experienced technician
3.3		**...must** be possible to remove without introduction of new tools	

[6] Regarding requirement 2.1, 2.2, 2.7; detailed performance requirements are classified, hence left out of the list.

3.4		**…must** supply information/instructions about how to handle appropriately/safely	easily accessible and understandable (not necessarily on component)
3.5		**…must** allow tracking of component	
3.6		**…must** express quality and company genuine equipment	according to expression board
4	**Other**	***It is considered positive if the solution...***	
4.1		...contributes to decreased total down-time	
4.2		...contributes to a more time efficient service procedure	
4.3		...contributes to a less demanding service procedure for the user	in terms of physical and mental load
4.4		…expresses quality and company genuine equipment	according to expression board[7]
4.5		...contributes to less transports	
4.6		…allows for sorting/stacking/efficient packaging	

7.6.2 Final concept effect goals

The goals, which the final concept had to respond to in the new system are presented and explained in Appendix XVI. The goals are arranged in *primary effect goals*, which the concept must fulfil, and *secondary effect goals*, which are desired to be fulfilled.

[7] As a complement to the written requirements an expression board is constructed, where images and adjectives describe the desired product expression. The expression board is supplied in Appendix XV.

8 FINAL CONCEPT REFINEMENT

The final concept and the design solutions are presented in this section. First the concept is described in the bigger system with overall considerations and the processes. Then the product concept attributes are described, divided for the respective subsystem in which the solution is implemented.

8.1 FILTER REMANUFACTURING

In addition to the filter remanufacturing concept described in the section *second concept description*, it was decided that, for the remanufacturing solution to be environmentally efficient enough, the filters must be washed in the reman facility. The concept scenario is also based on the fact that all filters; oil and fuel filters, are remanufactured in order to obtain the quantities and increase the environmental and economic gain to a level, which makes investments in a remanufacturing facility and product redesign justifiable.

To allow for the LCA, the remanufacturing process had to be quite explicitly described with transportation distance to the facility and energy and water consumption during filter cleaning. These explicit assumptions are declared for in the appended LCA report, Appendix XX.

The process consists of the steps represented in Figure 27. A remanufactured set of clean filters is picked up at the service centre by the technician, loaded into the service van and brought to the customer. At the customer, the machine is located and the service is commenced according to the

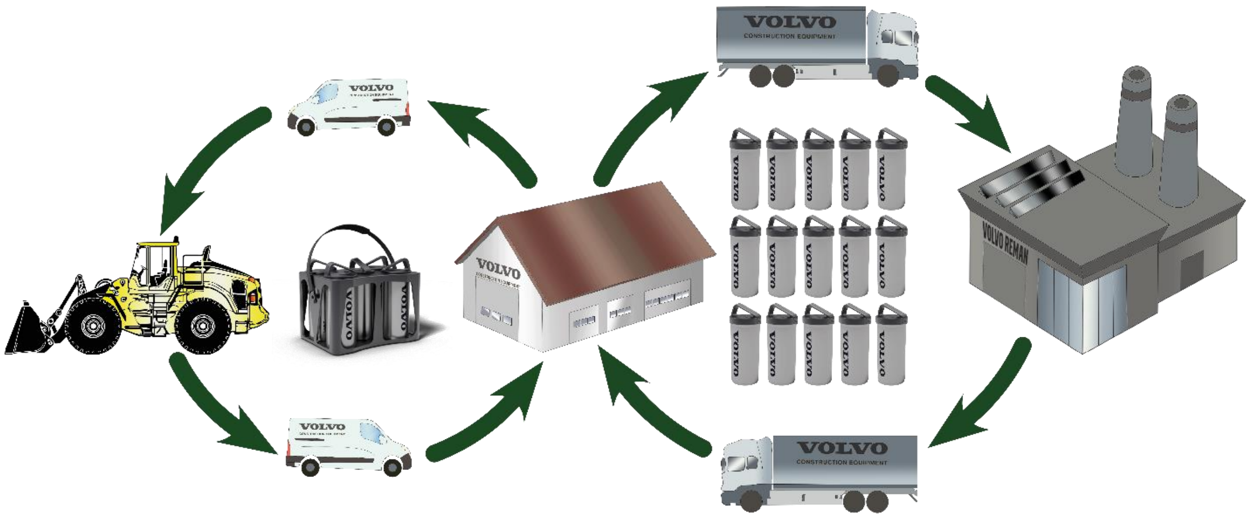


Figure 27: Final concept, schematic overview. Illustrates how the filters travel in two loops: one set of filters, between the wheel loader and the workshop and the larger pool of filters circulating between serviced center and remanufacturing facility.

service procedure described for the reference system. The filters are replaced one by one and used filters are placed in the transportation unit in which the remanufactured set of filters came. The set is then brought back to the service centre and, at appropriate intervals, picked up and sent to remanufacturing.

The remanufacturing procedure in the reman facility is described in the flowchart in Figure 28. At arrival, the filters will go through a pre-cleaning to allow for a first inspection and logging of components after the filters have been removed from the transportation unit. Then, filters will be disassembled and the parts washed separately. The parts are then reassembled and the filter tested according to the performance requirements. The process is assumed to be semi-automatic, with manual disassembly and reassembly and automatic washing and testing.

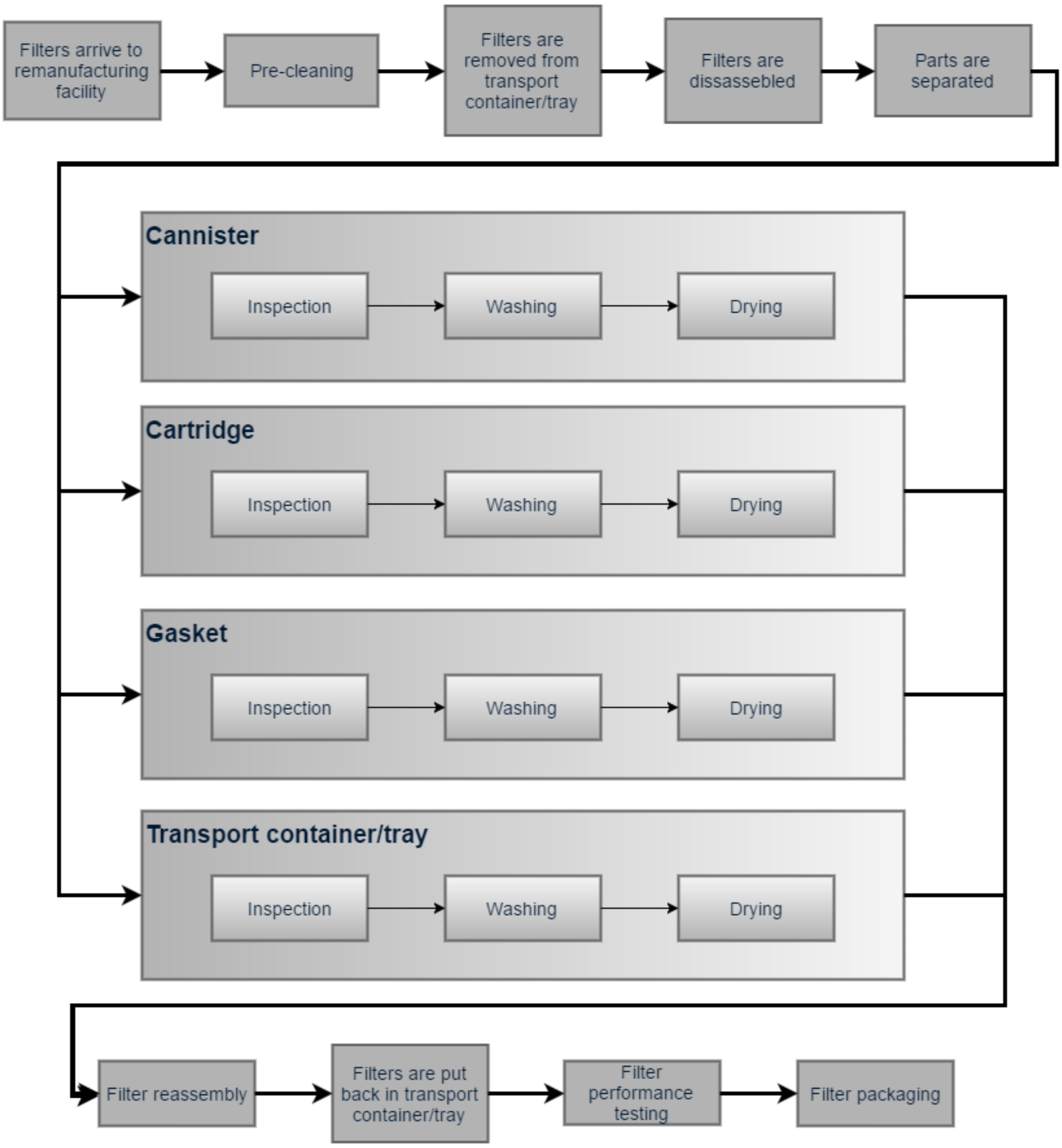


Figure 28: Schematic overview, briefly describing how the remanufacturing process is thought to work

8.2 THE CONCEPT FILTER

In the following paragraphs, the final filter concept (Figure 29) is presented in terms of its product attributes.

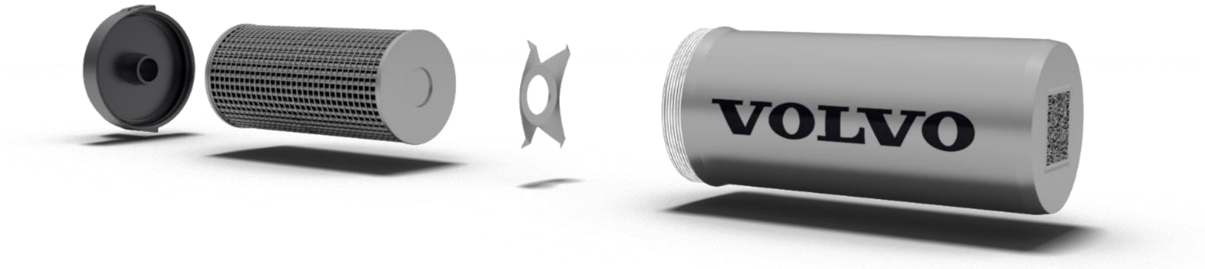


Figure 29: Explode view, major component. From left: Lid, filter cartridge, by-pass spring and canister

MAIN FUNCTIONALITY AND PERFORMANCE

The relevant performance requirements regarding flow and pressure are fulfilled by preserving much of the interior surfaces similar to the same as the reference filer; the volume remains a static design parameter. The filtration capacity requirements however are expected to be fulfilled through adopting solutions from existing products with similar filtration requirements, further described in the filter cartridge sub-section. In addition, a similar bypass solution is implemented for the concept.

To resist multiple washing aluminium was selected for the canister. Stainless steel was also considered, however discarded due to the weight which would have been required and due to the differences in production possibilities between the materials considering the desired design. In order for the filter cartridge to endure multiple washes, an existing stainless steel filter mesh solution (Figure 30) was selected.

Figure 30: Photo of product sample of existing filter solution from

Figure 31: Filter concept from below, with QR-code visual

To save transported amount of material compared to the reference solution, the concept design has eliminated the interface plate from the transported unit. The main functions of the interface plate are to attach the filter to the machine, bring structural integrity and distribute incoming fuel. Attaching to the machine is solved by an alternative attachment system. The structural integrity is obtained by thicker material and a slightly different shape. The distribution of fuel is done by a static unit, similar to the interface, which stays on the machine.

Removing the interface also caused problems related to the transportation. First, the new attachment solution had to be protected in order to endure multiple transportations and also, the interface to some extent helped keep the filter inside clean before mounting; these issues were resolved through a protective transportation lid presented under "*transportation tray*".

Today, there is a lot of information printed on the canister. Some of which is not easy to understand, nor adapted for the specialized company technicians. This might be due to the fact that users can vary after the service program ends. However, in a functional sales model we can expect a more homogenous user group. Due to their high level of knowledge and experience regarding the service operation, the information which is necessary to be provided by the filter can be assumed to be minimal. Therefore, only the logo is printed on the canister. However, if the technician perceives a need for additional information, this can be obtained by scanning the QR-code which is laser engraved on the bottom of the casing, seen in Figure 31. The page connected to the QR offers information about safe handling, hazards and risks, assembly instructions and more, although it must be further evaluated if such a solution provides enough information to the user. The QR-code is also intended to function as an identifier in the reman factory.

There is also a marking engraved on each filter component and the lid, telling which filter type they belong to, in this case: "main fuel filter" is engraved, to allow for separation of the five different filters changed with the same interval.

8.3 THE ATTACHMENT SYSTEM

The filter-machine attachment system is described in the following paragraphs. To endure the large number of dismounting and mounting over the expected life, alternative attachment solutions were considered. Several different systems were conceptualized and evaluated in regards to their individual potential, together with machine experts from the current service provider.

The selected solution ensures that the force is no longer applied to the canister body when twisting it during the dismounting, but only to the new attachment solution, called the *lock nut*. The solution, referred to as the "*meat grinder*" attachment is already in use among some filter manufacturers today. The solution is illustrated in Figure 32 below.

Figure 32: Attachment functionality overview

The reason to why the lock nut sits on the machine is so the technician does not have to carry the weight of the lock nut during the attachment process. In addition, it also prevents losing the lock nut and scratching the canister. The lock nut is screwed on by hand when mounting while dismounting can be assisted with the existing filter wrench if necessary. The lock nut must endure quite some stress during filter detachment and if the lock nut gets damaged or worn out, it is possible to replace it by removing the bottom section of the filter housing. The suggested solution makes it impossible to use the filter as a "*handle/grip surface*" when releasing the filter from the machine; hence reducing the risk for damaging the canister.

Figure 33: Transportation system overview

To ensure the lock nut is used as intended and no force is applied to the canister body, the lock nut has been designed with the right *affordance*. In this case, meaning that the grip pattern on the lock nut has been designed to be recognised by the user and associated with the action that the designer desires. The second part in ensuring the correct use is to educate the users about the change in replacement procedure. Different lock nut shapes, grip patterns and sizes from various applications were assessed, before the final solution was selected. The fact that the filter body is static when the lock nut is tightened is believed to have the effect that no greasing of the gasket is required; which in turn saves time, due to one lesser step in the service procedure and also, saves the technician from additional contact with hazardous substances.

The surrounding contextual aspects were primarily considered in the design of the attachment system; for instance, by reducing the number of moving parts, avoiding small spaces and horizontal surfaces where there is a risk for material build-ups. The attachment system ought to prevent spillage during dismounting through a solution where the filter canister remains still, while the lock nut is the only part moving. Also, the canister walls are slightly higher in relation to the location of the inlet, which causes the percentage of the volume which is filled with diesel to be smaller than that for the reference solution.

8.4 THE TRANSPORTATION SYSTEM

The transportation system seen in Figure 33 is presented in the following section.

THE TRAY

After the possibility to clean the filter, preventing the filter to be in any way damaged during handling and transportation is the most important aspect in the effort to increase the product life. The suggested solution ought to do this, first through the design of the filter; a robust casing without sharp edges as previously accounted for. The more important contribution to dent and scratch prevention comes from an external product. The transportation tray offers protection to the filters from right after dismounting to the point when the filter is remounted at the machine. The transportation tray allows the filters to be securely fastened to prevent them from moving around during transportation. The upright position in combination with the lid, also helps preventing diesel leakage. In addition, the bottom plate of the tray is diesel proof, with a wall around the edge which will further prevent diesel leaking. Since five, similar sized filters are replaced at the same intervals; the suggestion is to have a combined transportation tray for all five filters.

The shape of the transportation tray (see Figure 33) is considering anthropometric features of the technician. The distribution of weight was considered when the location of the filters was decided and the carry shoulder strap was added to facilitate carrying.

THE LID

To prevent contamination of the important clean side of the filter between cleaning and mounting a transportation lid was designed (see Figure 34). The lid attaches to the set of threads which are used for mounting the filter to the machine housing. The filter lid is supposed to be removed from the clean filter just prior to assembly and then screwed onto the used filter to prevent diesel leakage during the transportation.

Figure 34: Transportation lid overview

A centre-cone integrated to the lid prevents the cartridge from moving around inside the canister; hence reducing the risk for damage or excessive wear during handling and transport. The edge of the lid extends down over the full length of the threads to protect them from damage. Also, a more robust type of threads has been used for the concept compared to the reference.

The grip flange on top is quite small, and the shape has been selected among other alternatives since it implies gentle handling (since it bears little resemblance to a "*power grip*"). The reason is to make the technician generate just the right amount of force, hence not risk damaging or wearing out the filter prematurely.

The filter lid is designed to allow for attachment of a carabiner, as shown in Figure 35. This will allow the technician to snap the filter to the belt while climbing up to larger machines. The reason for this addition is primarily because, it is anticipated that this will lead to the lid staying on the canister until just prior to replacement, hence reducing the risk for filter material contamination. However, it is also considered a safety and ergonomics benefit that the technician's hands can be freed up before and after filter replacement.

Figure 35: Transportation tray, additional functionality

Two different approaches were considered for preventing spillage during transport; either draining the filter from remaining fuel or to enclose the canister. The latter was selected, since draining would cause additional risk of spillage. It would imply an additional, time consuming step and it would also be difficult to ensure that the filters are entirely emptied. The downside of the containment solution however is that the remaining fuel in the filters add to the total weight that has to be transported. On the other hand, the reman facility will be a better place to deal with hazardous liquids, than directly on site, as would be the alternative.

8.5 ADDITIONAL DESIGN CONSIDERATION

ADDITIONAL REMANUFACTURING CONSIDERATIONS

In order to allow for the washing, all parts are supposed to be produced in materials which can resist the minimum of 40 washings, as stipulated by the requirements. This also concern the transportation lid and tray. In addition, all components are possible to easily separate from each other, to allow for an efficient washing.

ERGONOMIC USE

The final design has considered design for ergonomic use aspects described in the theory in Bohgard (2011). Instead of both pressing the filter upwards and twisting when mounting, as for the reference; the suggested solution allows the filter to be held in one hand while using the other to screw on the lock nut the first couple of threads, before the weight of the filter can be released and the lock nut can be screwed on. In addition, a carry strap can be attached to the transportation tray to facilitate carrying, see Figure 36.

Figure 36: Transportation tray, carry solution

Another important ergonomic design improvement was regarding adequate feedback; the reference solution offered insufficient feedback to the technicians for when the reference filter was in the right position. For the purpose of feedback, but also not to risk over or under tightening the filter, a small step-out the bottom of the thread (“stop-edge”) which meets the lock nut edge when appropriately tightened was added to the canister.

INSPECTION AND TESTING

A suggestion for testing of the solution after cleaning is to test for instance differential pressures. Too high differential pressure would indicate the filter is not clean, hence it is still clogged which prevents the flow and too low differential pressure indicates there is a leak in the filter media, which is letting fuel pass through with less resistance.

RECYCLABILITY

The concept is designed to be entirely separable into parts (see Figure 37) each containing a single, documented material mix, i.e. a specific stainless steel alloy (parts 2-7), rubber mixture (8), plastic mixture (1 and the tray) and aluminium alloy (9). It was considered whether the different parts in the cartridge were going to be separable as well, to allow replacement of worn sub-components; however, the solution was discarded, due to the conclusion that such solution might compromise the structural integrity of the cartridge, hence the main functionality of the filter.

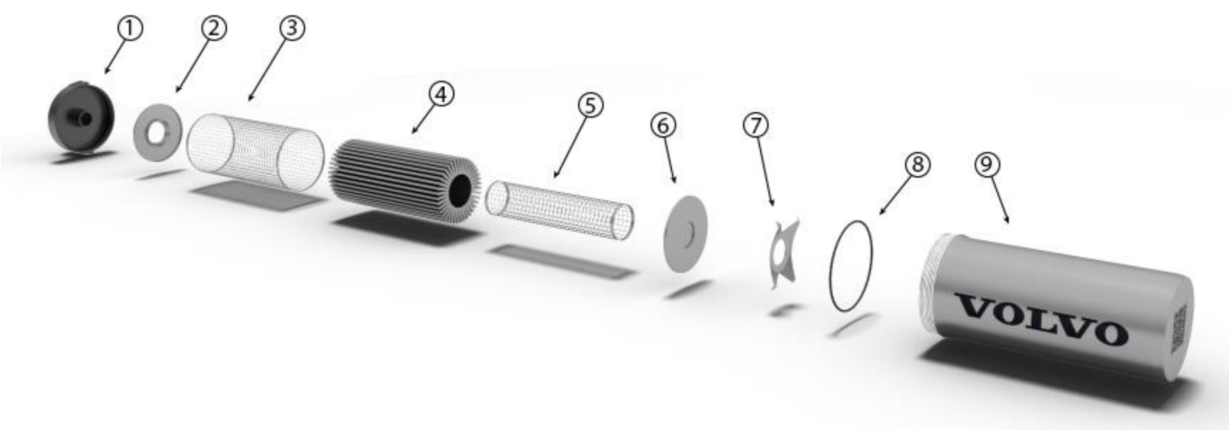


Figure 37: Concept, exploded view. (1) Transportation lid (2) Filter element cap (3) Outer tube (4) Filter element (5) Inner tube (6) Filter element cap (7) Bypass spring (8) Gasket (9) Canister

Also, all units are sufficiently marked with material content since it is reasonable to assume that some filters might end up out of reach for the company; thus, the markings help ensure recyclability even in such cases.

AESTETICS AND EXPRESSION

For or the filters to be used for as long time as possible, it has been concluded that they also need to look attractive. However, that does not automatically mean that they must look brand new; it is possible that even though a filter looks as if it is well-worn on the outside but is perfectly fine on the inside it can still be trusted. However, more testing and research is needed in this area.

However, for this study, it was deemed important that scratches and smaller damage was concealed as much as possible, which was achieved by a brushed surface (Figure 39). The material and the design will also allow a thin surface layer to be lathered away at a point in time when scratches and cuts are compromising the overall appearance of the filter. The expression is also maintained through the filters being delivered wrapped in paper to the assembly facility. This is to avoid the filter body being painted when mounted on the engine block.

Figure 39: Material properties close-up rendering

Figure 39: Final concept, realistic rendering. With place for all filters replaced at the same service intervals

Three factors were mainly considered for the design to achieve the desired visual and tactile expression; the surface quality including material, colour and surface treatment. The second factor is the visual and tactile expression of the form/shape. Many variations were assessed to find the satisfactory form expression. The third factor was the functionality, both perceived and actual. The finalized concept can be seen in Figure 39.

8.6 FINAL CONCEPT EFFECT GOAL FULFILMENT

A qualitative concept verification against the effect goals is presented in Table 11 below. For each effect goal, fulfilment is justified with concrete examples in the right column.

Table 11: Effect goal fulfilment evaluation

Effect goal	Goal fulfilment explanation
The solution is required to…	
...prevent damage during handling and transport If the filter ought to be reused for more than 40 cycles, the filter and/or the system needs to be designed accordingly.	- Robust canister with no sharp edges - Robust threads - Protected and secured by transport tray solution - Threads protected by lid - Canister secured by lid centre cone
...prevent filter contamination during handling and transport The downstream side of the filter must remain entirely clean during transportation from remanufacturing facility, to the client until attached to the machine.	- Lid prevent contamination from outside - Lid centre cone prevent contamination between up and down stream side - Possibility to attach carbineer might lead to the lid staying on for longer.
...resist multiple mounting/dismounting In order for the solution to withstand at least 40 mounting/dismounting; the attachment system must be designed accordingly.	- Lock nut solution prevent force to be applied directly to filter canister - Robust threads - Large threaded surface better resists external force - Less wear on gaskets since filter body is static when lock nut is tightened - A stop-edge on the canister prevent over-tightening of lock nut.
...allow for washing As specified in the requirements list, the filter needs to withstand a minimum of 40 cleaning cycles, hence the filter must be designed accordingly.	- Filter is “disassembleable” - Washing away particles is allowed by the stainless-steel filter mesh - Materials for all components enables washing - Split lines and cavities are avoided when possible
...fulfil relevant performance requirements The design is required to deliver the corresponding performance as the reference; i.e. sufficiently respond to the technical/functional requirements as defined for the existing fuel filter regarding fuel pressure, filtration capacity and flow rate.	- Similar pressure resisting and fluid dynamic properties can be expected since the design of the inside is maintained relatively intact - Selected technical solutions are proven to work in similar application (aluminium canister, lock nut and stainless steel mesh)
...avoid transportation of excessive matter/materials Since remanufacturing rely on transportation of the components, the possibility to reduce the material being transported must be considered.	- Lock nut is static on the machine - Filter interface is static on the machine, integrated to the housing

...avoid diesel spillage during dismounting Since the filter canister will be filled with diesel, spillage must be prevented when used filter is detached.	- Higher edge, relative to containing diesel volume
...avoid diesel leakage during handling and transport The filter cannot cause contamination of people or the surrounding while being handled and transported.	- Transport tray maintain up-right position - Lid encapsulate the canister
…provide adequate information The information provided on the components must be adequate for the user and the use.	- Lock nut offers the right affordance (prevent the use of filter body as grip when dismounting) - QR-code enables additional information to be obtained - Any unnecessary information is avoided
...allow tracking of the product Tracking of the complete product and possibly even the individual components is deemed required, to optimize distribution, handling and procedures.	- QR-code enables easy tracking on site, during transport and in reman facility. - Components are individually marked
...allow for inspection/testing After remanufacturing, the performance of the filter needs to be ensured by inspection and quality testing.	- Filter is disassembleable - Components can be manually or automatically scanned for defects - Quick connection to a rig after reman for testing is possible
...allow for high value recycling The design must allow high value recycling through considering the design for recycling aspects.	- Business model ensure materials stay with the same owner which provides total control and insight - Business model allow for 100 % return rate - All parts which made from different materials are separable - Parts are marked for content - Clean parts are recycled, since being cleaned in reman facility.
The solution is required/desired to…	
…maximize life expectancy in general The solution should consider how the expected life of the filter can be maximized in general; other aspects affecting the filter life than what is presented above.	- Large threaded surface better resists external force - Robust canister - Brushed metal canister surface conceal damage and scratches - Parts can be replaced - Canister material and design allow lathering/grinding/polishing to retain appearance - Filters are delivered in protective packaging to assembly line when new. - Filters are delivered wrapped in paper to prevent being painted in assembly line.
...avoid introduction of new tools If not justifiable in relation more prioritized demands, introduction of new tools is	- Existing tools can be used for dismounting and no tool is used for mounting

undesirable due to the risk of additional material usage.	
...consider relevant ergonomic aspects The attachment system and the overall handling must consider relevant physical and cognitive ergonomic aspects; i.e. allowing for ergonomic use and to ensure adequate information presentation	- The lock nut solution enables mounting - Feedback when fastened is provided by the stop-edge on the canister. - The weight of the transport tray is favourably distributed for being carried by one person - The tray shape considers the technician's hip - A shoulder carry strap is provided - Possibility to attach carbineer to free technician's hands
...consider the demanding environment The suggested solution must consider the demanding context, in regards to dirt, grease, etc.	- Few moving parts - Few split lines and cavities - Allow for easy wiped off - Threads are protected from dirt by lid - Lid prevent rain, snow or dust from entering the canister
...achieve the desired expression The solution's form, surface treatment, material, use etc. must comply with the overall expression defined in the expression board (Appendix XV).	- The variables: form, material, colour and surface quality has been considered in relation to the expression board. (For detailed motivation of the design decisions related to the expression see Appendix XVII)
...contribute to better service operation It is considered positive if the new concept in any way can contribute to a service operation which is better from the technician's perspective. Faster and/or with less risks involved.	- On site greasing of gaskets might not be required, which saves time and the risk for the technician to come in contact with hazardous substances.

8.7 CONTRADICTORY AND CONFLICTING GOALS

Contradictory goals were identified and dealt with for the final solution. First, the typical environmental sustainability conflict between a robust design to last longer (resist wear and multiple replacement, refurbish and remanufacturing) versus a lower weight product (less material usage, low emission transportations and smaller ergonomic loads during assembly etc.). The final solution reached a compromise on this point, where aluminium was used due to the beneficial strength-to-weight ratio compared to steel and since the aluminium also allow for remanufacturing and high value recycling.

Other identified contradictions between different goals are the level of cleanliness of the filter as opposed to the possibility to separate pieces; for remanufacturing and for high value recycling. From the recycling point of view, this was solved by ensuring all inseparable parts were the same material composition. From looking at similar solutions, it seems that the concept will fulfil the requirements about remanufacturability; however, the design must be further evaluated on this aspect.

The cleanliness requirements also, to some extent contradict the desire to remove parts from the design to reduce excessive material transportation; since a more open design might cause a higher risk for filter contamination and diesel leakage and spillage. This contradiction was worked out through the implementation of a transportation lid.

III. CASE L150 - FINAL CONCEPT EVALUATION

The final concept evaluation primarily aims to verify how well the final result responds to the project aim and goal. The evaluation also aims to assess the product's successfulness in relation to effect goal and requirements; with a special focus on assessing the potential environmental impact changes connected to the suggested alternative.

Due to the fact that the product is still at a conceptual stage, the evaluation is only theoretical, and based on the final concept and scenario description, computer models and renderings as presented in the result. The theoretical evaluation is divided into three parts; a concept evaluation against the predefined evaluation criteria, a qualitative assessment with the rapid eco assessment tool, previously used to assess the reference and an extended environmental impact evaluation with LCA.

9 FINAL CONCEPT EVALUATION

9.1 QUALITATIVE CRITERIA EVALUATION

The Pugh's matrix inspired final concept evaluation against the predefined criteria is presented in Table 12. The previously defined evaluation criteria are used for the evaluation. However, evaluated to better represent the objective; *assess improvement in relation to all stakeholders*, with particular focus on the user and environmental sustainability. The definitions of the criteria are supplied in Appendix XVIII.

Table 12: Final evaluation matrix, verifying the concept against the reference for the different evaluation criteria listed in Appendix XVIII. (1) means the concept is better than the reference, (0) means they are equal, and (-1) means that the reference is better than the concept. The score for the new concept sum up to 5 out of a possible 11.

User benefit (serviceability/)	**Hazard/Risk**	1
	Cognitive load	1
	Physical ergonomic load	1
Customer benefit	**Performance/reliability**	0
	Profitability/cost	0
Volvo benefit	**Economic sustainability**	0
	Take advantage of knowledge and hard capacity	-1
Environmental benefit	**Material selection**	0
	Fuel consumption	1
	Material usage	1
	Waste generation	1
	Result	**5** (11)

As can be seen in Table 12, the concept outperforms the reference for most of the criteria concerning user and environmental benefits. This is likely due to that these characteristics have been prioritized in the process. The reason to why the concept scores the same as the reference when it comes to *customer* and *company benefits* is related to that these aspects has not been prioritized as much. They are also hard to grade before the concept (process and product) has been further defined and the business case has been solidified.

9.2 QUALITATIVE EVALUATION: RAPID ECO ASSESSMENT

The result of the rapid eco assessment is presented in Appendix XIX. The assessment showed that since the eco strategies very much have directed the design decisions, many of the strategies have been considered. However, as described in the table in appendix, little has been done in category 3: "design for manufacturing innovations", which is since the end-result of the project is only conceptual, hence these aspects are not yet considered to the full extent.

9.3 QUANTITATIVE EVALUATION: LIFE CYCLE ASSESSMENT (LCA)

In the following chapter is the conducted life cycle assessment presented. The focus is on the actual results from the comparison of the two filters. To make the comparison more understandable some parts of the inventory analysis and some assumptions have been declared. A report describing the conducted LCA according to ISO_14040 (2006) is found in Appendix XX, in which more details can be found about how the assessment was carried out and limited.

9.3.1 PROCESS

The LCA was conducted according to the process described by ISO_14040 (2006) and modelled in GaBi (software Thinkstep AG). According to suggestions from ISO_14040 (2006), a goal and scope was defined, an inventory assessment conducted and finally an impact assessment done which was made understandable through an interpretation subsection. The goal and scope should be defined and work as guiding marks throughout the process. The scope decides the system boundaries of the studied system, information about system boundaries is crucial to understand the impact assessment. Because of that, a brief description of the system will follow:

The *goal* of this particular study was to perform one LCA on the existing fuel filter and one on the new concept filter to compare their environmental impact.

The *purpose* was to use LCA as an assessment tool in the product development process to see if the product, developed for a circular business model, was better for the environment than the existing solution.

INITIAL FLOWCHART

Both LCAs covered the life cycle form cradle to grave since materials use was of interest. Flow charts showing all parts of the fuel filters' lives can be seen in Figure 40. Note that the *life cycle* used to describe the flows in the LCA differs from the *product life stages* used in the product development terminology in previous chapters.

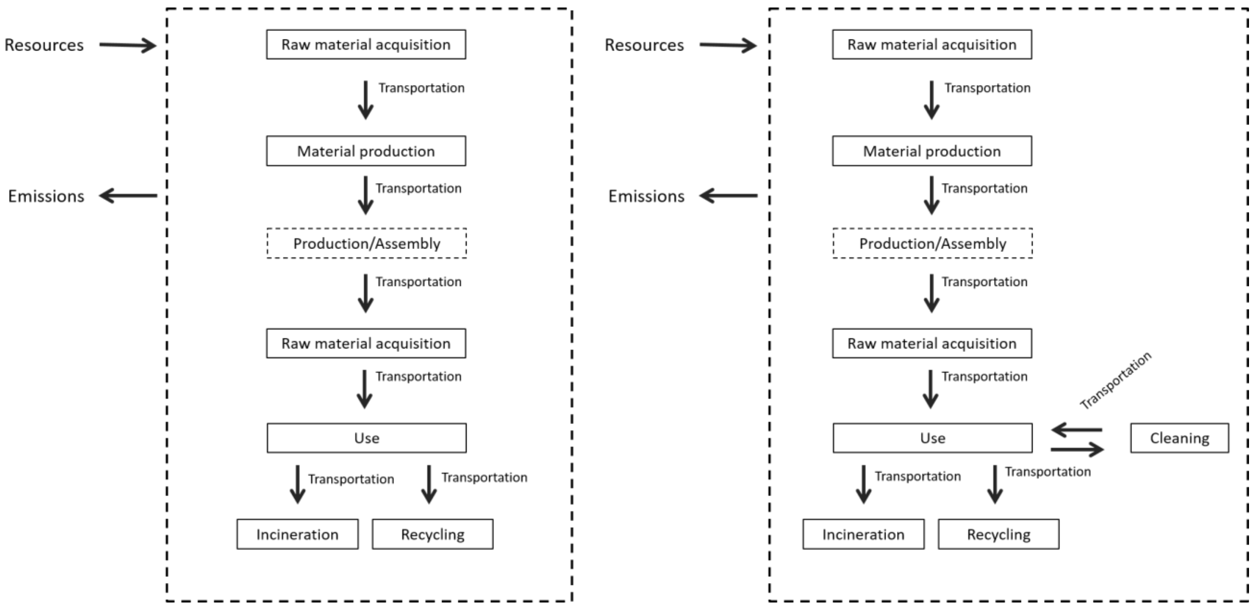


Figure 40: Initial flowcharts, reference (left) and concept (right)

FUNCTIONAL UNIT

The functional unit was set to *20 000 hours of fuel filtration in one wheel loader L150,* which is the function of the main fuel filter. 20 000 h is the estimated amount of available operating hours in the wheel loader used in this study.

SYSTEM BOUNDARIES

Geographical boundaries were set to Europe for parts production and assembly, and Sweden for the use phase and end of life. Extraction of materials and manufacturing of parts were included in the LCA as well as transports of the *assembled* fuel filter.

In the impact assessment results are presented based on production, use and end of life. For this study the use phase was decided to cover the moment the filter leaves the factory door until it enters the recycling facility. That way all transports were included in the use phase.

INVENTORY ANALYSIS

An inventory analysis was developed based on the goal and scope definition. This is normally done by drawing a flow chart and make lists showing inputs and outputs. In the case of the concept the impact assessment built mainly on estimations and assumptions. This was because the concept was not in the stage of maturity where all materials and their weights were yet defined. Therefore they, together with production processes had to be estimated. However, the available information about the existing solution was not comprehensive enough to fully build the assessment on, therefore it had to be supported by assumptions and manufacturing videos. All flowcharts and inventory lists for the assessment are found in Appendix XX. Figure 41 and Figure 42 are exploded views of the concept filter and the reference filter to reveal the differences. Table 13 gives an overview of the materials in both filters.

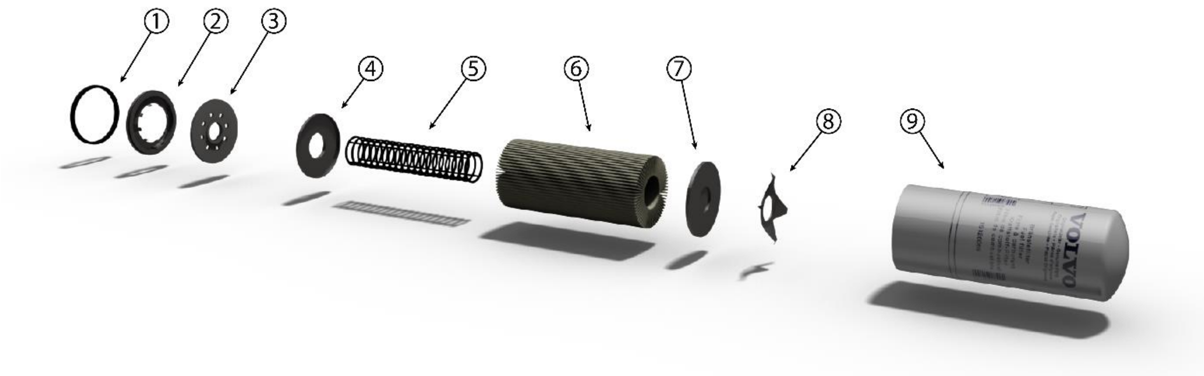


Figure 41: Exploded view, reference filter: (1) Gasket (2) Retainer sheet (3) Interface plate (4) Filter element cap (5) Inner tube (6). Filter element (7) Filter element cap (8) Bypass spring (9) Canister

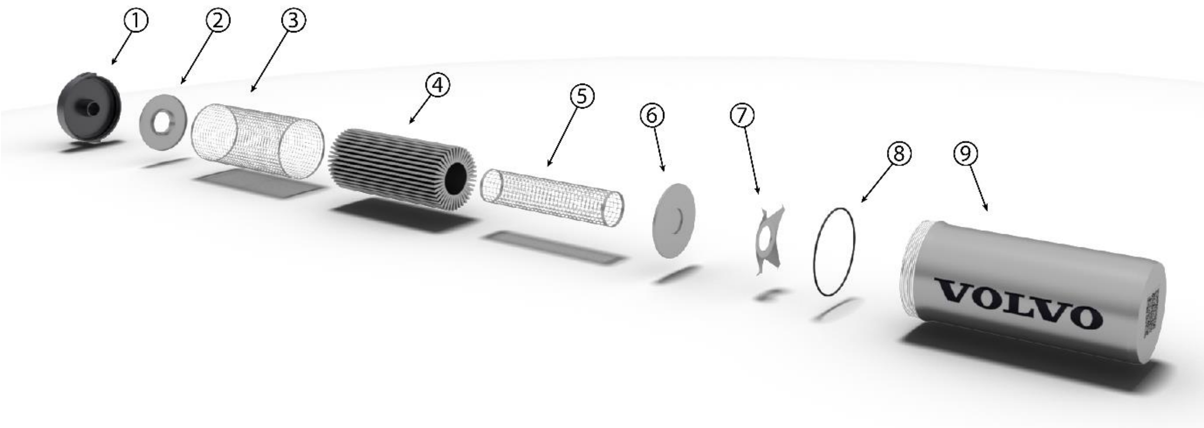


Figure 42: Exploded view, concept filter: (1) Transportation lid (2) Filter element cap (3) Outer tube (4) Filter element (5) Inner tube (6) Filter element cap (7) Bypass spring (8) Gasket (9) Canister

Table 13: Material content in the reference filter and in the concept filter respectively.

Part	*Material, reference*	*Material, concept*
Canister	Stainless steel	Aluminium
Filter media	Cellulose	Stainless steel
Inner tube	Nylon	Stainless steel
Filter media caps	Stainless steel	Stainless steel
Spring	Stainless steel	Stainless steel
Gasket	Styrene-Butadiene rubber	Styrene-Butadiene rubber
Supporting grid	Not applicable	Stainless steel
Interface plate	Stainless steel	Not applicable
Element cap	Stainless steel	Not applicable
Transportation lid	Not applicable	Plastic

The remanufacturing procedure needed to be somewhat defined for the LCA modelling. Table 14 shows the data used in the model. The production of the facility itself was not included in the LCA.

Table 14: Remanufacturing process data

Inflow material	*Quantity/one filter*
Detergent	20 [g]
Electricity	229 [kJ]
Water	4 [kg]
Steel parts	12.8 [kg]
Rubber parts	10 [g]

9.3.2 RESULT

In the following section the results from the assessment are presented, starting with results based on comparing one filter against the other. Further down is the impact assessment presented.

9.3.2.1 MATERIALS

Table 15 shows how much material is needed for each filter solution to provide fuel filtration over 20 000 h in a wheel loader L150. It was estimated that one of the concept filters could withstand all wear and tear for one machine life time. However, the filter might be possible to use even after the assumed time. The assumption of one filter per machine should be seen as a conservative assumption, in the following analysis the number 1.16 filters are used. This is because slightly more filters than machines are needed since the machines are not supposed to stand still and wait for their filter to come back. The reference filter is lighter but since 40 filters are needed instead of 1.16 it needs over 21 times as much materials.

Table 15: Material usage comparison; the weight of the reference filter and the concept filter respectively both based on functional unit and individual filter

	Reference filter	*Concept filter*
Materials use for 20 000 h	55.3 kg	2.59 kg
Materials use per filter	1.37	2.23

Figure 43 shows material content in each filter. It is obvious from the graph that the concept filter is heavier and contains a large amount of aluminium.

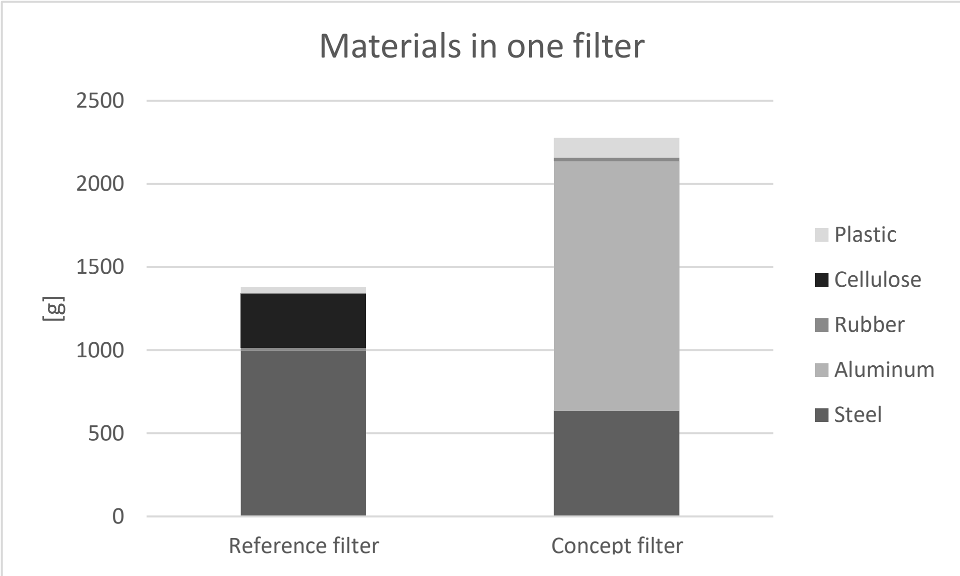


Figure 43: Materials content in each filter. The reference to the left and the concept to the right

9.3.2.2 TRANSPORTS

Table 16 shows the distance each 20 000h of fuel filtering requires. The reference concept travels more than double the amount of the concept solution. This is since each reference has to be transported from Germany to Sweden whereas the concept only has to do that journey 1.16 times and then it is only taken back and forth to Flen in Sweden.

Table 16: Comparison of the transports needed to provide the wheel loader with main fuel filtration for 20 000 h.

Product	*Kilometres*
Reference	76 800
Concept	32 496

9.3.2.3 IMPACT ASSESSMENT

The following graphs are showing the difference between the reference filter and the concept filter based on the functional unit for all chosen impact categories.

GLOBAL WARMING POTENTIAL

As can be seen in Figure 44, the concept filter has minimal global warming impact compared to the reference solution. Both have biggest impact during the production step, thus tied to materials extraction and pollution.

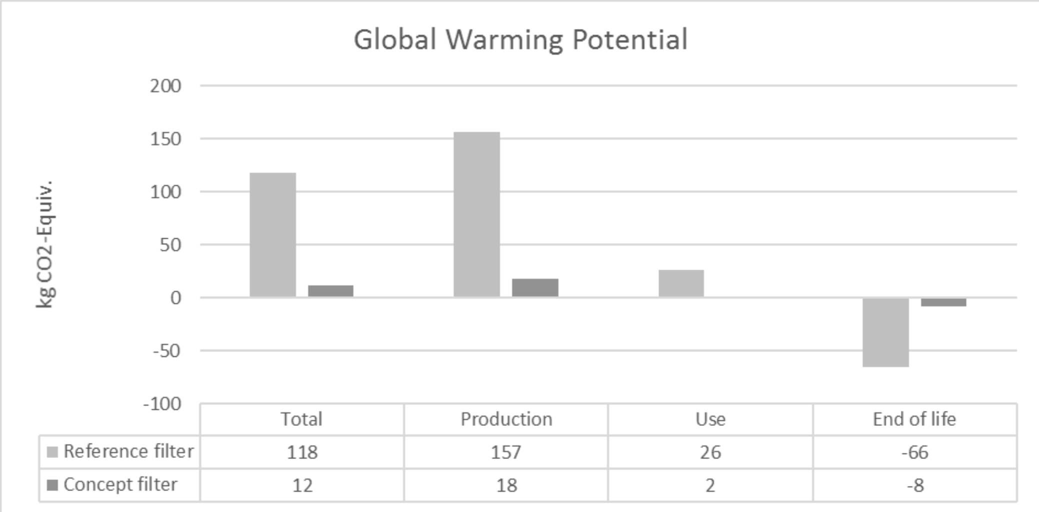


Figure 44: Graph showing the global warming potential for the reference filter and the concept filter

The largest impact caused by the reference is the process of extracting, producing and working the containing steel. The largest impact caused by the concept is instead the extraction and manufacturing of aluminium components. The emissions are in both cases carbon dioxide, tied to energy production to feed energy into material extraction processes. Since most impact in both cases comes from the production phase, it indicates it was right to focus on decreasing the material consumption per functional unit. The graph also shows that the material reduction gave the desired, lowered impact.

ACIDIFICATION POTENTIAL

Figure 45 shows that the acidification potential is much smaller for the concept filter. Largest impact has the production phase in both filters cases.

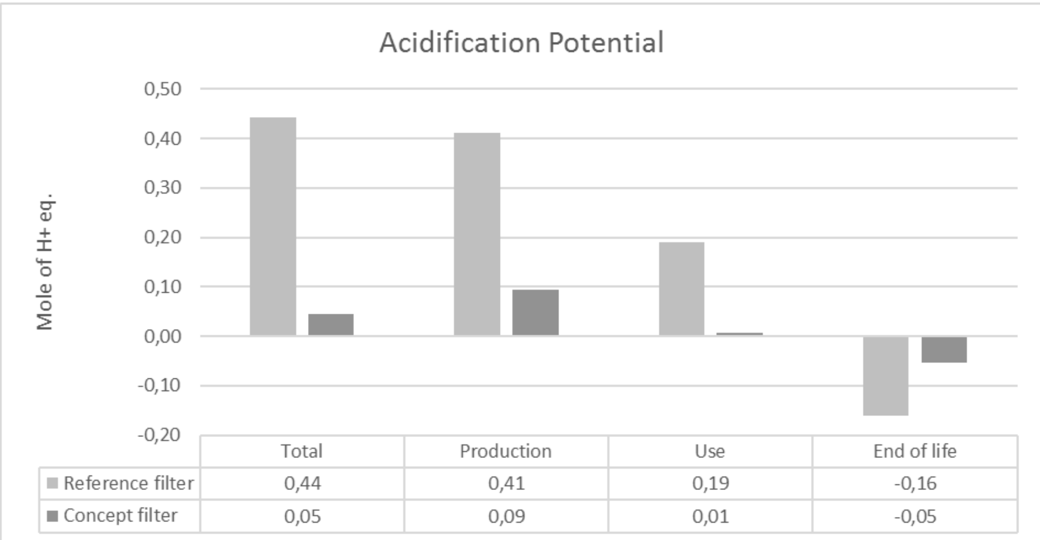


Figure 45: Graph showing the acidification potential for the reference and concept filter

It is somewhat surprising that the concept filter has high acidification potential compared to the reference filter in the production phase despite the much lower weight. But aluminium production is resource heavy and it is especially Sulphur dioxide from the production of the canister that shows in the result. For the reference filter, it is emissions of the same kind that dominates and they are also tied to material and production of the canister. The acidification potential from the use phase in the reference filter case stem from emissions of nitrogen oxide caused by combustion of diesel due to transportation.

EUTROPHICATION POTENTIAL

Figure 46 shows that production phase and use phase have similar amount of emissions that cause eutrophication for the reference filter. It is, again, the steel production that causes emissions but also the large amount of transportation that is required for the reference filter. The shape of the eutrophication graph and the acidification graph are similar since they are results of the same sources of pollutions. However, the numbers are relatively very small in both cases.

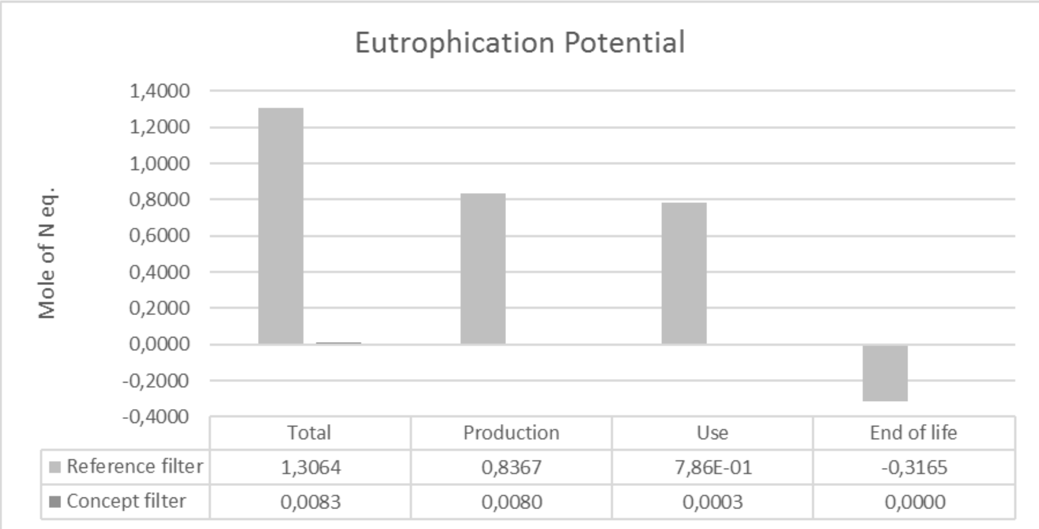


Figure 46: Graph comparing the eutrophication potential of the concept and reference filter

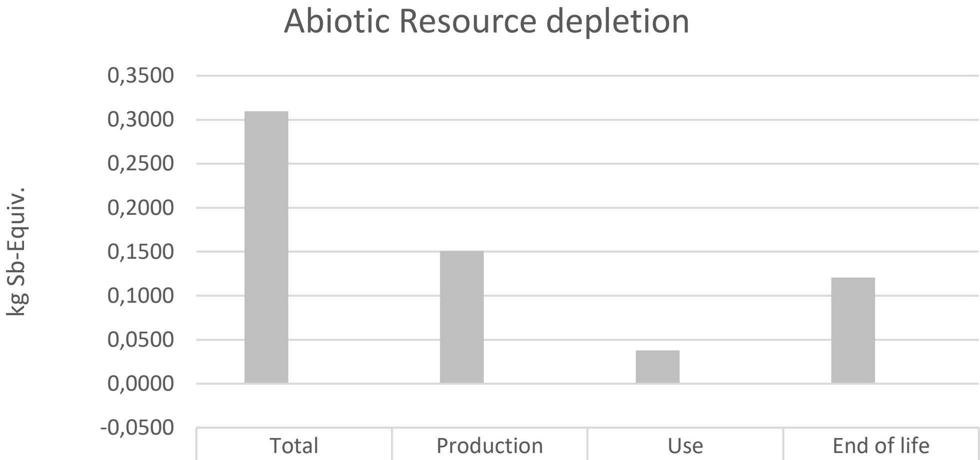
What makes the reference filter dominate is the lager amount of transportation by truck that emits nitrogen monoxide. This causes emission in the concept fuel filter case too but the amount of transportation is much lower. What also causes emissions for the concept filter is the detergent production in the form of ammonium.

ABIOTIC RESOURCE DEPLETION

shows the difference in abiotic resource use. The concept filter uses very few resources compared to the reference concept which is visual in this graph.

The use of resources is very spread over all kind of resources considered in this impact category. What stands out is the use of borax, indium and colemanite in the process estimated for the cellulose cartridge in the reference filter. However, this is an approximated process and if those materials are used in reality is not known.

For the concept filter, it was the production of the canister that was most resource consuming and the materials standing out was bauxite and tantalum. For the use-phase it was the production of detergent used for remanufacturing that stood out using indium. In this impact category are fossil fuels needed for production of aluminium and steel included.



	Total	Production	Use	End of life
Reference filter	0,3095	0,1508	3,79E-02	0,1208
Concept filter	0,0002	0,0004	0,0000	-0,0002

Figure 47: Graph showing abiotic resource depletion for the concept and reference filter

9.3.2.4 IMPACT ASSESSMENT CONCLUSION

Over all it can be said that the LCA has shown how the material reduction has led to reduction of environmental impact. The new way of handling the filters has also led to a big reduction in transports. What is worth paying attention to is the use of aluminium for the canister in the concept filter; aluminium was chosen since it is a light material and it was desired to keep the mass low not to cause unnecessary impact during transport. However, other impact categories show how aluminium causes the biggest impact for the concept. In the refinement of the concept it is suggested that a throughout stress test should be done on the canister to be sure how big the load on it will be and after that look into if other materials are possible and what effects that would have on the transported mass.

The GaBi software, and associated database with the dataset available for the project, could not provide a good number for water use. It would be desirable to be able to compare the reference filter with its water consuming cellulose cartridge solution with the washable concept filter. However, the water estimated to be needed for the concept filter is a very rough estimation and the water may also be recyclable within the process. In Sweden, where the LCA was placed is water consumption not a big problem. If the facility is placed in a country with not so abundant fresh water resources, this factor must be better researched and could in fact have a big impact on the local area. This is somewhat a result gap and it is something worth considering when moving forward with the concept development.

9.3.2.5 ROBUSTNESS TESTING

In the following section are the results from the sensitivity analysis presented. A sensitivity analysis was made on the remanufacturing procedure and in the form of a breakeven analysis between the concept and the reference filter.

SENSITIVITY ANALYSIS

In this part of the sensitivity analysis the idea was to increase consumption of all resources needed during the remanufacturing process, including transports, since the very nature of the concept builds on remanufacturing. The remanufacturing procedure was not described in detail in the concept development section and the amount of ingoing resources was considered needed to be tested to understand how an increase of resource consumption could play out if the procedure would be developed. This was done by multiplying the remanufacturing process with 2 and 10. This way a doubling of needed resources was represented with 80 washings instead of 40 and an increase with 10 times the amount was represented by 400 washes. Since transportation was also included it would represent that the distance to the remanufacturing facility would double in the first case and tenfold in the second.

Global warming potential

Figure 48 shows that even if all the factors in the remanufacturing process were multiplied by 10, with energy consumption, transport, water use, spare parts and soap included, the concept filter is still better for the environment, considering global warming potential. This is a good indication of that the remanufacturing process is a better solution than disposable filters.

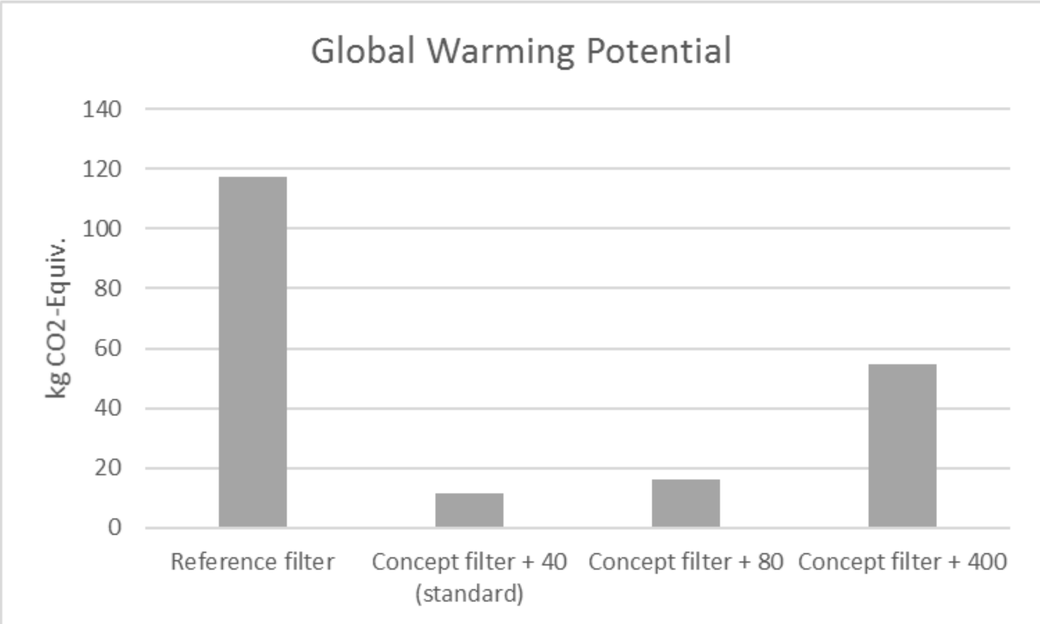


Figure 48: Graph showing how the global warming potential is affected when the parameters of remanufacturing are changed

The biggest change between times two and ten is that the rubber production passes the production of steel spare parts in terms of emissions. This tells us two things, the remanufacturing procedure itself is not a large source of emission and the amount of spare parts needs to be kept low.

Sensitivity analysis and conclusion

The remanufacturing process was the biggest area of uncertainty in the model over the concept due to the readiness of the concept. Values for what was thought to be needed were estimated and because of that, it was interesting to see how the results developed when they were increased. However, some of the factors multiplied by 400 are not likely to be that big, such as water use and spare parts. On the other hand, it gave a good indication of what is most important to think about when the remanufacturing process is developed.

It is worth refining the filter design until it requires as little spare parts as possible to keep the environmental impact at a minimum. There is a lot of potential to develop a remanufacturing facility which can allow for low impact if principles of reuse are implemented, for example could heat used to wash and dry filters be used in the factory.

BREAKEVEN

A breakeven analysis was made to see how many times the concept filter needed to be re-used before it was a better option than the reference filter in terms of greenhouse gases emitted. Figure 49 shows

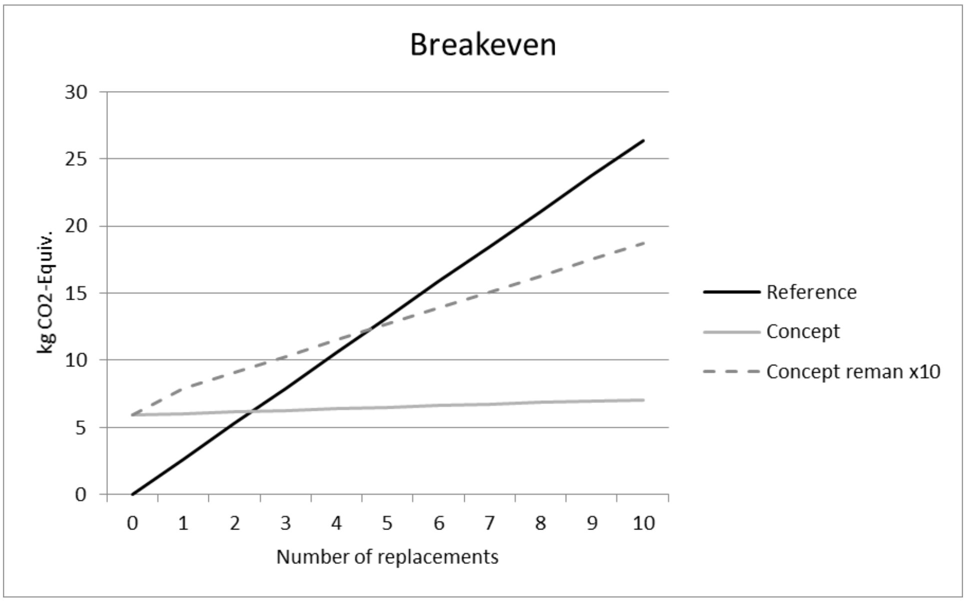


Figure 49: Showing breakeven point between the concept filter, concept filter with resources for remanufacturing multiplied with 10 and the reference filter.

the result from the breakeven analysis. The concept filter has a much higher amount of initial emissions (5.9 kg) but the remanufacturing process emits very little. Due to this, the concept filter has soon paid off its initial emissions and the reference filter, which emits 2.64 kg each, is the less good option already after 2.25 replacements. To make the comparison more interesting the high resource consuming remanufacturing concept was also included in the breakeven analysis (green line). If the remanufacturing process is that expensive, resource wise, it will still take only four reference filters to breakeven.

It might be surprising that the breakeven point is after so few exchanges. But considering that the concept filter only weights slightly more than the reference, it is more understandable. It has already been shown that the impact for both filters is in the production phase and that even if a concept filter is remanufactured 400 times during 20 000 h it is still a better option. This indicates that the remanufacturing process is not very resource requiring.

10 DISCUSSION

As a response to the project aim, the following chapter will discuss the use and sustainability centred development process defined beforehand and utilised for the particular case. First, the outcome from implementing the process on the case will be discussed, that is the final concept solution. Thereafter, the implementation of process in the particular project is elaborated on. And lastly, the more general learning outcomes are discussed, in the meta perspective section.

10.1 THE CASE AND THE FINAL CONCEPT

In this section, the final concept's potentials and weaknesses are discussed. Furthermore, the concept's expansion possibilities and recommended next steps are covered.

The final concept is developed to suit a wheel loader in functional sales model, inspired by circular economy. The main environmental advantage from such a model, compared to today's situation, is that the producing company is incentivized to optimize the service and maintenance. The concept offers a part of the solution to reduce cost and environmental effects from service and the use of consumables. In addition, the new design also gives incentive to take advantage of other principles, inspired by circular economy. First, the concept opens up for more users to use the same product, it allows for reuse, remanufacturing, repair and extended use. In the products end-of-life phase, it also allows for easier recycling compared to the reference, since it is quite easy to disassemble and separate materials. These are also materials for which there is a market to resell the materials after recycling. All these factors might contribute to resource saving beyond what was shown with the LCA. To add to this equation is that the 40 reuse cycles for the concept filter might be a conservative assumption. A product life of 40 cycles was assumed based on that today's suppliers of similar solutions guarantee their products to last the lifetime of the vehicle. Thus, for the L150, and with preserved replacement intervals, resulted in the 40 use cycles as the minimum requirement. Though, it is reasonable to believe that the filters can be designed to endure more than 40 cycles and that the intervals can be extended, hence giving raise to even larger economic and environmental savings.

A weakness with the concept is that more could probably have been done to resolve the underlying problem to why fuel filters are at all required; referred to as: "*eliminate or reduce the basic need*". The underlying problems were identified as the fuel being contaminated and the injectors being very sensitive. Though, these were not questions which suited the particular project very well, they are interesting aspects to investigate in other projects. In this project, the scope somewhat directed the process towards resolving symptoms rather than the actual problems. If the objective would have been less focused towards generating a tangible product, it is believed that the problem could have been addressed on a higher level of substitution. Thus, higher impact can be obtained in accordance with the theories about levels of substitution by Holmberg (1998). As the project was carried out, the final concept might contribute to a lock-in towards fossil fuel powered engines. Though, the solution is at the same time providing guidelines for how environmentally better products can be developed already today.

To go from product concept to final product, further analysis is required to determine the exact structural properties of the product through dynamic fatigue tests, pressure analysis and possibly optimizing the flow through fluid mechanic simulations of the system. Filtration capacity seems to require empirical tests to guarantee sufficient performance. Thus, another step could be to carry out these ISO standardized tests on filter prototypes. Next, complementary real life testing would be appropriate, to ensure satisfactory performance in field. Including prototyping and trying out the washable filters small scale, for instance together with individual customers with a large machine fleet.

It would be important in such a test situation to verify the solution with users to make sure that requirements about easy use are met.

Making the reman solution economically and environmentally justifiable, including setting up a reman facility, redesigning the product and establishing new business relations etc., will probably require high quantities of filters. The concept allows expansion to include all sizes of fuel and oil filters in the construction equipment machine catalogue. The solution, is also believed to be compatible with old technology, for machines already on the market. Thereto, expansion to all diesel engines in the whole Volvo Group is believed to be a possible next step to obtain high quantities; even though this will include extensive reassessment of these new systems and the related requirements. Regarding trucks for instance, other requirements are important, such as product weight and the accessibility in the compressed engine room.

A few perks have been identified connected to the circular business model and the studied system, from which the company can benefit. First, the model might facilitate in keeping customers loyal to the brand, which is mentioned in theory by Tukker (2015) as a typical benefit from introducing service system schemes. In addition, the close customer relation makes it easier to understand the customer, and develop products, sufficiently adapted to the customer needs. The environmental responsibility shown through reuse of products and a revised company view on consumables can also be used for green marketing purposes to attract new and existing customers.

There is obviously a bit of a way to travel before the solution can be implemented. The next step could be to specify the functional sales model more in detail and establish it internally in the company. In addition, the business case should be explored in relation to the functional sales model. How can the solution create revenue for the company and what is a reasonable time horizon? After that, a next step could be to reach out to companies owning the filter technology. However, even more important is to strengthen the relation to today's service provider, which possesses the real customer insights and understanding of the service systems. To ensure that the user considerations, including physical and cognitive ergonomic aspects, are being satisfactory met, the solution should be evaluated with physical user evaluations with a physical product representation; as described in the later sections of the product development framework, in chapter 3.

Even though results are promising, the concept is just a small piece in the transition to a circular business model. Even so, the solution is a bridging technology towards truly sustainable ways of making business and as a good case study in how it can be achieved. The solution can be implemented quite easily already in today's system, since much of the required infrastructure for the remanufacturing is already in place and the technology behind the concept is available.

10.2 THE DEVELOPMENT PROCESS – IMPLEMENTED

Under this headline, the implementation of the process framework will be discussed. The section will elaborate on which aspects were successful and which were less useful in the particular case, and the reasons to why this was the case.

The demand for a pre-planned project forced the design process to be quite explicitly defined already before the prestudy. This might have caused a problem due to the unknowns regarding what the reference product could be. It showed that a user centred process was not entirely suitable for the type of product selected, with a quite limited user contact throughout its operating life, and some process alterations were necessary, for instance extensive user interviews and user tests were excluded.

The idea of using criteria was to guide the process in a desired direction, considering all stakeholders and thereafter help in selecting paths and solutions to ensure the project would have a clear end-result, a tangible concept which would allow for evaluation, without constraining the process, as can be a risk when using product requirements. However, in this case also the criteria seem to have directed the process in a slightly undesirable direction, towards a too narrow solution space. The weakness in the method seem to be related to the chosen criteria and the weighting, rather than the principle itself. The constraining criteria regarding the company compliance, completion level and technical feasibility could probably better be introduced later in the process to maintain an open solution space in the early ideation stages.

Because the criteria were used in the design process the new design was naturally anticipated to be better, when evaluated against the very same criteria. Using the criteria as guides in the process has led to the desired outcomes most times; however, it makes the criteria very influential and if aspects are missed out in the criteria, these aspects might be entirely lost in the process. This stresses the importance of carefully considering the criteria, the need to anticipate their contribution and possibly reassessing them. An example of such missed aspects might be economic feasibility; which has led to the fact that no conclusions about the business case and the economic sustainability can be made.

When it comes to the scenario, it is believed that it must be better rooted in the organization and the company's long term objectives and strategies, in order for the method to be truly successful. This conclusion is somewhat in line with what is suggested in Bocken et al. (2016); referred to as the "*integrative perspective*", saying that companies need to have a clear overall vision before product and business model can be designed to become more circular. In this particular case, this could not be done due to that concrete visions and strategies could not be communicated in detail by the company.

The scenario is defined as ten years from today and the result of this was a context and product description very close to the one of today. This scenario was considered reasonable at the time. However, in hindsight it could have been better to try looking beyond the anticipated technical horizon and try to foresee what would actually be established on the market in ten years from now. This would have been an advantage when considering that a product in its design stage today, will have a lead-time of a few years before it reaches the market. A possible definition of the wheel loader then could have looked very different; involving the concepts of electric drivelines and autonomous or remote driving for instance. Followed by a result, more in line with that technical development. More insights about the company's current research engagements could have pushed the project in such direction.

The initial idea was that the development of the product concept and the scenario were to be done simultaneously, a method supported in Bocken et al. (2016), claiming that development of business model and design must go hand in hand. Although, the project showed that there might be a risk that, by doing so, an ideal case is built; in which the product and the scenario converges, resulting in a seemingly successful concept, even though the scenario, and thus the concept, might have lost its connection to reality during the process. As for the criteria, it seems that the scenario had a major influence over the process and the end-result in the particular case, again stressing the need for careful considerations and trying to forecast the consequences when such methods are utilized.

Another problem with designing for a scenario is that reality might develop in entirely different directions. For this case, for instance if the functional sales scenario is never introduced full scale, the final concept will fall short. On the other hand, learning outcomes can still be obtained regarding life cycle thinking and important aspects to consider in relation to this. And despite the scenario might never occur as described in the case, the concept can still work for alternative scenarios; even though the machine is not part of a functional sales model, the company can still offer filter take-back and remanufacturing of used filters to their customers as a complement to the existing use-dispose solution.

Another relevant question raised during the projects was how close the scenario should be to the current situation. This is a typical trade-off between implementability and innovation i.e. how soon can the solutions be implemented, versus how big of an improvement can be obtained. Even though improvements have been proven short term a lock-in is hindering the concept from being entirely justifiable from an environmental point of view. That is because the final concept will induce investments, both monetary and in resource usage for a setting up a remanufacturing facility which is a draw-back, considering the aim to achieve an entirely sustainable solution over time.

One very important factor leading to the extensive resource reductions was the decision to establish an environmental objective early in the product redesign process; a strategy which is also recommended by van Nes and Cramer (2006). In this case, the objective was to focus and prioritise *resource efficiency*. Since the studied reference product was found to be a passive product, not resource consuming when used, the material resource efficiency focus was appropriate. However, an absence of tools was experienced, when it came to supporting the designers in which decisions are extra important to consider in relation to the different product types. Especially, relevant guidelines or recommendations would have been very helpful, since it was quite difficult to pinpoint some of the less intuitive contributions from the use-phase during the development. Such as in the studied case, additional transports and maintenance.

Another very influential factor behind the satisfactory result was the level of abstraction on which improvements where suggested. Major impact could be obtained by starting on the highest level, and redesigning the goals of the system, in this case the incentive for the company to reconsider their view on consumables. Followed by the design of the system level flows, through the introduction of remanufacturing of used products in our case. And further on to the lower levels, designing the functionality of a product in such system and lastly the tangible product attributes to fulfil the corresponding functionality requirements. Thus, major improvements could be obtained, even though only minor alterations were made to the product; to summarise, after redesigning the system and introducing the remanufacturing scheme, the functionality level design was focused on supporting the alternative system and the functionality was in in turn supported by the product level design suggestions. The reason to why solutions are considered on different hierarchies is the previously presented theories about levels of substitution (Holmberg 1998); discussing the effectiveness of a change in relation to the level on which it is implemented.

The ecodesign, or Design for environment mindset (DfE), discussed in Tingström (2007) was believed to be the most important factor in achieving environmental impact reductions. The mindset included constantly tweaking tools towards an environmental focus. Thereto, the mindset promoted a continuous consideration of the life cycle perspective in the decision making which, amongst other benefits, gave the silent stakeholders room to influence. Also, the fact that the scope of the project quite clearly stated resource efficiency as the prioritized environmental aspect made an important contribution to the mindset and had a major influence on the final result.

Identified ecodesign tools were used to the best of our abilities and are believed to have affected the result positively. However, the focus of the tools used were on ideation and the final evaluation of a well-defined concept. The process was lacking tools to support continuous decision making; for instance, quickly weighing use-phase aspects to contribution from production for a number of impact categories. Such tools do not have to be numeric, but rather just guide the decision-making towards more sustainable alternatives and help the designer in prioritizing actions. What is requested, is a "*Life* *cycle based environmental impact assessment for the functionality in product systems*". The absence of such tool box is identified and problematized around by a number of authors (Tingström 2007, Bocken et al. 2016). However, since *user centred design* and *LCA,* both revolve around *functionality*, the authors of this thesis point out that the idea of such a tool coming to existence is not unrealistic.

Assessing a concept with LCA comes with a lot of challenges and might at first sight seem contradictory to the very nature of an LCA. A concept is ambiguous and uncertain, not much is decided and even less is known compared to what is generally needed to be in an LCA where every process, material and matter of transportation needs to be known in detail. However, involving LCA in the product development process gave some benefits; since it addressed aspects such as materials choice, material thicknesses, and transportations. However, an experienced LCA analysist could probably better have decided at what stages and in what areas the LCA could be allowed to be less accurate; that is, only at the spots where the system knowledge and available data can support this accurateness.

Conducting an LCA on the final concept in this project could be compared to conducting an LCA on circular economy, on small, conceptualized scale. The conducted assessment in this project clearly indicates that circular economy has advantages over linear economy when it comes to environmental impact, which is mostly tied to the major decrease in materials use over the life of the wheel loader. However, the reason to why the concept uses less materials is tightly bound to principles of circular economy being used in the development process.

Even though the final concept showed major material resource saving, the end-result can be questioned; not as much in terms of the project aim and scope, as when it comes to long lasting sustainability improvements. One reason to why the target was somewhat missed might have been due to the process being constrained by a few factors. First, the limited access to information and the studied system, due to the distance between Gothenburg and Eskilstuna; hence the possibility to obtain a complete picture of the system, related problems and the direction of the technical and technological advancements. Secondly, the type of internal knowledge that was obtained from the interviews was quite limited to certain areas, due to proximity to people with these types of competences and knowledge; which in turn forced the project towards these areas. Thereto, the access to real users to observe and interview was quite limited, which is believed to have affected the outcome negatively. Lastly, the project experienced a limitation from the process and the predefined end-result being quite explicitly defined, even before the project commenced; the predefined process and end-result offered little possibility to change directions when it was discovered that the project was turning towards designing lock-ins.

10.3 THE DEVELOPMENT PROCESS – META PERSEPECTIVE

Under this headline, the project result is discussed from a more holistic and general point of view and the findings are placed in an extended context.

The framework was developed from material from a number of different sources, which is considered a strength. However, no contradictory theories were found, criticising the used theories. This might suggest that the referenced sources make up a too narrow base for conclusions around whether the framework is supported in theory. It can only be concluded that the framework was quite successful in the very specific case of this study.

It seems that much of the successfulness in the case is somewhat a result of the very good match between ecodesign and a user centred design. First, the system perspective promoted by the use centred process, especially when complemented with the life cycle perspective, seem to have had an important contribution to the resource savings. And just like our hypothesis predicted, the idea of prolonging product life or sharing a product leads to a higher use-rate per individual product. This means that, even though the initial system has no or weak links to a user, a maintained user perspective is very important and potential users must be anticipated; such as shared-use users, secondary user, maintenance personnel, remanufacturing mechanics etc. Since these new users might have a major influence over the product's life cycle performance and environmental impact, user centred product design is crucial. First, to ensure they are actually being used at all; and hence, utilization being optimized. And secondly, that the products are used correctly and responsibly, to optimize use efficiency. Otherwise, trade-off effects can quite easily weigh up for the expected resource savings. A system perspective is argued in Bocken et al. (2016) to be an important key to avoid such undesirable effects.

In alignment with Tingström (2007) the project has acknowledged the difficulties in using LCA early in the product development process. One of the problems, which was touched upon previously, is the fact that early concepts are surrounded by many uncertainties; the tangible attributes are not yet fully determined, to the level which is required by the LCA methodology as it is described in ISO 14 040. Another reason to why LCA is not appropriate in the early product development stages, addressed in theory and confirmed by the project, is that a vital parameter in supporting innovations is for methods to yield quick results, and to promote fast decision-making (Tingström 2007). The project also experienced that, in order to make relevant estimations, handle data gaps and to find the right level of the assessment, a quite high level of knowledge was required; both in the studied domain and about the use of LCA. The way LCA was used in this project, the method contributed to a focus on lower level improvements when forcing to define product attributes quite explicitly; while the process, still promoted a focus on higher level substitutions.

Even though the solution is better than the reference, the solution can be argued to have slightly missed the goal of being entirely resource efficient over an extended time horizon. The solution is creating a potential revenue stream from a system built around a fossil fuel dependent product and which in addition build on a system relying on transportations to a high extent. This obviously raised some thoughts about the designer's role and ethics:

- What responsibility do the designers have in ensuring the environmental aspects remain a priority also after the concepts are handed over to the company for further development and launch.
- How can designers make sound decisions about when investments in additional use of resources are justifiable; considering trade-offs, technical advances, and lock-in effects? Example: *Pose the revenue from remanufactured fuel filters and the investments in the suggested remanufacturing chain will be one, even though a small, contribution holding back the transition to more environmentally sustainable drive line. A possible consequence of such lock-in effect would be a substantially negative influence on the environment.*
- A related question will be, when we can allow ourselves to wait for anticipated technical advances and when we are better doing something to reduce environmental impact in the current system? Even though the changes might risk creating lock-in effects? Perhaps prognostic LCA's can be utilized to support in this kind of decision making?
- Another question raised during the project, on the topic of substantial and long term improvements, is how we can incorporate the business model as a factor in the development process, to ensure the results will be truly resource efficient systems? To close in on the answers to these questions, further research is requested.

11 CONCLUSION

As a response to the project aim: "to explore the use and sustainability centred product development process", the case stressed the potential to obtain real environmental impact reduction, quantitatively verified with LCA, from a development process guided by a pronounced focus on use and sustainability aspects. Over the machine's operable life time, the final washable filter solution is expected to save approximately 95 % of the material usage, 60 % of the transportation distance and about 90 % of the total impacts on global warming.

The use of circular economy as inspiration and guidance, resulted in a concept with verified environmental impact reductions, compared to the reference product in the linear business model. This fact brings credibility to that the concept of circular economy and in particular, the principle about material resource efficiency, has the potential to lower the environmental impact from consumption. As anticipated, the circular business model *functional sale*, in this case led to an increased use rate per individual product; which stresses the importance of user considerations in the product development process, including both existing and anticipated, new users. In addition, use centred design is essential, in order to ensure that the increased usage per products is as resource efficient as can be.

The final concept's successfulness is also believed to be a result of the fact that the solution considers the entire system. Since, according to the theories about levels of substitution, changes are more efficient the higher up in the system hierarchy they are implemented; from the overall system goal and flows, to the functionality and lastly to the tangible product attribute level. The systemic perspective is promoted from both the user design and circular design perspectives, which further emphasises the strengths of a combined user and sustainability centred perspective.

In the particular project, it was deemed useful to define an environmental objective early in the process in order to manage contradictory environmental aspects. In this case, the overall environmental objective focused on material resource efficiency. The case could also conclude that both the *scenario*, used to manage the situation of designing for a not yet existing future, and the *evaluation criteria*, used to maintain relevancy were very influential over the process; hence needs to be carefully considered and well aligned with the company vision and strategy, in order not to steer the project off in undesirable directions.

In addition, the use of what is referred to as the *ecodesign mindset* seem to have contributed to the positive case result; as it stresses environmental aspects in every decision. However, the absence of easy-to-use design tools, to make use of the mindset and promote sustainable alternatives was acknowledged. The project has, in alignment with product development theories, also concluded that using LCA according to the ISO-standard, is not efficient as a concurrent design support tool. However, the project can recommend LCA to be used on existing product systems to address current issues and raise awareness of the life cycle perspective. Results from such LCAs are recommended to be part of design, or re-design, processes to reduce impact.

It can be concluded that by introducing the final concept, major reductions can be obtained in all impact categories in the analysed scenario. Although, some concerns remain: the environmental impact reduction risk to be negatively affected, depending on how the company decide to proceed with the concept. This is because the concept risks creating lock-in effects from an environmental point of view, due to that the generation of revenue is dependent on a fossil fuel based system.

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LIST OF APPENDICES

APPENDIX I - LIST OF INTERVIEWEES

Reference	Conmpany	Position
Interviewee 1	Company (VCE)	-
Interviewee 2	Company(VCE)	-
Interviewee 3	Service provider	-
Interviewee 4	Service provider	Technician
Interviewee 5	Company (VCE)	-
Interviewee 6	Company (Group)	-
Interviewee 7	Company (VCE)	-
Interviewee 8	Company (trucks)	-
Interviewee 9	Company, (VCE)	-
Interviewee 10	Company (VCE)	-
Interviewee 11	Company (Group), VGTT	-
Interviewee 12	Company (Group), VGTT	-
Interviewee 13	Recycling company	Environmental manager

Due to integrity reasons, many of the respondents detailed position has been left out of the list.

APPENDIX II - STAKEHOLDER ANALYSIS

Stakeholder	Motivation		Method		Constraints		Risk		Relation to product		Influence on machine design.	
	Linear	**Circular**	**Linear**	**Circular**	**Linear**	**Circular**	**Linear**	**Circular**	**Linear**	**Circular**	**Linear**	**Circular**
Buyer/Owner	Keep line running.	Keep line running.	High uptime/ productivity	High uptime/ productivity	Breakdowns, maintenance costs	Breakdowns,	High	Low	Medium-none	Medium-none	Medium-high	Medium-high
User/operator	Complete task.	Complete task.	Driving skills/ product performance	Driving skills/ product performance	Break downs and waiting.	Break downs and waiting.	Low	Low	Close	Close	Low-Medium	Low-Medium
Volvo/ Business plan	Sell machine.	Rent out machine	Develop high quality machines and parts.	Sell function of machine and reduce cost for service and maintenance.	Breakdowns leading to bad reputation. Lack of information to satisfy customers' needs.	Breakdowns that leads to bad reputation. Lack of information to satisfy customers' needs.	Medium.	High.	Medium-close	Medium-close	Big.	Big.
Dealer/middleman	Sell machine and service.	Find the right machine for the right application.	Understand customer needs.	Understand customer needs.	Lack of information.	Lack of information.	Medium	Medium	Close	Close	Medium	Medium
Service personnel	Keep reputation with high uptime.	Keep reputation with high uptime.	Regular service intervals.	Nurture relations. Quickly be at site when	Context. Communication.	Context. Communication.	Medium	Low	Close	Close	Low-Medium	Low-Medium
Investors	Economically sustainable company.	Economically sustainable company.	Chase cost, earn money on aftermarket products.	Durable and long lasting products to avoid down-time and repairs.	High development costs.	High development costs.	High	High	None	None	Big.	Big.
Environment	-	-	-	-	Limit amount of resources and sinks	Limit amount of resources and sinks	None	None	High	High	medium- hight	Low

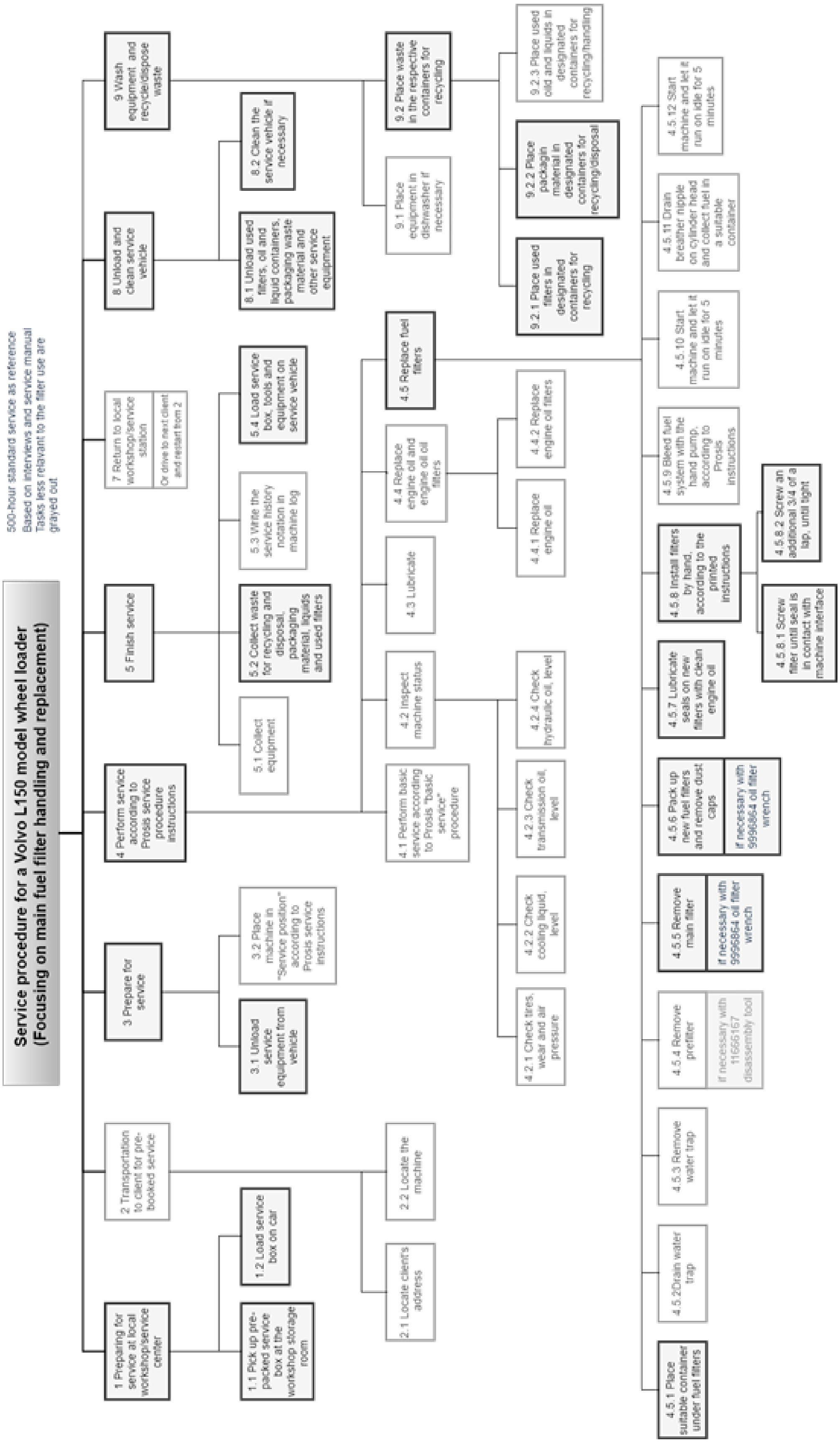
APPENDIX III - KEY AREA SELECTION

Key areas			Evaluation criteria										
			Volvo compentency	Societal benefit	User benefit	Customer benefit	Volvo benefit	Innovation potential	Competency	Material resource efficiency	Energy efficiency	Average	Weighted Average
		Criteria weight	1	2	3	3	3	2	5	5	4		
	1	Repair and Maintenance	4	4	3	4	5	4	5	4	4	4,1	13,0
	2	Remanufacturing	3	4	1	2	4	4	2	4	4	3,1	9,6
	3	Utilization	2	3	1	5	5	4	4	3	3	3,3	10,7
	4	Use efficiency	2	2	3	5	3	4	4	2	5	3,3	10,8
	5	Reuse	1	3	1	3	4	3	2	5	5	3,0	10,2
	6	Repurposing	1	3	1	3	4	5	2	5	4	3,1	10,2
	7	Recycling	2	3	1	2	3	4	3	3	3	2,7	8,4
	8	Material selection	3	1	1	2	3	2	2	4	4	2,4	8,1
	9	Organisational structure	2	1	1	3	4	4	1	4	1	2,3	7,2
	10	Business model	2	1	1	4	4	4	1	5	2	2,7	8,6

APPENDIX IV - COMPONENTS AND MATERIALS DECLARATION

Ref.	Component name	Primary function	Secondary function (s)
	Filter body		
9	canister	contain filter	contain diesel prevent particles from entering withstand pressure support filter act as handle/grip when detaching/attaching protect filter provide surface for information/instructions
8	spring	allow over pressure bypass	keep filter in place (centre)
2	retainer sheet	keep housing and interface together	seal housing and machine interface lead diesel provide attachment of gasket
	Interface		
3	interface plate	connect filter to machine	seal fuel system downstream prevent copying spread fuel provide structural integrity to design
1	gasket	seal fuel system (upstream-outside)	put "pressure" on threads to lock
-	small gasket	seal fuel system (upstream-downstream)	-
	Filter cartridge		
6	Cellulose filter material	mechanically filter out particles from fuel	-
-	Glue/ "sealing foam"	seal between up- and downstream	glues metal capping discs to cellulose cartridge
5	Inner tube	support filter	Transfer force to spring in case of over pressurized container
4	Top cartridge capping disc	support filter	keep flanges apart prevent leaking of contaminated fuel to clan side of filter transfer pressure to inner tube in case of over pressurized container
7	Bottom cartridge capping disc	support filter	keep flanges apart prevent leaking of contaminated fuel to clean side of filter
	Related components		
-	Dust cap	prevent particles from entering before installation	stay on place during distribution be recyclable inform about recyclability
-	Transportation packaging	Protect filter during transport	Inform user
	Coating/Paint		
-	White paint	protect casing	express Volvo's graphic identity express Volvo genuine component
-	Blue inscriptions	inform user about use and installation	inform about after life treatment express Volvo's graphic identity express Volvo genuine component inform about manufacturing ensure product tracing by printed serial no. and bar-code

APPENDIX V - HIERARCHICAL TASK ANALYSIS (HTA) FOR THE SERVICE PROCEDURE WITH FOCUS ON THE MAIN FUEL FILTER HANDLING



APPENDIX VI - PERSONA AND USE-SCENARIO

Jonas, a 39 year old service technician from Uddevalla, currently employed at Swecon, Mölndal. Right after his graduation from high school as a heavy vehicle mechanic he got a job at a small workshop in his hometown. A couple of years later he met his wife, Sandra, and soon went to live with her in an apartment just outside Gothenburg city. Jonas decided to take the opportunity to get the most out of his education in heavy machinery and applied for a new job as a mechanic at Volvo BM, heavy, off-road equipment centre in Mölndal, where he has stayed ever since, however moved on to become an on-call service mechanic for the same Volvo service center. In their free time, Jonas and his wife spend a lot of time with projects in an old villa, which they bought and moved into almost ten years ago. Over the last couple of years, most weekend for more than half the year are spent in their camper van, travelling Scandinavia, for their two daughters, Nellie and Eleonore, 11 and 15 to compete in the motocross series.

Figure: Persona illustration

The reason to why Jonas has remained at Volvo during all these years has much to do with the quality of genuine Volvo equipment; the quality makes his life easier as a technician and the meetings with proud Volvo customers is a rewarding part of his job. Also, he appreciates the variety in his work, with different machines, different tasks and different clients; he seldom knows what the next day has to offer. The varying tasks and contexts also comes with some down sides; the working conditions are sometimes not ideal. An October morning in a muddy quarry, cold, dark and wet and with rain just pouring down is obviously not the most pleasant conditions for a service. Neither is it easy to keep the delicate filters clean when changing them a hot, dry day in June, where the dust whipped up by the wind, from conveyors and from off-road equipment moving around the site is almost impregnable. If you are lucky though, the customers have made room for and parked the machine in their workshops, but that's more of an exception than rule. Sometimes the filters leak too and everything gets messy; the clothes, the machine, the toolbox and tools, spare part and even the back of the car becomes contaminated with fuel and oil. The washing machine back in the workshop really saves the day. When thinking about it, Jonas is surprised nothing has been done to improve the handling of the filters during all these years; it seems filters have remained more or less the same for as long as he can remember.

Unlike some of his older colleagues he can really see the advantages from the recent shift towards more sophisticated components and the use of software to determine the machine's status and search for problems. Jonas believes it has made most jobs faster and with pleased clients as a result. He is really looking forward to the remote failure detection system, which he has read is on its way; it could help him be even more prepared when arriving to the Volvo owners in the area. After working with heavy equipment for almost 20 years his body is not what it used to be. Nowadays he rather work on machines where it is really easy to reach; climbing around on a two-story high wheel loader is something he leaves to his younger colleagues. Jonas is not afraid to get his hands dirty for the right reasons. However, to risk shortening his life due to diesel fumes and diesel and oil spill on his skin is definitely not something he is prepared to do. Even though the working conditions have improved by miles during the last decade, he still feels improvements could be made if only the equipment designers would listen to the expertise from the field. Though, he is proud about how far his workshop has come in terms of environmental responsibility. Separating hazardous materials such as filters, spray cans and paint buckets, used oils and other liquids etc. in different containers for recycling feels really good. What happens with the filters after the containers have been sent away on the other hand, is not something he has thought much about.

APPENDIX VII - RAPID ECO ASSESSMENT, COMPLETE RESULTS

	Eco strategy wheel consideration	Rapid assessment	Comment
1	Design for: Innovation		
1,1	Rethink how to provide the benefit	Not yet considered	More can be done
1,2	Design flexibility for technological change	Not yet considered	More can be done
1,3	Provide product as service	Not yet considered	More can be done
1,4	Serve need provided by associated products	Not yet considered	More can be done
1,5	Share among multiple users	Not yet considered	More can be done
1,6	Mimic biological systems	Not yet considered	Major system changes and/or new innovations required before improvements are possible
1,7	Use living organisms in product system	Not yet considered	Major system changes and/or new innovations required before improvements are possible
1,8	Create opportunity for local supply change	Has been considered, to some extent	More can be done
2	Design for: Reduced material impact		
2,1	Avoid materials that damage human or ecological health	Has been considered, to the best of abilities	Major system changes and/or new innovations required before improvements are possible
2,2	Avoid materials that deplete natural resources	Has been considered, to the best of abilities	Major system changes and/or new innovations required before improvements are possible
2,3	Minimize quantity of material	Not yet considered	More can be done
2,4	Use recycled or reclaimed materials	Has been considered, to some extent	Considered due to economic incentive. More can be done
2,5	Use renewable resources	Has been considered, to some extent	More can be done
2,6	Use materials from reliable certifiers	Has been considered, to the best of abilities	-
2,7	Use waste byproducts	Assessment pending	More information required
3	Design for: Manufacturing innovation		
3,1	Minimize manufacturing waste	Has been considered, to the best of abilities	Considered due to economic incentive. Major system changes and/or new innovations required before improvements are possible
3,2	Design for production quality control	Assessment pending	More information required
3,3	Minimize energy use in production	Assessment pending	More information required
3,4	Use carbon-neutral or renewable energy sources	Assessment pending	More information required
3,5	Minimize number of production steps	Assessment pending	More information required
3,6	Minimize number of components/materials	Not yet considered	More can be done
3,7	Seek to eliminate toxic emissions	Assessment pending	More information required
4	Design for: Reduced distribution impact		
4,1	Reduce product and packaging weight	Has been considered, to the best of abilities	Considered due to economic incentive.
4,2	Reduce product and packaging volume	Has been considered, to the best of abilities	Considered due to economic incentive.

4,3	Develop reusable packing systems	Not yet considered	More can be done
4,4	Use lowest-impact transport systems	Not yet considered	More can be done
4,5	Source or use local materials and production	Not yet considered	More can be done
5	Design for: Reduced behavior and use impacts		
5,1	Design to encourage low-consumption user behavior	Not yet considered	More can be done
5,2	Reduce energy consumption during use	Not yet considered	More can be done
5,3	Reduce material consumption during use	Not yet considered	More can be done
5,4	Reduce water consumption during use	Not yet considered	More can be done
5,5	Seek to eliminate toxic emissions during use	Not yet considered	More can be done
5,6	Design for carbon-neutral or renewable energy	Has been considered, to some extent	More can be done
6	Design for: System longevity		
6,1	Design for durability	Not yet considered	More can be done
6,2	Design for maintenance and easy repair	Not yet considered	Not regarding the filter design, More can be done
6,3	Design for re-use and exchange of components	Not yet considered	Not regarding the filter design, More can be done
6,4	Create a timeless aesthetic	Not yet considered	More can be done
6,5	Foster emotional connection to product	Not yet considered	More can be done
7	Design for: Transitional systems		
7,1	Design upgradeable product	Not yet considered	More can be done
7,2	Design for second life with different function	Not yet considered	More can be done
7,3	Design for reuse of components	Not yet considered	More can be done
8	Design for: Optimized End of Life		
8,1	Integrate methods for used product collection	Not yet considered	More can be done
8,2	Design for fast manual or automated disassembly	Not yet considered	Not regarding the filter design, More can be done
8,3	Design recycling business model	Has been considered, to some extent	More can be done
8,4	Use recyclable non-toxic materials	Has been considered, to some extent	More can be done
8,5	Provide ability to biodegrade	Not yet considered	More can be done
8,6	Design for safe disposal	Not yet considered	More can be done

APPENDIX VIII - FINAL CRITERIA WEIGHTING

	Customer benefit	Technological feasib	Concept completion level	Company compliance	Material selection	Energy consumption	Material usage	X	O	
Serviceability	x	x	x	x	o	x	o	5	0	5
Customer benefit		o	o	x	o	x	o	2	0	2
Technological feasibility			x	x	o	x	o	3	1	4
Concept completion level				x	o	x	o	2	1	3
Company compliance					o	o	o	0	0	0
Material selection						x	o	1	5	6
Energy consumption							o	0	1	1
Material usage								0	7	7

APPENDIX IX - INITIAL 8 FUNCTIONALITY CONCEPTS DESCRIPTION

Concept 1 - Replaceable Cartridge

General description

The concept is based on that only the filter media itself, the cartridge (Figure 1), is replaced during the service procedure. To allow cartridge replacement, filter design changes are required. The contaminated cartridge in sent for incineration and energy recovery.

Figure 1: Replaceable cartridge concept

Advantages

- All materials are separable.
- Less material use, only filter material is replaced.
- High realization level, been done before.
- The disposed part can be used for heat recovery.

Limitations

- Replacement must be done on site with changing and challenging working environments.
- Might be difficult to maintain cleanness during exchange of filtering media.
- Increased risk for contamination of technician from hazardous liquids and fumes
- Require additional manual work.

Unique elements

- The replacement of the filter material allows a good insight in the performance of the filter thanks to that the old cartridge can be scanned while replaced.
- Contains a disposable unit.
- Require no changes to fuel system.
- Allows for personalization of the casing; since it stays on the same machine.

Concept 2 - Twin-filters

General description

The idea behind the concept is to save material by having several product sharing material; i.e. less material to be scrapped for each service. For this concept, the suggestion is for the pre-filter and the main fuel filter to be integrated in the same canister (Figure 2) by redirecting the flow from out-in, out-in to in-out, out-in. The solution also ought to reduce service time since both filters are changed in one replacement.

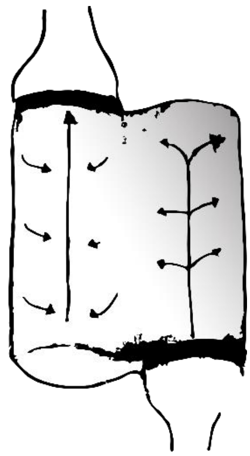


Figure 2: Twin-filter concept

Advantages

- Has the potential to be somewhat material saving.
- It might reduce service times.

Limitations

- The principle is not used today, which might indicate that the technology is non-existent or inefficient.
- There is a risk for a two-in-one solution it is important to be more complicated to install or heavier to lift.
- Combined functionality might cause reversed performance synergy. (1+ 1 < 2)
- The solution only has limited material saving potential.
- Difficult to implement the filter type on existing machines.
- Both filters must be replaced at the same time.

Unique elements

- It combines two functions in one.

Concept 3 - Docking station

General description

The machine is docked to a station overnight (Figure 3), where filters are cleaned, hence the machine requires. Thereto, the machine is refuelled with pre-filtered diesel from the docking station, to avoid contamination.

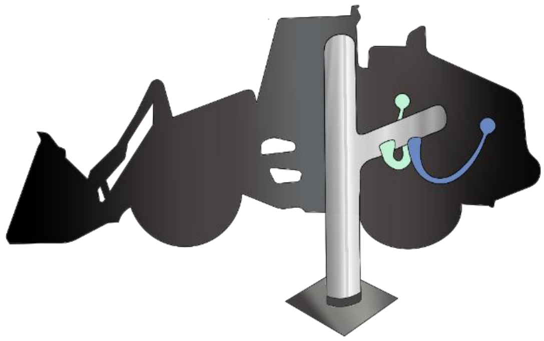


Figure 3: Docking station concept

Advantages

- Filters does not have to be replaced.
- Diesel thefts can be avoided since the tank is always empty when the machine is not in use.
- The unit can be shared between all machines on site.
- It's a Swiss-army knife device, which has the potential to handle multiple issues in future applications.

Limitations

- The docking station needs to have more functions in order for it to be economically justifiable.
- There must be many machines in the fleet, sharing the same docking station for the solution to be efficient.
- The technological feasibility for such solution is yet uncertain.

Unique elements

- The solution can work as a bridging technology for electrical wheel loaders.
- It's a technology that is stationary instead of carried by the machine.
- It is based on shared function principles.
- It is ought to treat the underlying issue with poor refuelling hygiene and diesel quality.

Concept 4 - Recyclable Design

General description

The solution ought to improve both the recyclability and the actual recycling rate, by considering the design for recyclability principles to the full and innovate solutions to improve return rate (Figure 4).

Figure 4: Recyclable design concept

Advantages

- Less contamination in the recycling process.
- Less material waste.
- The process of changing filters remains and no additional training of the technicians is required.
- Principles are relatively easy to implement on current design.

Limitations

- The amount of filters, and the amount of materials disposed is still the same.
- The principle counteracts reuse or repurposing.

- Existing filter design and development is owned by suppliers.

Unique elements

- This concept requires the least changes in system and product design, technology and logistics.
- Concept also aims to change behaviour; making it more likely that the filter is actually recycled.

Concept 5 - Filter remanufacturing

General description

Used filters are collected and sent off to a central remanufacturing facility where the filters are brought back to as good as new standard, before sent back to the service centres (Figure 5).

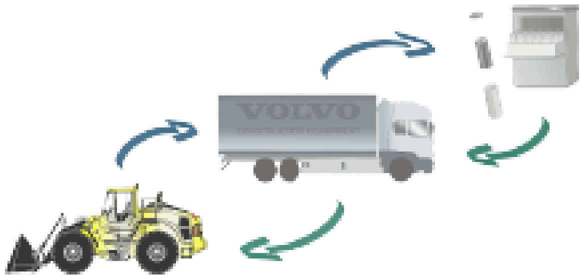


Figure 5: Remanufacturing concept

Advantages

- Most of the material is reused
- Filters are cleaned in a secure environment.
- Can be made profitable and expanded to all filters.
- Does not require additional work for technician
- The company has experience in the field of remanufacturing.
- Filters are similar which allows for an automated process.

Limitations

- The solution is transportation dependent.
- An unknown buffer of filters is required to keep the loop running.
- Setting up the reman-facility and the logistics chain requires major initial investments.

Unique elements

- A testing procedure can guarantee performance since the remanufacturing is done at a plant.
- Almost the entire filter is reused without any extra job for the technician.

Concept 6 - Condition based replacement

General description

The fuel filter is changed when the filter performance is insufficient, instead of within a predetermined time interval. The need for replacement based on monitoring data from either an external analysis equipment or existing differential pressure readings (Figure 6).

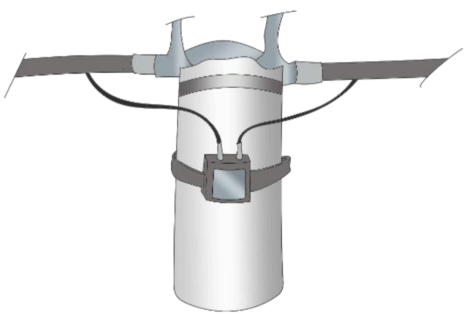


Figure 6: Condition based replacement concept

Advantages

- Longer useful life reduces overall material usage.
- Less filter replacements are required; which implies reduced cost for labor and material and reduced total down-time.
- Solution also provide a status report of the machines condition.

Limitations

- The solution relies on additional technology.
- Needs to be implemented in multiple devices within the machine to be fully effective.
- Replacement should be done by operator to avoid extra traveling for technician.
- The condition determining technology needs to be accurate and reliable.

Unique elements

- Filters are only changed when actually needed.
- Solution might provide additional information about the condition of the machine.
- Have potential to help avoid breakdowns before they occur.

Concept 7 - Local filter cleaning

General description

The contaminated filter is brought back to the service centre where it is disassembled and put in an industrial dishwasher (Figure 7). Filters are then reassembled and stored until next service.

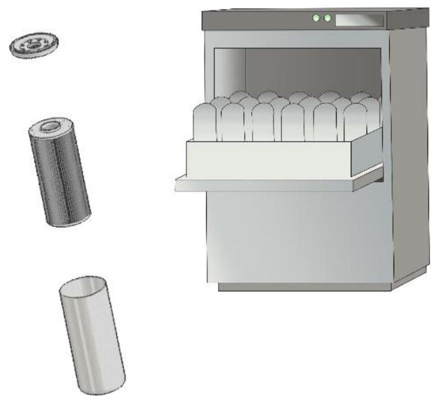


Figure 7: Local filter cleaning concept

Advantages

- A washing machine already exists in the workshop which could be expanded/redesigned to allow for filter washing.
- No disposable parts which is material saving.
- Exchange procedure will be similar to today's procedure.
- Substantially reduced transportations.

Limitations

- Buffer filters are required, since the number of machines in service centre cover area is quite small.
- The workshop needs to be able to treat the wastewater.
- Uncertainty whether the technology is available and affordable.
- Additional devices might need to be used to determine the cleanness and guarantee the performance of the washed filters.
- The number of filters in each workshop might not be enough to support a fully automated procedure, which will in turn increase the need for manual labour.

Unique elements

- The filter is made reusable locally.
- It might take advantage of technology that already exists in the workshops.
- Could make the service centres self-sustaining when it comes to filters.

Concept 8 - Portable Cleaning Device

General description

The technician bring a portable cleaning device (Figure 8) which is connected to the fuel system, both up and downstream from the filter(s). The filter is then flushed backwards with a particularly clean diesel until completely clean.

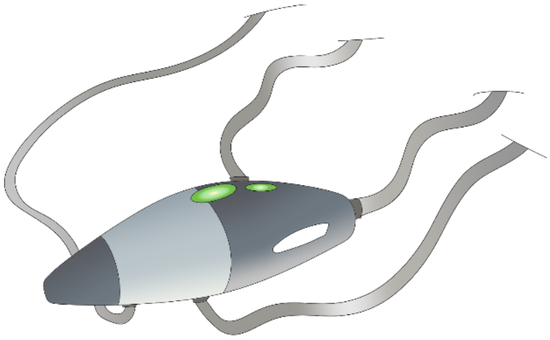


Figure 8: Portable cleaning device concept

Advantages

- No disposable parts at all.
- The same cleaning unit can be used for multiple machines.
- Fewer steps in the filter cleaning/changing process.
- Could be extended to be used for oil filters.

Limitations

- The technology does not seem to exist on this type of systems today.
- Solution needs to be made small to work efficiently.

Unique elements

- It’s a portable solution.
- Filters are not removed from the machine.
- Very little material is disposed.
- To clean the filters by flushing them backwards is unique for this concept.

APPENDIX X - INITIAL 8 FUNCTIONALITY CONCEPTS’ EVALUATION

All Concepts evaluation

The concepts are evaluated in relation to how well they are assumed to perform in relation to a set of predefined evaluation aspects. The result of the evaluation is presented in Table 1 (unweighted) and Table 2 (weighted) below.

Table 1: Unweighted evaluation result

		Serviceability	Customer benefit	Technological feasibility	Concept completion level	Material selection	Energy consumption	Material usage	Average	Compared to average
Concepts	Cartridge	4	4	5	4	5	4	4	4,3	12%
	Twin-filters	3	5	3	3	4	3	3	3,4	-10%
	Docking station	5	5	2	2	3	5	3	3,6	-7%
	Recyclable	4	4	5	4	5	3	2	3,9	1%
	Remanufacturing	4	5	5	4	5	3	4	4,3	12%
	Condition based replacement	4	5	3	3	3	2	3	3,3	-14%
	Washable filter	3	5	5	4	4	4	5	4,3	12%
	Portable vaccum cleaner	5	5	2	2	3	4	4	3,6	-7%
	All concept's average	4,0	4,8	3,8	3,3	4,0	3,5	3,5	3,8	

Table 2: Weighted evaluation result

		Serviceability	Customer benefit	Technological feasibility	Concept completion level	Material selection	Energy consumption	Material usage		
	Criteria weight	5	2	4	3	6	1	7	Weighted Average	Compared to average
Concepts	Replacable cartridge	20	8	20	12	30	4	28	17,4	15%
	Twin-filters	15	10	12	9	24	3	21	13,4	-12%
	Docking station	25	10	8	6	18	5	21	13,3	-12%
	Recyclable design	20	8	20	12	30	3	14	15,3	1%
	Remanufacturing	20	10	20	12	30	3	28	17,6	16%
	Condition based replacement	20	10	12	9	18	2	21	13,1	-13%
	Washable filter	15	10	20	12	24	4	35	17,1	13%
	Portable cleaner	25	10	8	6	18	4	28	14,1	-7%
	All concept's average	20,0	9,5	15,0	9,8	24,0	3,5	24,5	15,2	

As can be seen in the table, the result is quite conclusive; three concept seem to stand out among the rest, all well above the all concept weighted average (15,2). Local filter cleaning, Replaceable cartridge and Filter remanufacturing are selected for further development.

Pugh’s Matrix

The result from the comparison is presented in Table 3 below.

Table 3: Pugh's matrix evaluation

		Serviceability	Customer benefit	Material selection	Fuel consumption	Material usage		
	Criteria weight	3	2	4	1	5	Average	Weighted average
Concepts	Replacable cartridge	-1	0	1	1	1	0,4	1,4
	Twin-filters	1	0	0	1	1	0,6	1,8
	Docking station	1	1	0	1	1	0,8	2,2
	Recyclable design	0	0	1	0	1	0,4	1,8
	Filter remanufacturing	0	1	0	0	1	0,4	1,4
	Condition based replacement	0	1	-1	1	1	0,4	0,8
	Local filter cleaning	-1	1	1	1	1	0,6	1,8
	Portable cleaning device	1	1	-1	1	1	0,6	1,4

The conclusion which can be drawn from the Pugh’s evaluation is limited to that all seven concepts seem to outperform the reference (since above 0), considering the predefined evaluation aspects. Though, no conclusions regarding the concepts’ relative performance can be made.

APPENDIX XI - SWOT; THREE FUNCTIONALITY CONCEPT

SWOT; Cartridge concept

Strengths

- All work is done on site
- Only transportation of cartridge necessary, i.e less weight needs to be transported
- Result in material savings, since only the cartridge is disposed and replaced
- Cartridge can be incinerated and heat can be recovered
- The concept builds on existing and working technology
- No changes have to be done to the engine or fuel system to implement the filter solution
- Require skilled labour, which today is used by the company as a marketing argument for societal sustainability.

Weaknesses

- Replacement induces a messy procedure
- Solution requires warehousing of cartridges, compared to other concepts.
- Workshop needs to keep handling hazardous waste (as done today), which is costly.
- The procedure risk exposing the technician for hazardous substances.
- Requires handling of hazardous and flammable waste
- Value recycling impossible due to contaminated material (incineration and heat recovery possible)
- Performance can not be ensured
- More steps in the exchange procedure
- Performance is dependent on the quality of the installation performed by the technician
- Solution build on disposing principles rather than reuse

Opportunities

- Organic/Bio-based materials can be used for the disposable content.
- The solution has been used before, hence compatible with known technology
- The solution does not require big volumes to still gain environmental benefits
- Allow for a more expensive product; with more features, such as sensors and better design for easier disassembly and longer exchange intervals
- Could expand to oil filters and fuel filters on all construction equipment (and trucks and busses etc.)
- Technicians have full control over the condition of the fuel filter and can acknowledge performance variations.
- On-site recycling might be possible to further reduce transported weight.
- (Since major investments are not required, there is little risk to build a system around a solution which might not be relevant for future businesses.)

Threats

- Hard to ensure cleanliness during change due to challenging work environment.
- Risk of harmful diesel and grease contamination of equipment, tools and person.
- No performance testing after replacement of the filter is possible.
- Suggested technology goes transverse what is done today.
- The principle is not commonly used today for heavy equipment, which might indicate there are problems connected to the solution.
- Alternative, future fuels might require different solutions

SWOT; Centralized remanufacturing concept

Strengths

- The filters are reused in "the first cycle"; the multiple use leads to major material savings over the life cycle
- Exchange process is known to the technician and requires no additional work compared to reference.
- Reman is a well-known and appreciated solution within the company
- Solution is in line with what customers are taught today; the importance of exchange hygiene and quality tested genuine filters.
- No inseparable mixing of materials
- No or only small changes needs to be done to the existing engine or fuel system to implement the suggested solution
- No disposables to handle through expensive waste management programs.
- Company remain in control over filters and materials over the full useful life

Weaknesses

- The location of the reman facility determines the extent of the environmental benefits.
- Large investment to build up the reman chain (competences, facility and equipment, logistics etc.)
- Every machine needs more than one filter; i.e. an idle buffer of filters is required.
- The reference product lack some of the characteristics of "remanufacturable products", since it does not require skilled labour, is relatively cheap, does not contain especially scarce materials.

Opportunities

- Allow for a more expensive product; with more features, such as sensors and better design for easier disassembly and longer exchange intervals
- Can guarantee cleanliness; performance testing possible
- Possible to incorporate an automated process can, which may increase profitability.
- Possibility to have good waste water treatment in the reman facility
- Could expand to oil filters and fuel filters on all construction equipment (and trucks and busses)
- Multiple-use transport packaging solution is possible
- High value recycling is possible due to the facts that materials are washed before disposed and the exact alloys are known

Threats

- May require quite large volumes of filters to be profitable and environmentally sustainable
- The energy consumption for reman risk to limit the environmental benefits.
- Risk of losing the old supplier and expertise
- The required remanufacturing procedures are unknown today
- No known filter remanufacturer in Europe.
- Risk of a technology lock-in; electric powertrain requires no fuel filters, hybrid technologies require less filtration and alternative fuels might require different solutions.
- High initial cost for washable filters; i.e. quantity and multiple use is essential.
- Solution implies a substantial risk to build a system around a solution which might not be relevant for future business directions.
- No known large scale fuel filter washing facility exists today, which might indicate that there are profitability and/or technology problems connected to the solution.
- Solution requires new competences and take little advantage of existing business cooperation.

SWOT; Local filter cleaning concept

Strengths

- The filters are reused in “the first cycle”; the multiple use leads to major material savings over the life cycle
- Exchange process is known to the technician
- No inseparable mixing of materials
- No or only small changes needs to be done to the existing engine or fuel system to implement the suggested solution
- No disposables (except wastewater) to handle through expensive waste management programs.
- Company remain in control over filters and materials over the full useful life
- Washing procedure is carried out locally; reduction of heavy transportations

Weaknesses

- Additional work for technician/workshop personnel
- Every facility needs washing equipment
- Every machine needs more than one filter; i.e an idle buffer of filters is required
- Requires local storage space for buffer filters

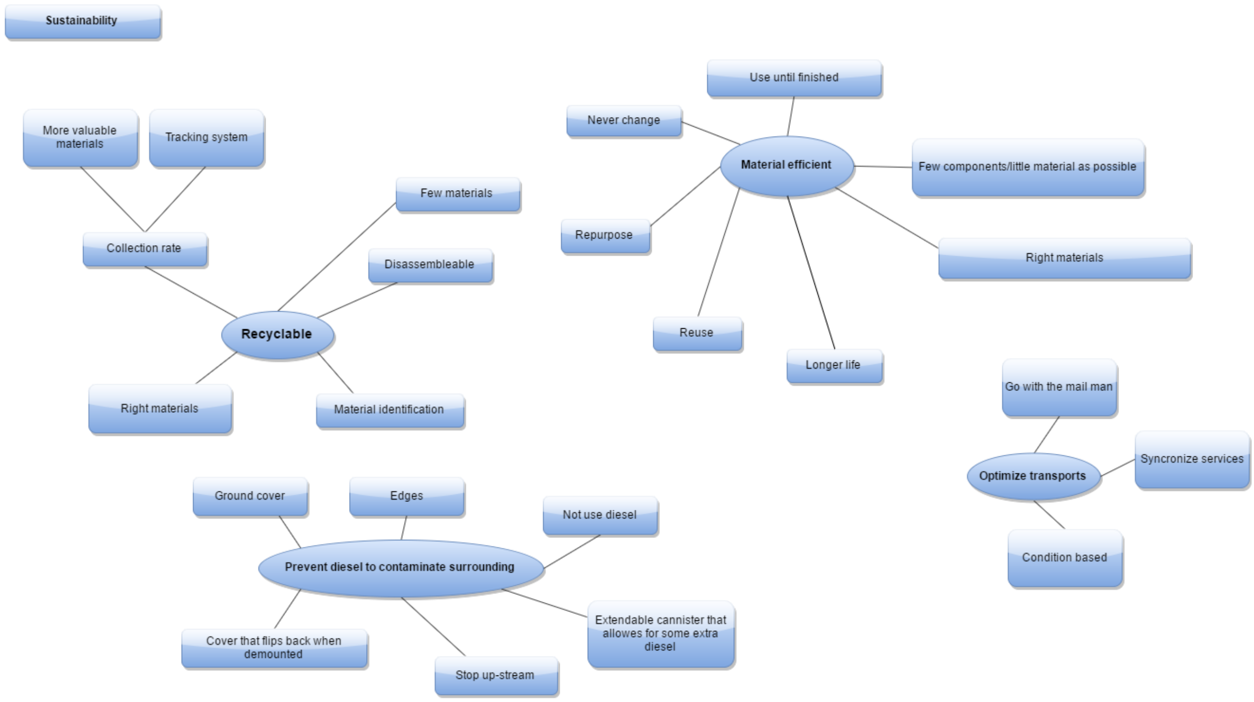
Opportunities

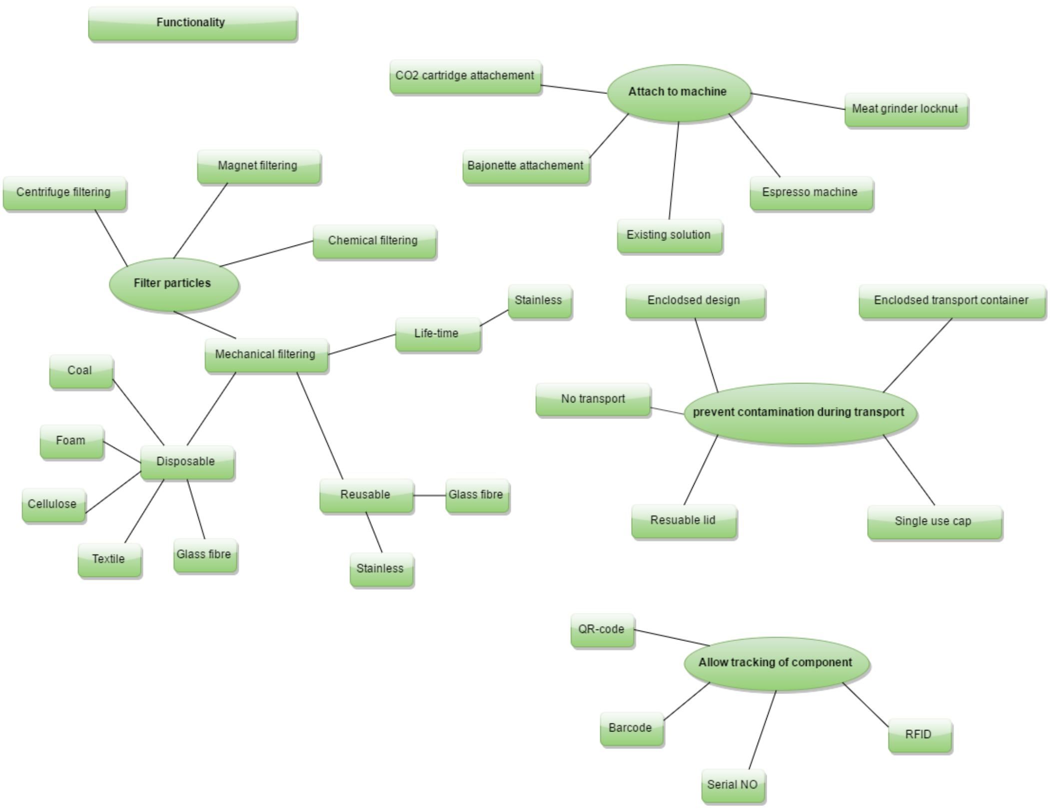
- Allow for a more expensive product; with more features, such as sensors and better design for easier disassembly and longer exchange intervals
- Can use the existing washing machine that is in use in the workshops today
- Possible to design a portable washing unit
- High value recycling is possible due to the facts that materials are washed before disposed and the exact alloys are known
- Could expand to oil filters and fuel filters on all construction equipment (and trucks and busses)
- Multiple-use transport packaging solution is possible

Threats

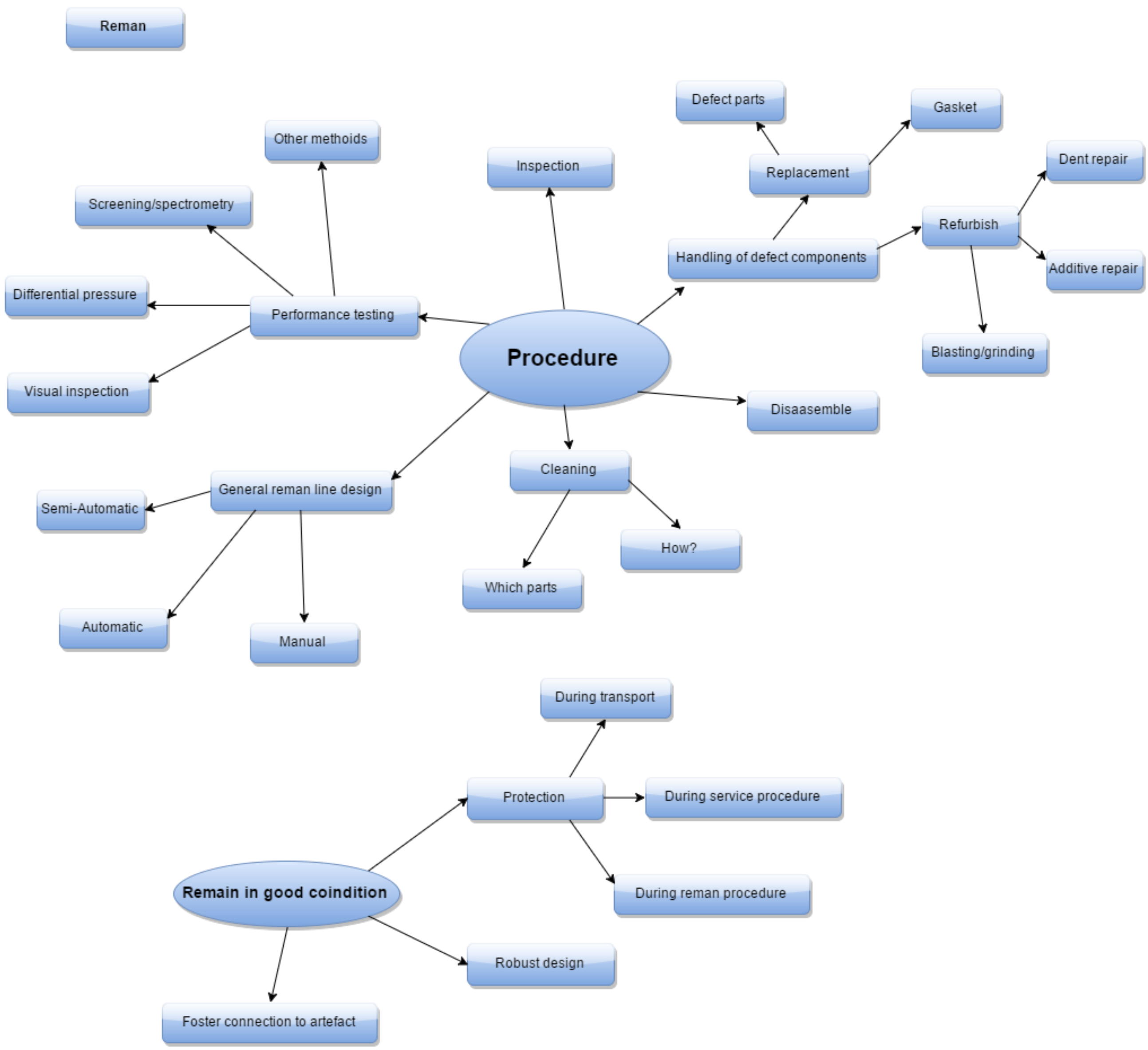
- Difficult to guarantee cleanliness
- Might be hard to ensure quality of the process, since there are many local sites with varying ability, regarding equipment, personnel, knowledge etc.
- There are quite small quantities at every local unit and it is uncertain if larger volumes of filters are required for solution to be profitable and environmentally sustainable.
- No known manufacturer of washable filters in Europe.
- Solution is not commonly used for the application.
- A possible risk of a technology lock-in; electric powertrain requires no fuel filters, hybrid technologies require less filtration and alternative fuels might require different solutions.
- High initial cost for washable filters; i.e. quantity and multiple use seem to be essential.
- Solution requires new competences and take little advantage of existing business cooperation.

APPENDIX XII - FUNCTIONALITY CONCEPTS BRAINSTORMING





APPENDIX XIII - REMAN CONCEPT BRAINSTORMING



APPENDIX XIV - REMAINING CONCEPT UNCERTAINTIES, EXPANDED

Cartridge

Artefact design

- How well sealed does it have to be between up and downstream side of the filter/cartridge?
- To make the outer casing durable enough to endure wear over the machine's entire life.
- To make the filter fastener durable enough to endure repeated change.

System design

- Educate customers about a new principle for fuel filter change, which is somewhat contradictory to the existing solution, which claim a strength in the encapsulated design.

Handling

- Not to contaminate the filter material during transportation and mounting.
- How to handle remaining diesel in filter canister?
- Not to contaminate the technician during cartridge replacement
- Not to contaminate technician or surrounding during transportation of contaminated filter
- Is it necessary and in that case, how to clean the canister at cartridge replacement?
- How to know which cartridge should be used for each application (separate them)
- How to handle contaminated cartridges in workshop
- Which aspects need to be considered regarding the context during cartridge replacement? Snow/rain, dust, cold/heat?

End of life

- To make the cartridge in a single material, which can still fulfill the performance requirements of today's filter. (Is it necessary to have one material if it is going to incineration?)
- Do we have to separate cellulose and diesel? Centrifuge, press, straight to incineration

Remanufacturing

Artefact design

- To make the outer casing durable enough to endure wear over the machine's entire life.
- To make the filter fastener durable enough to endure repeated change.
- Type of filter media appropriate for remanufacturing?
- Do we require additional warehousing?
- How can components be tracked?
- Are special tools required for filter assembly/disassembly on machine and in that case, how are they going to look like?
- How can we influence the technicians' behavior to take good care of the filters, in order to obtain longer product life?

System design

- How is the remanufacturing line going to work?
- Overall procedure? Automatic handling by robot?
- Inspection?
- Performance testing?
- How to keep track of part during reman?
- Do we have to replace some parts?
- How to decide which parts to scrap?

- Is repair of damaged or worn parts possible?
- Not to contaminate the filter material during transportation
- Not to contaminate the filter material during mounting.

Handling

- How is the remanufacturing logistic chain going to look like?
- How to handle remaining diesel in filter canister.
- Not to contaminate the technician during filter replacement
- Not to contaminate technician or surrounding during transportation of contaminated filter
- How to handle contaminated filters before reman in the workshop

End of life

- How to enable material identification when end of life is reached

Local washing

Artefact Design

- Is the workshop dishwasher clean enough to clean the main filter? Or is it necessary to design a complementary dishwasher?
- What is required to ensure cleanliness?
- Enclose clean side?
- Clean with purified diesel?
- Test afterwards?
- Are there other issues preventing use of the existing washing machine? Regulations?
- How can the parts be attached and the filter opened?
- How can the filter be attached to the machine interface?
- What type of filter media can resist a large amount of washings and still live up to the performance requirements?
- How long will the washable filter media last?
- Is a magnet required to handle metal residue/particles?
- Washable filters cannot handle more than 20% biodiesel (pressure issue). (The reference filter cannot either)

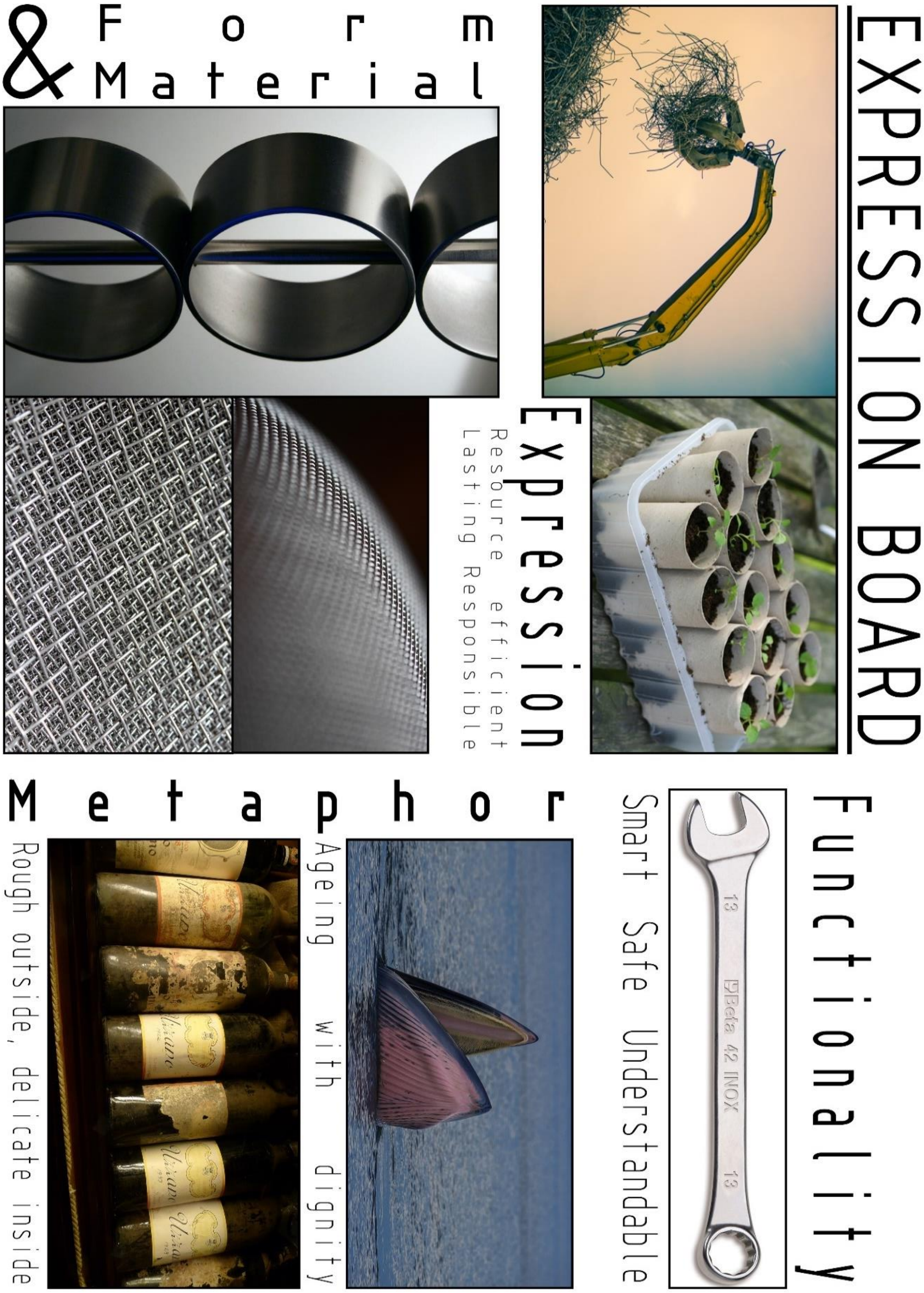
System design

- How can the transportation container be designed?
- Can the required level of cleanliness be ensured throughout the entire process, and how?
- How is the washing procedure going to be like? Is a special rack needed?
- What detergent is going to be used and how is the waste water going to be handled?
- How are washed filters going to be dried?
- How can customers be convinced of maintained quality of the cleaned filter.

Handling

- Who is going to assemble the clean filters?
- How can we protect humans from contamination during disassembly before washing?

APPENDIX XV - FINAL CONCEPT EXPRESSION BOARD



APPENDIX XVI - FINAL CONCEPT EFFECT GOALS WITH EXPLANATION

Effect goal
The solution is required to…
...prevent damage during handling and transport If the filter ought to be reused for more than 40 cycles, the filter and/or the system needs to be designed accordingly.
...prevent filter contamination during handling and transport The downstream side of the filter must remain totally clean during transportation from remanufacturing facility, to the client until attached to the machine.
...resist multiple mounting/dismounting In order for the solution to withstand at least 40 mounting/dismounting; the attachment system must be designed accordingly.
...allow for washing As specified in the requirements list, the filter needs to withstand a minimum of 40 cleaning cycles, hence the filter must be designed accordingly.
...fulfil relevant performance requirements The design is required to deliver the corresponding performance as the reference; i.e sufficiently respond to the technical/functional requirements as defined for the existing fuel filter regarding fuel pressure, filtration capacity and flow rate.
...avoid transportation of excessive matter/materials Since remanufacturing rely on transportation of the components, the possibility to reduce the material being transported must be considered.
...avoid diesel spillage during dismounting Since the filter canister will be filled with diesel, spillage must be prevented when used filter is detached.
...avoid diesel leakage during handling and transport The filter cannot cause contamination of people or the surrounding while being handled and transported.
…provide adequate information The information provided on the components must be adequate for the user and the use.
...allow tracking of the product Tracking of the complete product and possibly even the individual components is deemed required, in order to optimize distribution, handling and procedures.
...allow for inspection/testing After remanufacturing, the performance of the filter needs to be ensured by inspection and quality testing.
...allow for high value recycling The design must allow high value recycling through considering the design for recycling aspects.
The solution is required/desired to…
…maximize life expectancy in general The solution should consider how the expected life of the filter can be maximized in general; other aspects affecting the filter life than what is presented above.
...avoid introduction of new tools If not justifiable in relation more prioritized demands, introduction of new tools is undesirable due to the risk of additional material usage.
...consider relevant ergonomic aspects The attachment system and the overall handling must consider relevant physical and cognitive ergonomic aspects; i.e. allowing for ergonomic use and to ensure adequate information presentation
...consider the demanding environment The suggested solution must consider the demanding context, in regards to dirt, grease, etc.
...achieve the desired expression The solution's form, surface treatment, material, use etc. must comply with the overall expression defined in the expression board.
...contribute to better service operation It is considered positive if the new concept in any way can contribute to a service operation which is better from the technician's perspective. Faster and/or with less risks involved.

APPENDIX XVII - FINAL CONCEPT EXPRESSION ANALYSIS

Functionality
The concept expresses the use with a different material lid and a handle. Also, the transportation tray offers clear indications to how the filter is going to be mounted and so is the attachment system on the machine. The resemblance with

Form and Material
The form has been inspired by the stacked cylinders in the expression board; the overall cylindrical shapes and the smaller rounds, but also the robustness expressed by the setup and material thickness seen in the picture of the cylinders.

The materials used can to some extent be represented by the form and material images; however, since plastic products has been added to support the functions, the product does not fully resemble the board expression. However, the colour and shapes for the plastic products have considered the overall expression in terms of the shapes and also the colouring. The dark grey plastic parts are considered to bear the desired resemblance with metal objects. The two lower pictures are depicted in the clean and fine, stainless steel filtration mesh inside the canister.

Expression
The overall sustainable expression symbolized by the plants in cellulose cylinders is responded to by the product through the functionality; focusing on maintaining material value, through reuse. (the focus on sustainable design decisions) maintaining the materials in the closed value-loop

The desired expression symbolized by a metal recycling process can be said to have been achieved though utilizing the design for recycling aspects and by the circular model ensuring a 100% recycling rate.

Metaphor
The Metaphor is of course a very subjective measurement; however, it can be argued that the overall expression from the cylindrical shape and the chamfers below the threads and in the bottom, as well as from the rough and cold surface, indicates the product contain something valuable, in resemblance with for instance a vault.

APPENDIX XVIII - DETAILED EVALUATION CRITERIA DEFINITION

	Criteria	Explanation
User	Hazards and risks	An estimated risk situation for the user (combined quantity and sereneness).
	Cognitive load	The amount of negative cognitive load; including difficulty, time-pressure etc.
	Physical ergonomic load	The amount of negative physical ergonomic load; static and dynamic
Customer	Performance/reliability	Whether up-time can be ensured
	Profitability/cost	The effects on the total cost f ownership for the customer
Company	Economic sustainability	Generate revenues to cover costs
	Existing capabilities	Take advantage of current capital; structures, equipment and knowledge
Environment	Material selection	avoid the use of scarce and energy demanding and non-recyclable materials
	Fuel consumption	How it contributes to reduced fuel consumption over the life cycle of the wheel loader
	Material usage	contributes to reduced use of materials in total, over the life cycle of the wheel loader.
	Waste generation	the amount of waste generated

APPENDIX XIX - EVALUATION WITH RAPID ECO ASSESSMENT

	Eco strategy wheel consideration	Rapid assessment	Comment
1	Design for: Innovation		
1,1	Rethink how to provide the benefit	Not yet considered	More can be done
1,2	Design flexibility for technological change	Not yet considered	More can be done
1,3	Provide product as service	Not yet considered	More can be done
1,4	Serve need provided by associated products	Not yet considered	More can be done
1,5	Share among multiple users	Not yet considered	More can be done
1,6	Mimic biological systems	Not yet considered	Major system changes and/or new innovations required before improvements are possible
1,7	Use living organisms in product system	Not yet considered	Major system changes and/or new innovations required before improvements are possible
1,8	Create opportunity for local supply change	Has been considered, to some extent	More can be done
2	Design for: Reduced material impact		
2,1	Avoid materials that damage human or ecological health	Has been considered, to the best of abilities	Major system changes and/or new innovations required before improvements are possible
2,2	Avoid materials that deplete natural resources	Has been considered, to the best of abilities	Major system changes and/or new innovations required before improvements are possible
2,3	Minimize quantity of material	Not yet considered	More can be done
2,4	Use recycled or reclaimed materials	Has been considered, to some extent	Considered due to economic incentive. More can be done
2,5	Use renewable resources	Has been considered, to some extent	More can be done
2,6	Use materials from reliable certifiers	Has been considered, to the best of abilities	-
2,7	Use waste byproducts	Assessment pending	More information required
3	Design for: Manufacturing innovation		
3,1	Minimize manufacturing waste	Has been considered, to the best of abilities	Considered due to economic incentive. Major system changes and/or new innovations required before improvements are possible
3,2	Design for production quality control	Assessment pending	More information required
3,3	Minimize energy use in production	Assessment pending	More information required
3,4	Use carbon-neutral or renewable energy sources	Assessment pending	More information required
3,5	Minimize number of production steps	Assessment pending	More information required
3,6	Minimize number of components/materials	Not yet considered	More can be done
3,7	Seek to eliminate toxic emissions	Assessment pending	More information required
4	Design for: Reduced distribution impact		
4,1	Reduce product and packaging weight	Has been considered, to the best of abilities	Considered due to economic incentive.
4,2	Reduce product and packaging volume	Has been considered, to the best of abilities	Considered due to economic incentive.
4,3	Develop reusable packing systems	Not yet considered	More can be done

4,4	Use lowest-impact transport systems	Not yet considered	More can be done
4,5	Source or use local materials and production	Not yet considered	More can be done
5	Design for: Reduced behavior and use impacts		
5,1	Design to encourage low-consumption user behavior	Not yet considered	More can be done
5,2	Reduce energy consumption during use	Not yet considered	More can be done
5,3	Reduce material consumption during use	Not yet considered	More can be done
5,4	Reduce water consumption during use	Not yet considered	More can be done
5,5	Seek to eliminate toxic emissions during use	Not yet considered	More can be done
5,6	Design for carbon-neutral or renewable energy	Has been considered, to some extent	More can be done
6	Design for: System longevity		
6,1	Design for durability	Not yet considered	More can be done
6,2	Design for maintenance and easy repair	Not yet considered	Not regarding the filter design, more can be done
6,3	Design for re-use and exchange of components	Not yet considered	Not regarding the filter design, more can be done
6,4	Create a timeless aesthetic	Not yet considered	More can be done
6,5	Foster emotional connection to product	Not yet considered	More can be done
7	Design for: Transitional systems		
7,1	Design upgradeable product	Not yet considered	More can be done
7,2	Design for second life with different function	Not yet considered	More can be done
7,3	Design for reuse of components	Not yet considered	More can be done
8	Design for: Optimized End of Life		
8,1	Integrate methods for used product collection	Not yet considered	More can be done
8,2	Design for fast manual or automated disassembly	Not yet considered	Not regarding the filter design, more can be done
8,3	Design recycling business model	Has been considered, to some extent	More can be done
8,4	Use recyclable non-toxic materials	Has been considered, to some extent	More can be done
8,5	Provide ability to biodegrade	Not yet considered	More can be done
8,6	Design for safe disposal	Not yet considered	More can be done

APPENDIX XX - COMPARATIVE LCA

Fuel filters in a circular business model:

A comparative life cycle assessment

Cornelia Jönsson

Industrial Ecology, Spring 2017

Table of content

1. Introduction

The circular economy builds on circular flows of biotic and abiotic resources. Where used materials are fed back into the production system and no resources are wasted, to compare with the traditional linear model where materials are used and thereafter disposed. A challenge in a circular model is to collect materials after the product has been used. To facilitate this process, new business models may need to be developed (Mentink B., 2014). One possible way to go is to redesign the ownership structure for a product and sell, not the product itself, but rather its function, so called functional sales. The environmental gain of such business model is that more users can share fewer products; this decreases the total number of products on the market and in turn the amount of materials extracted from the planet. The secondary gain from such business model is maintained value of materials, since the materials in the products are more likely to be used longer (Semples, 2014).

Going from one business model to another puts pressure on product developers and producers since the revenue no longer comes from selling large quantities. What will generate profit is instead to sell the product as many times as possible with as little maintenance as possible (Mentink B., 2014). *Mistra REES* (Resource-Efficient and Effective Solutions) is a 4-year program run by a consortium of Swedish companies, universities and social actors with the vision to hasten the transition towards circular economy. The program aims to comprehensively research circular economy and resource efficiency to create a knowledgebase that can be useful when resource efficient and circular solutions are developed. (MistraREES, 2015). This LCA report is part of the thesis "*Preparing for tomorrow: exploring design adaptations on a wheel loader in a circular business model"* which in turn is part of the Mistra REES program and will contribute with knowledge about how the environmental impact is affected when a product is designed to fit in a functional sales business model. The sustainability and use centered product development process, which was used in the thesis and developed by the authors, can hopefully help contributing to a more sophisticated process to develop products for a circular business models. At the end of the program, the Mistra REES group is hoping to have created an information exchange between industry and academia.

Volvo Group, with the divisions: Buses, Trucks, PENTA and Construction Equipment, is one of the industrial partners in the Mistra REES project. This thesis project is carried out in collaboration with Volvo Construction Equipment (VCE) located in Eskilstuna, Sweden. VCE is developing off-road machinery, which includes dumper trucks, and wheel loaders amongst other heavy road work equipment. Perhaps the most versatile of the products in the VCE machine fleet are their different wheel loaders. The main objective for wheel loaders is to move material; possible use scenarios however stretches from loading dumper trucks deep down in Swedish mineral mines, to transportation of logs between storage and processing facilities in Brazilian lumber industry. Volvo aims for their construction equipment to maximize productivity by offering machines for each individual need; their wheel loaders come in many different variations and there are an array of different attachments and accessories available. (Volvo CE, 2015).

In order to manage the environmental life cycle impact from their wheel loaders, Volvo CE has been working with a range of innovations aiming to improve fuel efficiency. A more recent initiative is to also extend the products useful life, by implementing customer tailored maintenance agreements and remanufacturing of the components with a high remaining relative value (Volvo CE, 2015). In line with the current trend of many other environmentally aware companies, Volvo CE is exploring the opportunity to find new arrangements with their customers; offering functionality and a life-cycle responsibility as opposed to the traditional ownership. VCE's aim is to create change and be one of the companies in Sweden that drives the transformation towards a sustainable market, with less pollution (Gustavsson N. et al., 2015).

Part of the purpose for the master thesis project was to investigate important design aspects for a Volvo CE wheel loader to fit in a functional sales business model. More about this process can be found in the report: "*Preparing for tomorrow: exploring design adaptations on a wheel loader in a circular business model"*. However, to evaluate the outcome, and the process used, life cycle assessment (LCA) was utilized. This report will describe the procedure and results from the LCAs.

1.1 Goal

The goal of the study was to preform one LCA on the existing fuel filter and one on the new concept to compare their environmental impacts.

The purpose of this study was to use LCA as an assessment tool in a product development process to see if the product, developed for a circular business model, is better for the environment than the existing solution. The product development process was part of the master thesis "*Preparing for tomorrow: exploring design adaptations on a wheel loader in a circular business model"*, which aimed to feed data into a research project mentioned in the introduction. The intended audiences are the representatives at the company where the project was carried out and the participants in the research project.

1.2 Scope

The LCAs carried out were change oriented rather than attributional since not every process was fully accurately described. The focus was on the impact a change of filter model would have.

1.2.1 Initial flowchart

Both LCAs covered the life cycle form cradle to grave since materials use was of interest. Flow charts showing all parts of the fuel filters' lives can be seen in fig. 1 and 2.

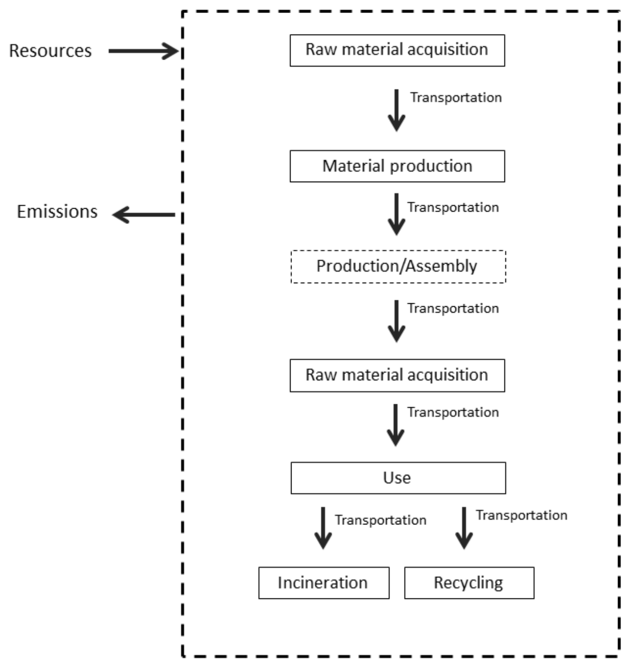


Figure 1. Showing a first flow chart of the reference filter life cycle.

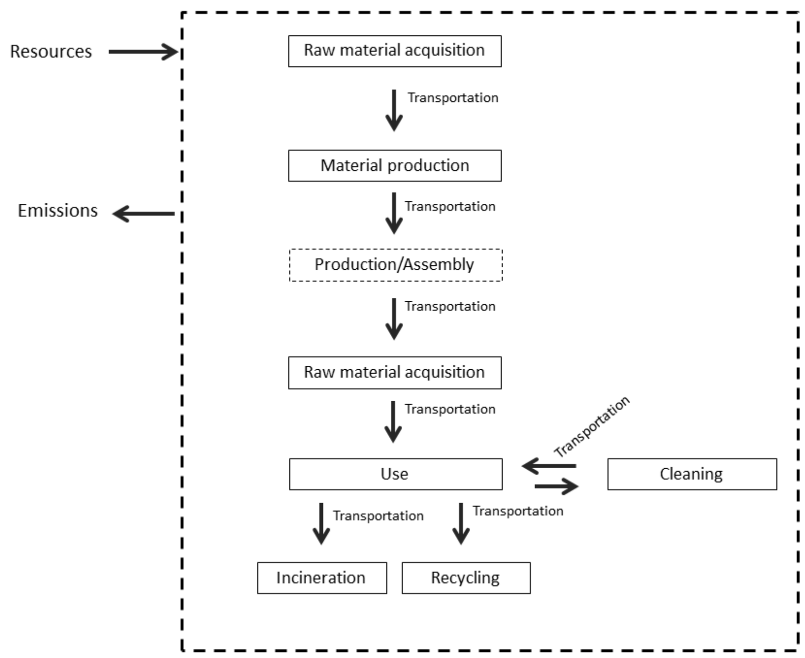


Figure 2. Showing a first flow chart of the concept filter life cycle.

1.2.2 Functional unit

The functional unit was set to *20 000 hours of fuel filtration in one wheel loader L150.* This timespan was used since it is the estimated lifetime of the wheel loader. A lifetime approach was needed to illustrate the difference in the two filter solutions; in the existing solution 40 main filters would be used over the lifetime of the wheel loader, and under the concept solution, only one filter is needed to meet the filtration standard.

1.2.3 System boundaries

Geographical boundaries were set to Europe for parts production and assembly, and Sweden for the use phase and end-of-life treatment. Extraction of materials and manufacturing of parts were included in the model as were transports of the assembled fuel filter. For this study the use phase is defined as from when the filter leaves the factory door until it enters the recycling facility, that way all transports are included in the use phase.

1.2.4 Limitations

The study was limited to the main fuel filter installed in a Volvo wheel loader L150H. Excluded from the study were:

- The glue and coting of the reference concept since the material was unknown and the amount was small.
- Transportation of the parts, before assembly.
- The set up and production of the remanufacturing facility.

1.2.5 Software

The modelling process was done using GaBi (thinkstep AG (ts)). The processes and material approximations within GaBi can be seen in tables 3, 7 and 10.

1.2.6 End-of-life plans

For the modeling of end-of-life for the metal parts of the filters, datasets developed by Volvo Group, were used for aluminum and steel. Volvo has currently approximated the process as if a part of the steel and aluminum used (20-50%) are made from scrap metal. The amount is dependent on the requirements of the material (aluminum or steel). This means that a percentage of the metals do not go to end-of-life processes but are instead modelled as if they were going straight back into the production. In that way, the material stays within the system boundaries and is not causing impact from extraction or end-of-life processes. The remaining metal is recycled and credits are given in end of life. Figure 3 outlines this process.

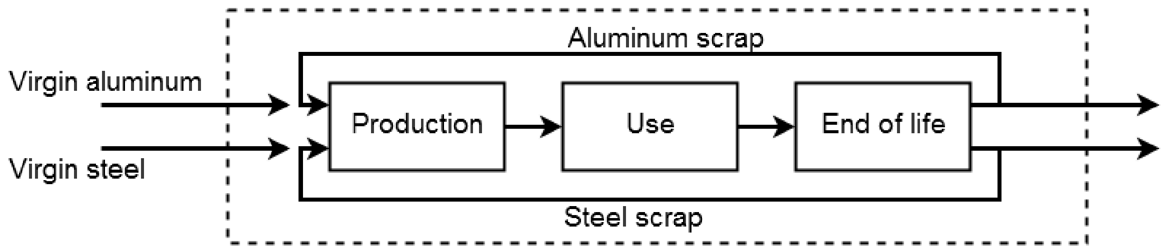


Figure 3. Aluminum and steel scrap are treated as raw materials going into the production phase and are subtracted from the initial amount of used resources.

For end-of-life of paper, plastic and rubber, data sets in GaBi were used, where the energy that was generated from the recycling process was used as energy credits in the model. The chosen processes are found in table 1 together with the chosen process for steel.

Table 1. Showing how the end of life processes were modelled in GaBi.

Material	GaBi recycling dataset	Reference
Paper	EU-27: End of lite of paper/cardboard (landfill/incineration	Based on Eurostat data (2012)
Plastic/rubber	EU-27: End of life plastics (landfill/incineration)	Based on Eurostat data (2012)
Steel	Steel EOL plan	Volvo

1.2.7 Impact assessment

The result thought to be most important in terms of the focus of the study is the *material use* and *global warming potential*. The impact category *materials use* showed if the new design of fuel filter was successful or not when it came to materials use. Kilometer traveled showed if the new concept lead to more transports and if it had impact on global warming potential. A summary of the impact categories can be found in table 2. The impact categories chosen were calculated based on *impacts ILCD/PEF recommendation* where ILCD stands for International Reference Life Cycle Data System and PEF product ecological footprint. Both are derived by the European commission and for details please see ILCD handbook (European Commission (EU), 2011). Since both LCAs used the same categories for the impact assessment and the difference in impact was most important, details about how the calculations were made are left out of this report. The impact of ozone was too small to show and was chosen not to include in this report.

Table 2 Showing impact categories chosen for the study.

Impact category	Unit
Climate change	kg CO_2-eq.
Eutrophication	Mole of N-eq.
Acidification	Mole of H+ eq.
Abiotic resource depletion	kg Sb-eq.

1.2.8 Sensitivity analysis

A sensitivity analysis was carried out from two aspects, first to test the concept by increasing the amount of resources used during the remanufacturing process to see if the concept was still a good option, second to make a breakeven analysis between the reusable filter and the disposable.

2. Technical overview

This chapter starts with an introduction about why fuel filters are needed and continue with describing the procedure for first the reference concept, the concept that is in use today and move on to describe the new, developed concept; the concept filter.

2.1 Fuel filters

For a diesel engine to run, diesel has to be delivered through the injectors into the cylinders where it is ignited. The injectors have a crucial role to make the engine more effective, by delivering the right amount of diesel at the right time. To be able to have an effective engine and meet the increasingly high requirements on exhaust gases the injectors have been made more and more complex to be able to deliver fuel at the exactly right moment. This has made them sensitive to particles in the fuel that cannot pass through the outlets of the injectors and risk to clog them. (Interviewee 1, 2016) A fuel filter is a physical barrier between the fuel tank and the injectors that separates particles from fuel.

It is not only particles that causes problem for injectors, water does as well. Diesel fuel always contains water which needs to be separated from the fuel to not cause problems in the injectors or in the combustion. The L150H wheel loader has two fuel filters; one pre-filter and one main filter. The pre-filter takes care of the bigger particles and the water which ends up in a container under the filter and is emptied manually when an indicator tells it is full. The main filter sits just next to the pre filter and takes care of smaller particles. Fueling a wheel loader is different from fueling a car. Off-road equipment is sometimes fueled from private diesel tanks which might not hold the same cleanness standards as do commercial gas stations. This, together with a dirty environment where the fuel-up takes place adds to the impurities (Interviewee 2, 2016).

2.2 Architecture of the reference fuel filter

The ingoing parts in the reference fuel filter are (see figure 4): a steel casing (9) which contains a cellulose based filter media (6) and is merged with a cap (2+3) which allows the filter to be spun-on the machine. In the bottom of the canister is a spring (8) which allows fuel to by-pass if the filter is clogged. The fuel flows in from the outside, it enters on the outside of the filter medium and leaves from the middle.

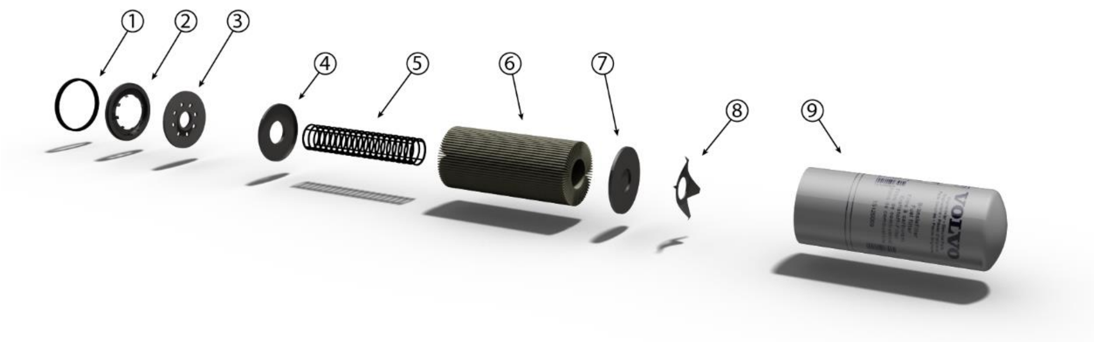


Figure 4. Showing all ingoing parts of the reference fuel filter. 1-gasket, 2- element cap, 3-interface plate, 4 and 7- filter media cap, 5- inner tube, 6- cellulose cartridge, 8-spring, 9- canister.

2.3 Reference filter in use

Filter exchange needs to be done on a regular basis to stay within the prescribed requirements for the fuel filters. When in use, the filter media gets clogged and prevents fuel from passing. Today filter replacements are part of the service agreements and is done every 500 hours. The interval is set with empirical testing to avoid clogging. If the filter is clogged, the fuel pump can fail and not enough fuel is delivered to the injectors causing the engine to lose power. Three oil filters and two fuel filters are replaced at this interval, which gives a total of 200 filters if the life length is 20 000 hours (Prosis, 2016)

Filters are ordered to the local workshop and sorted according to the service needed. The replacing procedure starts with the service technician bringing the right filters to the machine on site, turning the machine on service mode, detaching the existing filter with a filter wrench and putting the used filter in a container to bring back to the workshop. The gasket of the new filter is greased to facilitate the tightening and spun on the machine. When attached, the filter needs to be “bled” which is done with a hand pump, it needs 200-300 pumps to build up pressure and get rid of air in the system. The entire procedure takes about 42 minutes. Used filters are stored in a container for hazardous waste together with other fuel and lube filters. The container is picked up when full, by a recycling company. The procedure is illustrated in figure 5. (Interviewee 3, 2016, Prosis. 2016).

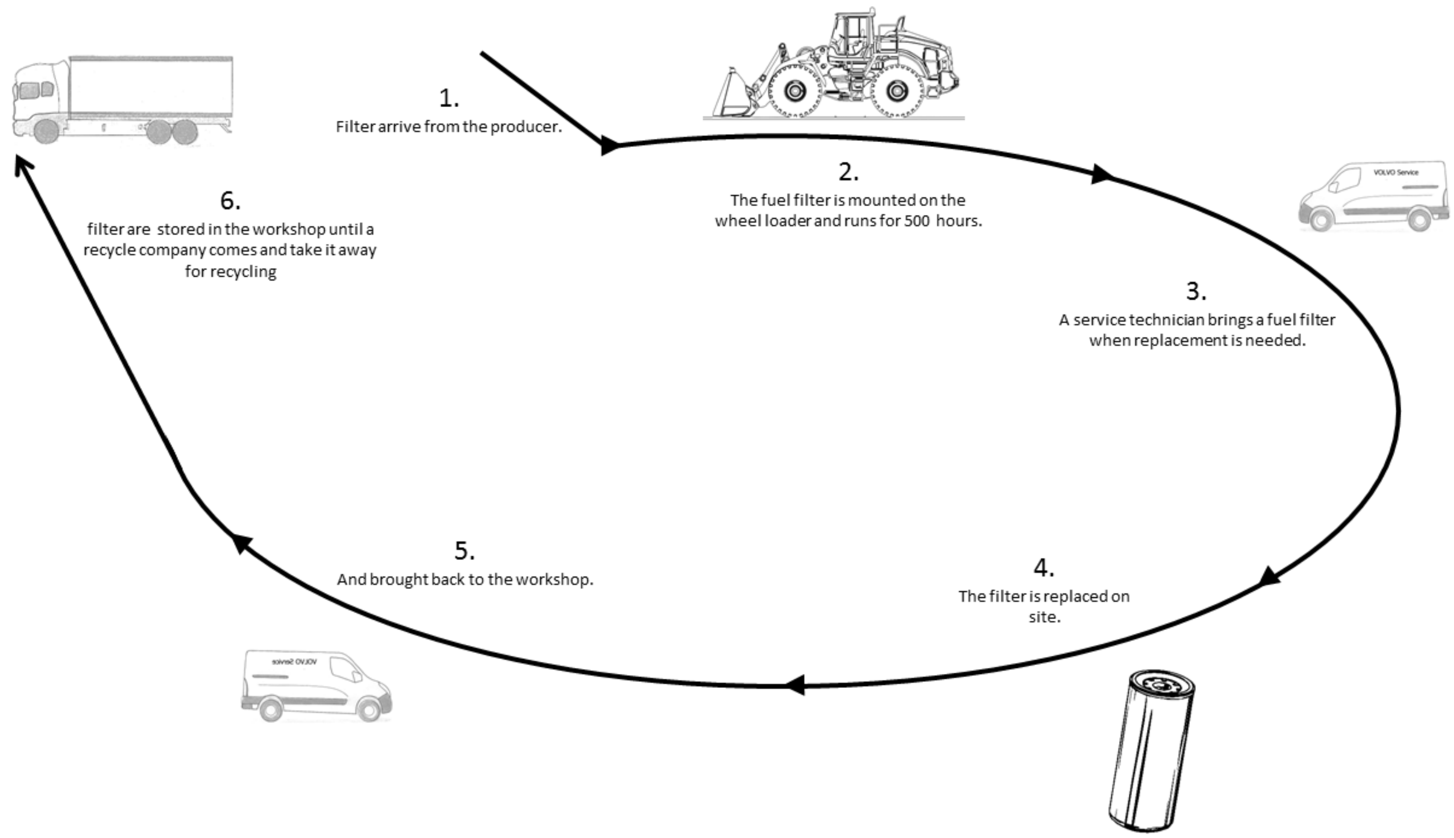


Figure 5. Showing an overview of the reference filters use phase.

2.4 Architecture of concept fuel filter

The developed concept was composed of an aluminum canister (9) with a cartridge (2-6) made from stainless steel. A gasket (8) helped to avoid leakage between the machine and the filter. The spring (7) from the reference concept was kept to allow for bypass of fuel. A big difference was that the interface cap (see component 3 in figure 4) was replaced by a different interface design. As can be seen in figure 6 is the attachment component no longer part of the filter but will stay on the machine and reduce the material and weight of the filter.

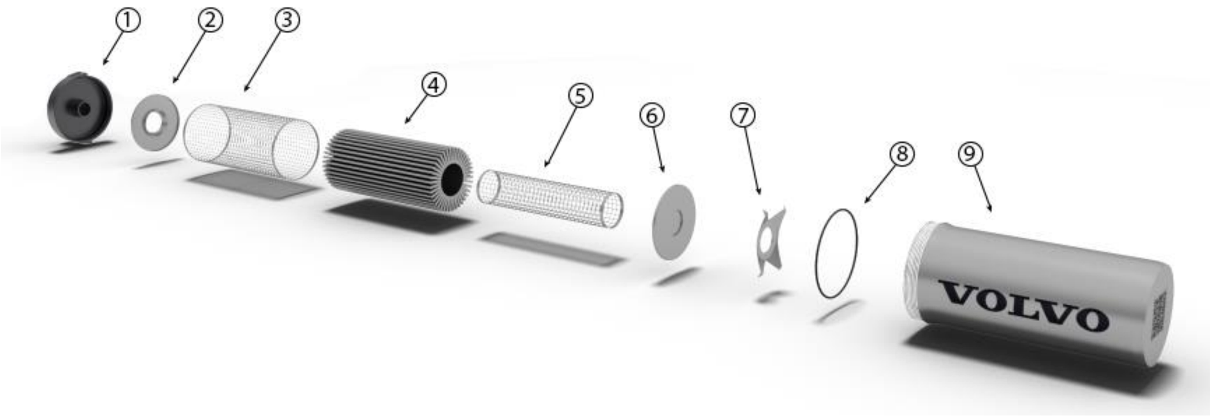


Figure 6. Showing the exploded view of the concept filter.1- transportation lid, 2 and 6- filter element cap, 3- supporting grid, 4- stainless steel filter media, 5- supporting inner tube, 7- spring, 8- gasket, 9- canister.

2.5 Concept filter in use

The new filter was assumed to be produced by the same supplier as today but the biggest difference was that the filter material in the cartridge was washable and the filter will no longer be disposable. The procedure was thought to be as follows (see fig. 7): the technician brings a clean fuel filter to the wheel loader that needs replacement, removes it from its transport container which also protects it from contamination. Unscrews the filter on the machine and put in the transport container, remove transportation lid and attach the new filter and take the used back to the workshop. Instead of disposing the filter it is sent to a remanufacturing facility to be washed before it comes back to be used again.

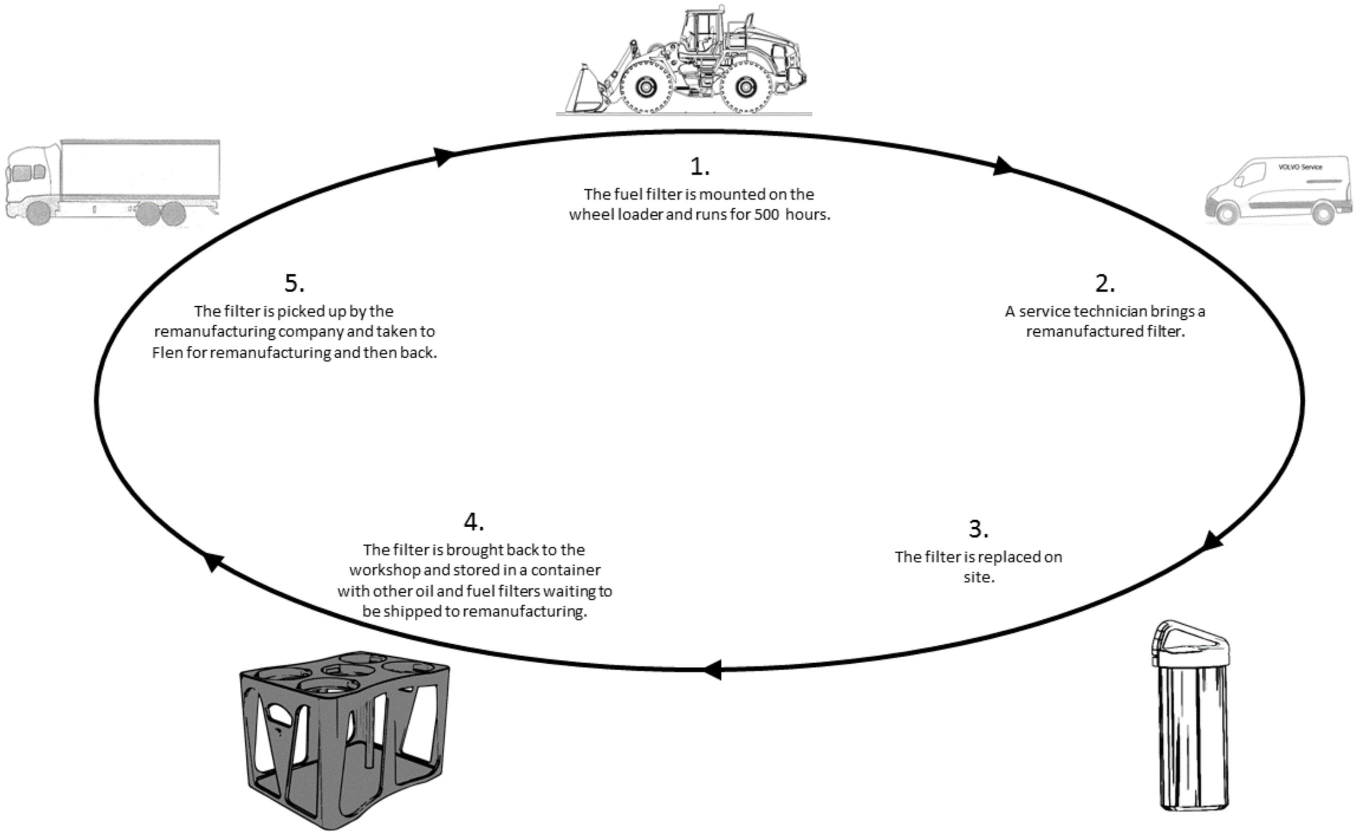


Figure 7. These are the steps the concept filter is going through during its use.

2.6 Remanufacturing of concept filter

The remanufacturing facility was placed in Flen, Sweden, for this study since the company already has a remanufacturing process in place at this location (Interviewee 2, 2016). The idea is that the filter arrives at the facility in its transport container and is disassembled. The different parts are then washed and dried. To make sure that the filter can perform as well as a new one a testing procedure is expected to be needed before it is put back in its container and sent back to the service facility to be mounted on another wheel loader.

In this scenario, the filter is replaced immediately; the machine is therefore not expected to wait for its filter to be washed to be able to run normally. Due to this slightly more filters were expected to be needed than machines that were under service contract at a certain service facility. For a facility that every year services 50 machines with this filter it was assumed that 8 additional filters were needed if the return time was 5 days. Fifty filters will sit on the machines, 4 are on remanufacturing and 4 are available for replacement which gives a total of 1.16 filters per machine.

3. Method

This chapter describes the methodology that was used to perform the study.

3.1 Methodology

Life cycle assessment is, in short, a way to describe and calculate the resources a product uses and the pollutions it causes during its life cycle. To be considered a LCA, the description must follow a standard of how the assessment should be conducted developed by ISO (ISO 140 40, 1997). ISO suggest that the procedure should be carried out in four steps:

Goal and Scope definition, where the product subject of the study should be defined, the intended application declared, the reason for carrying out the study and who the intended audience is. It is also recommended to clarify the system boundaries and what types of environmental impacts are considered. During this step a *functional unit* should be decided around which the analysis will focus, and to which all resource use and emissions will be related.

Inventory Analysis, in this step a system model should be developed according to the goal and scope definition. The model is usually in the form of a flowchart and comes with a list of inputs and outputs for all processes. The step also includes a calculation procedure where outputs and inputs are related to the functional unit.

Impact assessment aims to present useful results of the study. For doing so it uses two steps: classification where the different emissions and resource use are grouped into categories and, characterization where the emissions and resource use are summarized and their actual impact is calculated.

Interpretation, which has the goal to report and explain the results in an informative way and in this part, could also include opportunities and recommendations for how to decrease the impact of the product of service studied.

There are two general types of LCAs: consequential and attributional. In the consequential LCA an impact of a change to the system is analyzed, where-as in an attributional the impact of the system is investigated. The second type requires more accurate data to involve all aspects of how the system is affected by every process and material.

To test the robustness of the model and LCA, a sensitivity analysis can be performed. It is most useful if it is made on data that has been difficult to get correct or certain parts of the system that are more sensitive to change. (Bauman & Tillman, 2004)

4. Inventory analysis: reference filter

In this chapter, the reference filter will be described in detail. All information needed for the modelling and impact assessment is found here.

4.1 Flowchart

A more detailed flow chart was constructed (fig. 8) to facilitate the modelling of the life cycle. It is still a simplified model and the manufacturing/assembly/packaging- step was developed in the GaBi-model. The material for incineration that goes out from the use-process is packaging material and the dust cap. The end of life process is described in section 4.7.

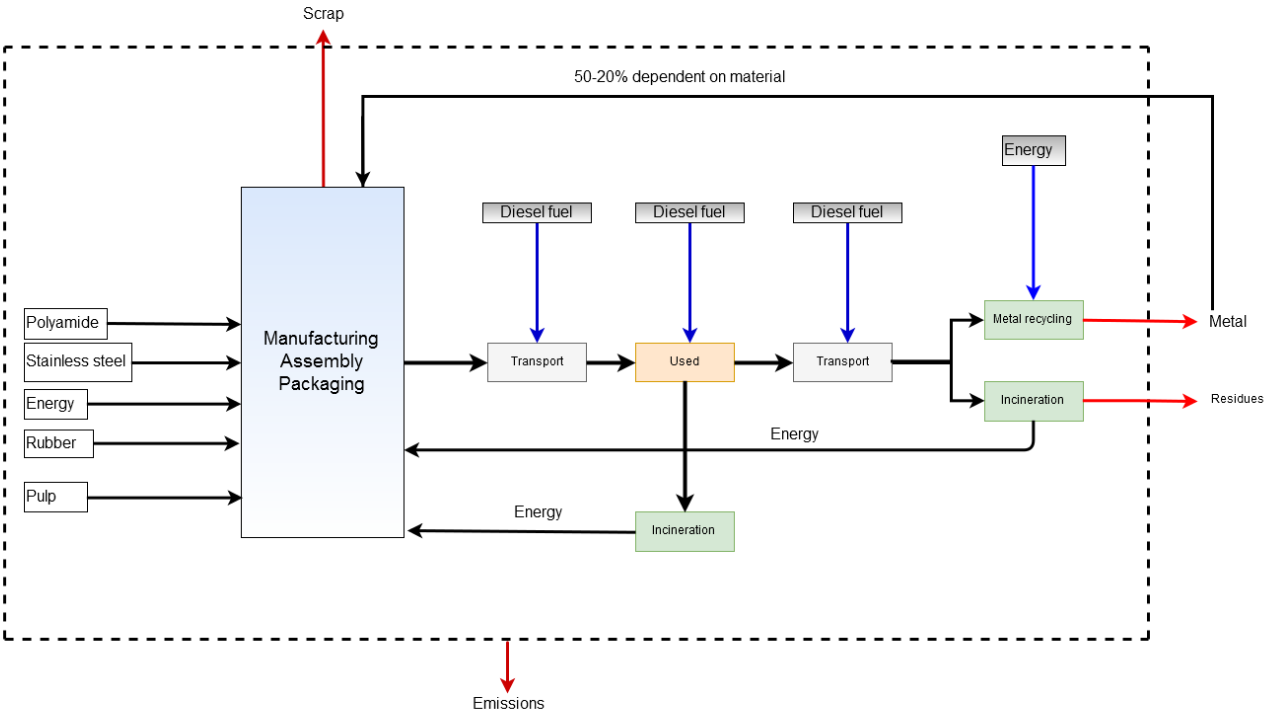


Figure 8. The life cycle of the reference filter modelled.

4.2 Production

Production of the reference fuel filter is done in Germany (Interviewee 1, 2016). All metal components are made at the same site as the assembly process. Raw material in the form of steel sheet comes to the factory and is deep drawn, or stamped and bended at the site. The different components surface treatments, if needed, are also made on site. The cellulose based filter medium comes to the factory as big rolls of paper and is both cut and folded at site. Most processes are automated but man labor is required in some processes. The only components that arrive ready made to the factory are the rubber gaskets and packaging materials. (HowiItsMade, 2014). Table 3 shows a materials and manufacturing processes list where the material in each component can be found together with how they are translated to GaBi data sets.

Table 3 Showing ingoing materials, weights, manufacturing processes and respective GaBi data set for the reference filter. Components corresponding to numbers are found in fig 4.

Component	Material	Weight [g]	Manufacturing	GaBi material	GaBi process	Ref. materials/Ref. processes
9. Canister	**Cold rolled carbon steel**	**535**	**Deep drawn**	**RER: Steel cold rolled coil**	**DE: Steel sheet deep drawing**	**Worldsteel/ Eco invent 259**
					EU-27: Electricity grid mix	Thinkstep
					RER: Steel cold rolled coil	World steel
					DE: Thermal energy from natural gas	Thinkstep
					EU-27: Infrared thermoforming (LD-PE Part, Ceramic at 950F/520C)	Thinkstep
					EU-27: Biopolyethylene Low Density granulate (LDPE/PE-LD)	Thinkstep
8. Spring	**Stainless steel**	**23**	**Stamped and bended**	**RER: Steel cold rolled coil**	**GLO: Steel sheet stamping and bending**	**Worldsteel** /Thinkstep
					EU-27: Lubricant at refinery	Thinkstep
					RER: Steel cold rolled coil	World steel
					GLO: Compressed air 7 bar	Thinkstep
					EU-27: Electricity grid mix	Thinkstep
2. Elementcap	**Stainless steel**	**98**	**Stamped and bended**	**RER: Steel cold rolled coil**	**DE: Steel sheet deep drawing**	**Worldsteel/Eco**

						invent 259
					EU-27: Lubricant at refinery	Thinkstep
					RER: Steel cold rolled coil	World steel
					GLO: Compressed air 7 bar	Thinkstep
					EU-27: Electricity grid mix	Thinkstep
3. Interface plate	**Stainless steel**	**268**	**Stamped, forged and taped**	**RER: Steel cold rolled coil**	**GLO: Steel sheet stamping and bending**	**Worldsteel/ Thinkstep**
					EU-27: Lubricant at refinery	Thinkstep
					RER: Steel cold rolled coil	World steel
					GLO: Compressed air 7 bar	Thinkstep
					EU-27: Electricity grid mix	Thinkstep
1. Gasket	**Butadiene rubber**	**16**	**Vulcanized**	**DE: Styrene-Butadiene Rubber (SBR) Mix**	**GLO: Vulcanization of synthetic rubber**	**Thinkstep/ Thinkstep**
					EU-27: Process water	Thinkstep
					DE: Styrene-Butadiene rubber mix	Thinkstep
					JP: Crude oil mix	Thinkstep
					EU-27: Electricity grid mix	Thinkstep
6. Filter	**Cellulose**	**264**	**Cut and folded**	**-**	**GLO: market for cellulose fiber, inclusive blowing**	**-/Eco invent**

material						
Glue	***Unknown***	**-**	**-**	**-**	**-**	**-**
5. Inner tube	**Nylon**	**36**	**Injection molded**	**DE: Polyamide 6.6 Granulate (PA 6.6) Mix**	**DE: Polyamide 6.6 (PA 6.6) GF injection molded part**	**Thinkstep/ Thinkstep**
					DE: Polyamide 6.6 Granulate (PA 6.6) Mix	Thinkstep
					EU-27: Electricity grid mix	Thinkstep
					EU-27: Process water	Thinkstep
7. Top + 4. bottom cartridge cap	***Unknown (metal)***	**74**	**Stamped and bended**	**RER: Steel cold rolled coil**	**GLO: Steel sheet stamping and bending**	**Worldsteel/ Thinkstep**
					EU-27: Lubricant at refinery	Thinkstep
					RER: Steel cold rolled coil	World steel
					GLO: Compressed air 7 bar	Thinkstep
					EU-27: Electricity grid mix	Thinkstep
Dust cap	**PET**	**4**	**Injection molded**	**DE: Polyethylene terephthalate granulate (PET via DMT)**	**EU-25: PET injection stretch blow molding**	**Thinkstep /Plastics Europe**
					DE: Polyethylene terephthalate granulate (PET via DMT)	Thinkstep
					EU-27: Wood pellets	Thinkstep
					EU-27: Electricity grid mix	Thinkstep

					EU-27: Process water	Thinkstep
					DE: Solid construction timber	Thinkstep
(9.) Coating	**Unknown**		**-**	**-**	**-**	**-**
Paper box	**Paper**	**63**	**-**	**-**	**EU-27: Liquid Packaging Board (LPB) production**	**-/ACE[1]/ELCD[2]**
Total:		1323				

[1] The Alliance for Beverage Cartons and the Environment (ACE)
[2] European Reference Life Cycle Data System

4.3 Transport

Transports were estimated for the existing filter based on available data (see table 4). The assembly was known to be done in Germany (Interviewee 1, 2016). However, the transportation of parts to the assembling facility was excluded due to lack of data and that the volumes and weights of each part were small so the effect on the end result was thought to be minor.

Volvo CE has a European warehouse in Gent (Underhallsnyheter, 2016) where the filters are transported before they continue to Sweden, in this case Göteborg. Moreover, the distance the technician traveled was approximated and for the end-of-life treatment filters were assumed to go to Halmstad.

Table 4 showing travel distances for one reference filter. The number needs to be multiplied with 40 to get the total transport for the functional unit.

Part	Geography	Kilometer	Vehicle	Reference
Fuel filter	Germany-Gent	450	Truck	Google maps
Fuel filter	Gent-Göteborg	1 240	Truck	Google maps
Fuel filter	Göteborg-Client	2x30	Truck	Google maps
Fuel filter	Client-Halmstad	170	Truck	Google maps
Total		**1 920**		

The transport was modelled with GaBi process *GLO:Truck (Thinkstep)* which is a combustion engine truck running on diesel with a Euro 0-5 mix emission standard. The truck has a total weight of maximum 5 ton and has a filling rate of 85%. With the diesel process *EU-27: Diesel mix at filling station (Thinkstep).*

4.4 Use

The fuel filter is a passive product and does not consume resources when mounted on the wheel loader. The considered impact during its use phase was the diesel needed by the machine to carry the filter. The amount of diesel used was determined with weight allocation according to table 5.

Table 5 showing how allocation of fuel was made to decide impact during use phase (during the entire life length) of reference filter. The total consumption of diesel allocated to the filter was 20 l

Calculation of use phase diesel consumption	
Wheel loader weight	23 405 [kg]
Fuel consumption per hour	18 l/h
Weight fuel filter	1.3 [kg]
Weight percentage	5.4 e-5%
Fuel consumption allocated to filter during 20 000h	20 [l]

4.5 End of life

Fuel and oil filters in Sweden are recycled by Rang-Sells in Halmstad. They have an automated procedure called ReUseOil where the filters are shredded in the first step. In the second step the material is centrifuged to recycle any oil which can be reused as motor oil. Metal is then separated from other materials to be melted and recycled and the residue is taken to incineration where the heat is recovered for district heating or heating of cement ovens. The plant recycles about 6 000 000 filters every year (Rangsells, 2011).

4.6 Energy consumption

Table 6 shows the energy consumption over the life of the reference filter. It is divided in non-renewable and renewable energy. The largest amount of energy, electricity, is needed during the production phase and the energy comes from non-renewable sources.

Table 6 the energy requirements from each stage in the life of the reference filter.

Reference filter		
Energy source	**Renewable [MJ]**	**Non-renewable [MJ]**
Production	184	1586
Use	16	1450
EOL	40	-722
Total	241	2314

5. Inventory analysis: concept filter

In this chapter the concept filter will be described in detail. All information needed for the modelling and impact assessment is found here.

5.1 Flowchart

As can be seen (fig. 9) the production of the remanufacturing facility was left outside the borders of the system. Waste products in the use phase come from spare parts, made from metal or rubber that needs replacement in the remanufacturing process.

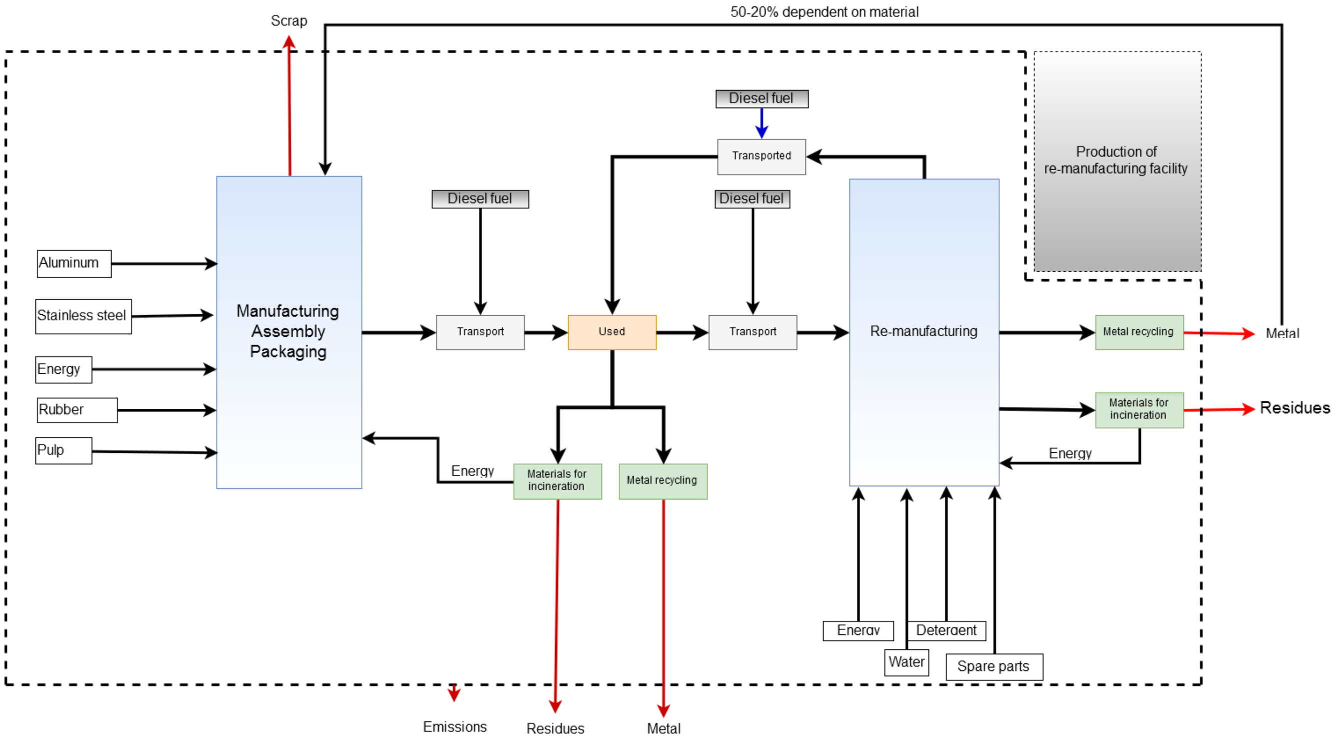


Figure 9. Flow chart of concept filter life cycle.

5.2 Production

As in the case of the reference filter, all production of metal parts is carried out in the same factory. Since the material and dimension of the canister is difference for the concept filter, another production process is required. The canister in the concept filter is made from aluminum and milled instead of the process of deep drawing. The filter medium is not made from cellulose but from woven steel wire which requires a weaving procedure instead of cutting and folding paper. The gaskets are taken from the same place but the packaging material this time is a plastic container. All materials, weights and processes are found in table 7.

Table 7 showing ingoing materials, weights, manufacturing processes and respective GaBi data set for the concept filter. Numbers correspond to numbers in fig 6.

Component	Material	Weight [g]	Manufacturing	GaBi material	GaBi process	Reference material/ Reference process
9. Canister	**Aluminum**	**1500**	**CNC**	**EU-27: Aluminum sheet mix RNA: Secondary Aluminum Ingot**	**EU-27: Aluminum profile (EN 15804 A1-A3)**	**-/ Thinkstep Thinkstep**
7. Spring	**Stainless steel**	**20**	**Stamped and bended**	**RER: Steel finished cold rolled coil**	**GLO: Steel sheet stamping and bending**	**Worldsteel/Thinkstep**
					EU-27: Lubricant at refinery	Thinkstep
					RER: Steel cold rolled coil	World steel
					GLO: Compressed air 7 bar	Thinkstep
					EU-27: Electricity grid mix	Thinkstep
8. Gaskets	**Styrene-Butadiene rubber**	**20**	**Vulcanized**	**DE: Styrene-Butadiene Rubber (SBR) Mix**	**GLO: Vulcanization of synthetic rubber**	**Thinkstep/Thinkstep**
					EU-27: Process water	Thinkstep
					DE: Styrene-Butadiene rubber mix	Thinkstep
					JP: Crude oil mix	Thinkstep
					EU-27: Electricity grid mix	Thinkstep

4. Filter material	**Stainless steel**	**500**	**Woven**	**GLO: Steel wire rod**	**-**	**Worldsteel/-**
5, 3.Supporting grid	**Steel wire**	**15**		**GLO: Steel wire rod**	**EU: Metal grid**	**Worldsteel/ Author**
					EU-27: Electricity grid mix	Thinkstep
					GLO: Steel wire rod	Worldsteel
					GLO: Welding seam 1m	Thinkstep
6, 2. Top+bottom cartridge cap	**Stainless steel**	**100**	**Stamped and bended**	**RER: Steel cold rolled coil**	**GLO: Steel sheet stamping and bending**	**Worldsteel/Thinkstep**
					EU-27: Lubricant at refinery	Thinkstep
					RER: Steel cold rolled coil	World steel
					GLO: Compressed air 7 bar	Thinkstep
					EU-27: Electricity grid mix	Thinkstep
Wrapping and packaging [3]	**Recycled paper**	**100**	**-**	**-**	**EU-25: Graphic Paper**	**-/Euro-graph/ELCD**
1. Filter container[4]	**Recycled plastic**	**120**			**DE: Plastic injection moulding part**	**Thinkstep**
					EU-27: Electricity grid mix	Thinkstep
					EU-27: Tap water	Thinkstep
					GLO: market for waste plastic	Ecoinvent

[3] Not seen in the figure
[4] Not seen in the figure

		plaster, final disposal	
		EU-27: Plastic granulate secondary	Thinkstep
Total	2275		

5.3 Transport

It was assumed that the company could have cooperation with their current supplier in the development of the washable filters and the supply chain would therefore look the same. The difference between the concept filter and the reference is the 4th post in table 8 where the transport back and forth to the remanufacturing facility is presented.

Table 8.Ttransports of the concept filter.

Part	Geography	Kilometer	Vehicle	Reference
Fuel filter	Germany-Gent	450	Truck	Google maps
Fuel filter	Gent-Göteborg	1 240	Truck	Google maps
Fuel filter	Göteborg-Client	2x30	Truck	Google maps
Fuel filter	Client-reman-client	30 576[5]	Truck	Google maps
Fuel filter	Client-Halmstad	170	Truck	Google maps
Total		32 496		

The transport was modelled with GaBi process *GLO:Truck (Thinkstep)* which is a combustion engine truck running on diesel with a Euro 0-5 mix emission standard. The truck has a total weight of maximum 5 ton and has a filling rate of 85%. With the diesel process *EU-27: Diesel mix at filling station (Thinkstep).*

[5] 392 km from client to Flen*2 (back and forth)*39 for amounts of replacement=30 576

5.4 Use

The fuel filter is a passive product and does not consume resources when mounted on the wheel loader. The considered impact during its use phase was the diesel that was assumed to be used to transport the filter by the machine. The amount of diesel was determined with weight allocation according to table 9.

Table 9 the allocation of fuel to the concept filter during its use-phase.

Wheel loader weight	23 405 [kg]
Fuel consumption per hour	18 l/h
Weight fuel filter	1.9 [kg]
Weight percentage	8.1 e-5%
Fuel consumption allocated to filter 20 000h	29 [l]

Diesel process EU-27: Diesel mix at filling station (Thinkstep).

5.5 Remanufacturing

The remanufacturing process would work as shown in figure 10. Filters will arrive in their transport containers to the facility and will be cleaned from dust and grease. Next, are they removed from their transport containers and diesel in the filters is collected. Containers and filters are taken to different cleaning processes and filters will be disassembled and parts separated for inspection. When inspected, they are washed separately and reassembled. After remounted in their transport containers, they are tested to make sure they are as good as new and then sorted and packed for transport back to next wheel loader for a detailed description of the process, see figure 10.

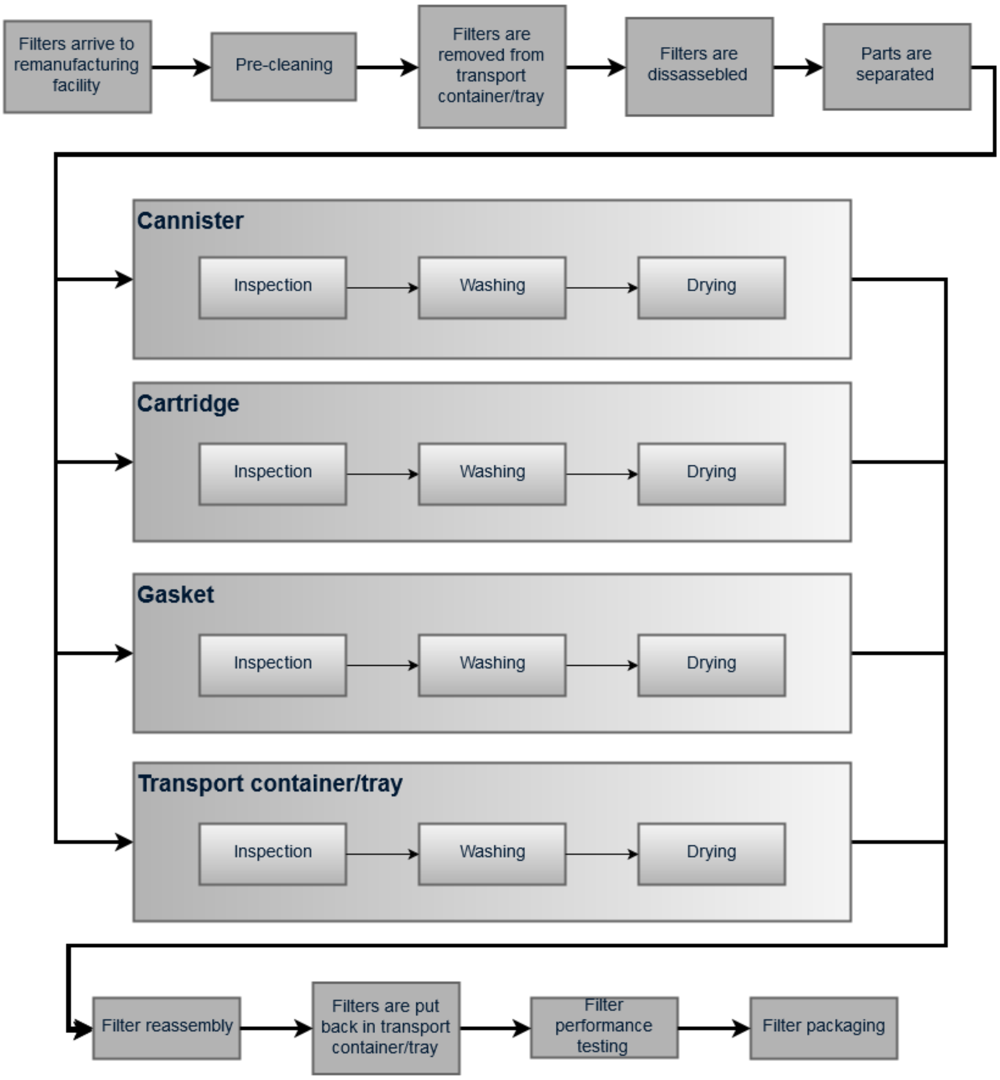


Figure 10. Flow chart showing the remanufacturing process.

A simplification, concentrated on material flows, was made for the GaBi modeling. The processes and materials are found in table 10.

Table 10 Processes used to model the remanufacturing in Gabi. Amounts of materials per wash of one filter.

Inflow material	Quantity/one filter	GaBi Process	Reference
Detergent	20 [g]	RoW: soap production	Eco invent
Electricity	229 [kJ]	SE: Electricity grid mix[6]	Thinkstep
Water	4 [kg]	EU-27: Process water	Thinkstep
Steel parts	12.8 [kg]	RER: Steel plate	Worldsteel
Rubber parts	10 [g]	GLO: Vulcanization of synthetic rubber[7]	Thinkstep

Steel and rubber parts were estimated to need replacement in 10% of the cases when the filter was in for remanufacturing. The numbers for water and detergent were simply assumed, but to estimate electricity consumption of an industrial washing machine was used as a reference (Wexiödisk, 2016) where 8 filters were thought to go in each of the baskets that could go into the machine.

5.6 End-of-life

The end of-life-for the concept filter will be determined by the remanufacturing facility which will replace parts when needed. The parts that are not viable for reuse are sorted out in either the inspection or the testing step and will be washed and discarded to steel or aluminum recycling. No shredding is needed. GaBi built in data sets were used for paper and plastic recycling and Volvo data sets for metals.

5.7 Energy consumption

In table 11 the energy consumption for each stage in the concept filter´s life cycle is shown. A large amount of energy is needed during manufacturing in which extraction of for example aluminum is included.

Table 11. Energy required for each step in the concept filter´s life cycle. The renewable energy is dominated by hydro and wind power.

Concept filter		
Energy source	**Non-renewable [MJ]**	**Renewable [MJ]**
Production	263	68
Use	36	21
EOL	-121	-45
Total	178	44

[6] A mix where nuclear and hydro power energy sources dominates.
[7] For ingoing processes see table 7

6. Result

In the following chapter the results from the impact assessment are being presented. Overall the concept filter has lower impact due to its material use.

6.1 Materials

Table 12 shows how much material is needed for each filter solution to provide fuel filtration over 20 000 h in a wheel loader L150. The reference filter is lighter but since 40 filters are needed instead of 1.16 it needs over 21 times as much materials.

Table 12. Shows the weight of the reference filter and the concept filter respectively both based on functional unit and individual filter.

	Reference filter	**Concept filter**
Materials use for 20 000 h	55.3 kg	2.59 kg
Materials use per filter	1.37	2.23

Figure 11 shows materials content in each filter. It is obvious from the graph that the concept filter is heavier and contains a large amount of aluminum.

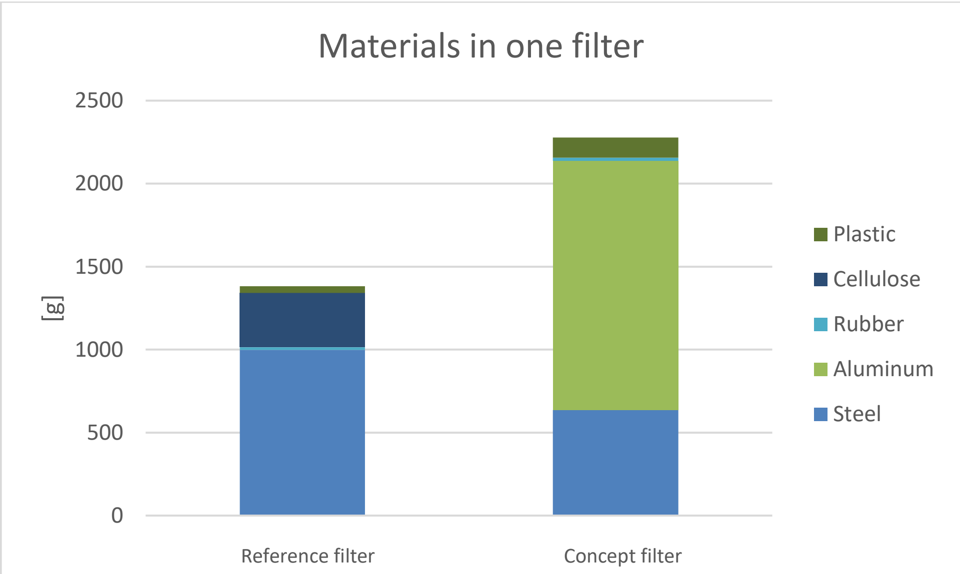


Figure 11 shows the materials distribution with-in each filter.

6.2 Transport

Table 13 shows the distance each 20 000h of fuel filtering requires. The reference concept travels more than double the amount of the concept solution. This is due to the fact that each reference has to be transported from Germany to Sweden, whereas the concept only completes that journey 1.16 times and then it is only taken back and forth to Flen in Sweden.

Table 13. Comparison of the transports needed to provide the wheel loader with main fuel filtration for 20 000 h.

Product	Kilometers
Reference	76 800
Concept	32 496

6.3 Impact assessment

The following graphs are showing the difference between the reference filter and the concept filter based on the functional unit for all chosen impact categories.

6.3.1 Global warming potential

As can be seen in figure 12 the concept filter has minimal global warming impact compared to the reference solution. Both have biggest impact during the production step, thus tied to material extraction.

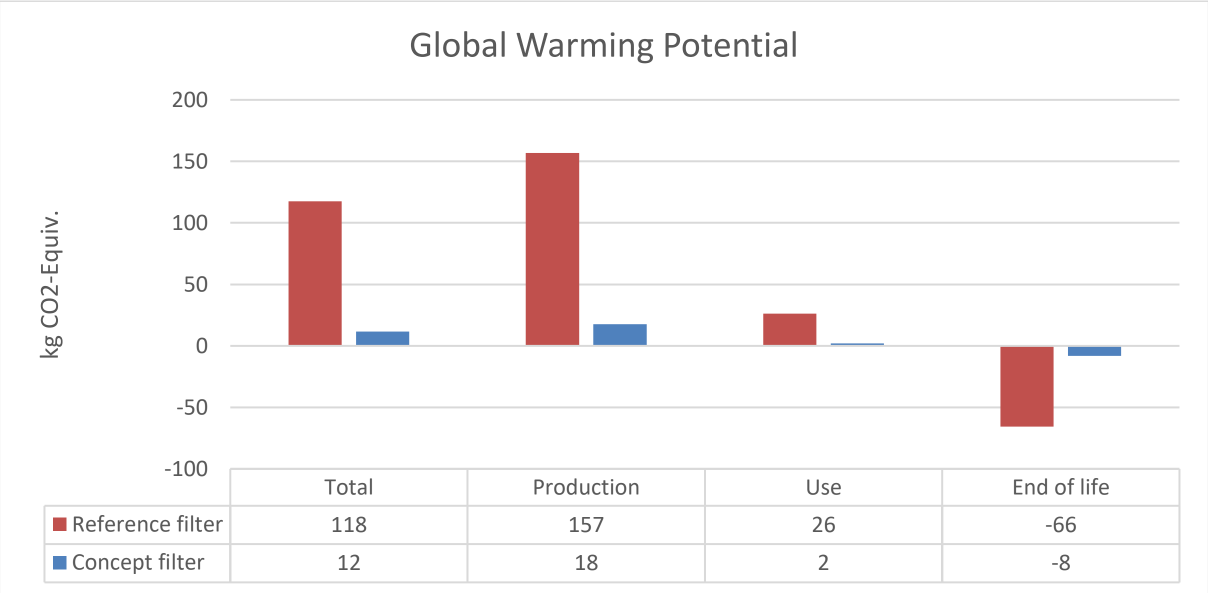


Figure 12.Graph showing the global warming potential for the reference filter and the concept filter.

The largest impact caused by the reference is the process of extracting and working the steel. The largest impact caused by the concept is instead the extraction and manufacturing of aluminum components. The emissions are in both cases carbon dioxide, tied to electricity production to feed energy into material extraction processes. Since the greatest impact in both cases comes from the production phase, it was believed that the approach to reduce the material consumption per functional unit was the most effective method of impact reduction. The graph also shows that the material reduction gave the desired, lowered impact.

6.3.2 Acidification potential

In figure 13 it is shown that the acidification potential is much smaller for the concept filter. Biggest impact has the production for both filters.

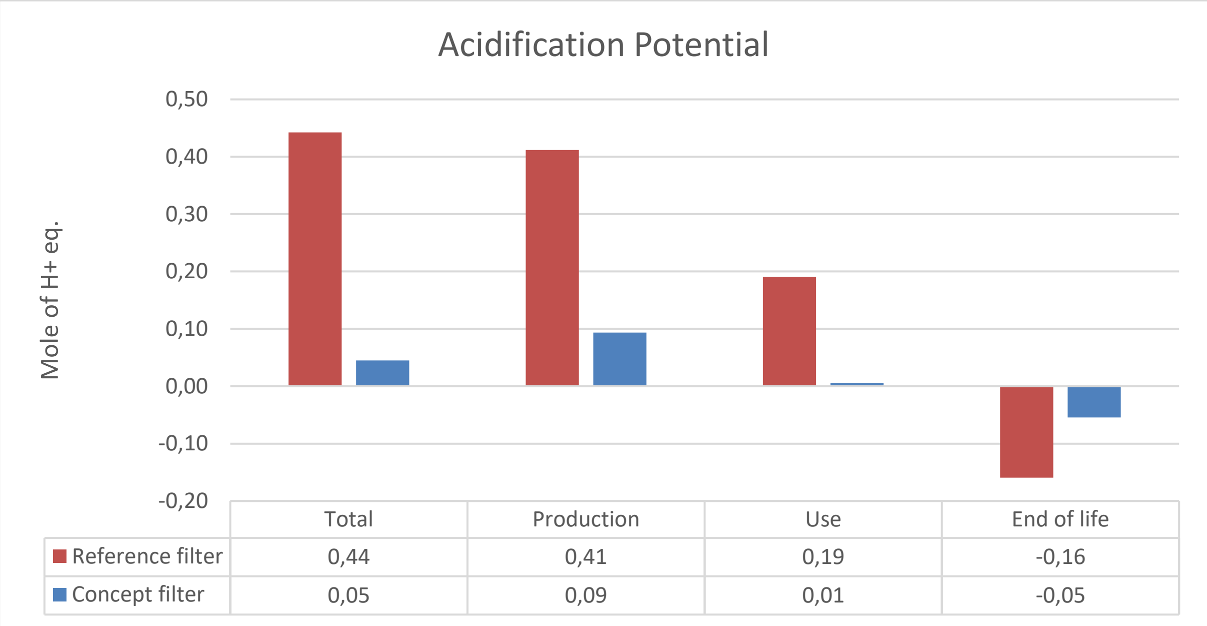


Figure 13. Graph showing the acidification potential for the reference and concept filter.

It is somewhat surprising that the concept filter has a relatively high acidification potential compared to the reference filter in the production phase despite the much lower weight. However, aluminum production is resource heavy and contributes Sulphur dioxide from the production of the canister that shows in the blue bar. For the reference filter, it is emissions of the same kind that dominates and they are also tied to material and production of the canister. The acidification potential from the use phase in the case of the reference filter is in the form of emissions of nitrogen oxide caused by combustion of diesel due to transportation.

6.3.4 Eutrophication potential

Figure 14 shows that production phase and use phase have similar amount of emissions that cause eutrophication for the reference filter. It is, again, the steel production that causes emissions but also the big amount of transportation that is required for the reference filter. All those numbers are small relative the 18 000 tons of NOx that was emitted in the region of Västra Götaland 2013 (Miljömål, 2016).

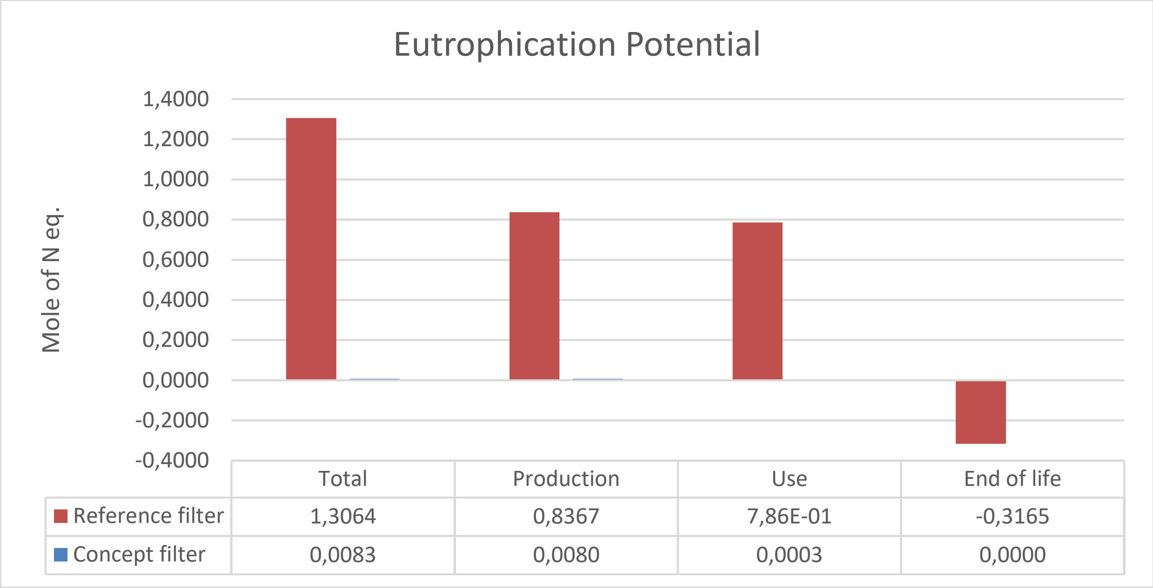


Figure 14 Graph comparing the eutrophication potential of the concept and reference filter.

What makes the reference filter dominate is the lager amount of transportation by truck that emits nitrogen monoxide. That is what causes emission by the concept fuel filter too but the amount of transportation is much lower. What also causes emissions for the concept is the soap production in the form of ammonium.

6.3.3 Abiotic resource depletion

Figure 15 shows the difference in abiotic resource use. The concept filter uses very few resources compared to the reference concept which can be seen in this graph.

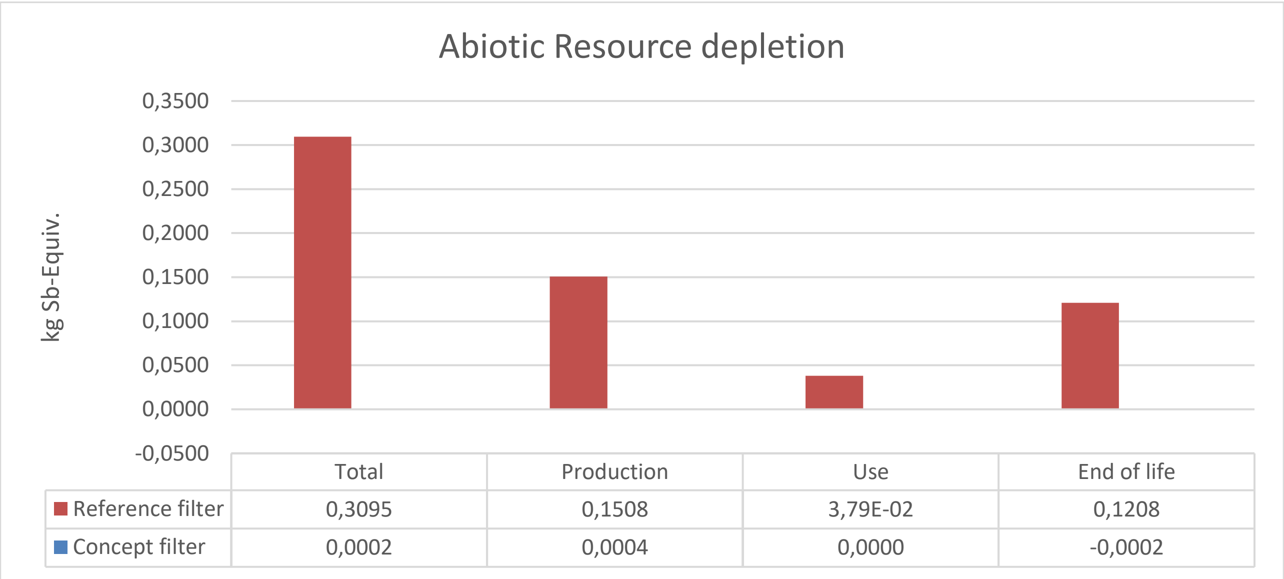


Figure 15.Graph showing abiotic resource depletion for the concept and reference filter.

The use of resources is very spread over all kind of resources taken into account in this impact category. What stands out is the use of borax, indium and colemanite in the process estimated for the cellulose cartridge in the reference filter. However, this is an approximated process and whether those materials are used in reality is not known.

For the concept filter it was the production of the canister that was most resource consuming and the materials standing out was bauxite and tantalum. For the use phase, it was the production of detergent used for remanufacturing that stood out using indium.

6.4 Analysis

Over all it can be said that the LCA has shown that the material reduction has led to reduction of environmental impact. The new way of handling the filters has also led to a big reduction in transports. What is worth paying attention to is the use of aluminum for the canister in the concept filter; aluminum was chosen since it is a light material and it was desired to keep the kilos down to not cause unnecessary impact during transport. However, other impact categories show how aluminum causes the biggest impact for the concept. In the refinement of the concept it is suggested that a thorough stress test should be done on the canister to be sure how big the load on it will be and after that look into if other materials are possible and what effects that would have on the transported mass.

6.3.5 Water use

GaBi software, with the dataset available for the project, could not provide a good number for water use for the model. It would be desirable to be able to compare the reference filter with its water consuming cellulose cartridge solution with the washable concept filter. However, the water estimated to be needed for the concept filter is a very rough estimation and the water may also be recyclable within the process. This is somewhat a result gap and it is something worth considering when moving forward with the concept development.

7. Sensitivity Analysis

In the following section, the results from the sensitivity analysis are presented. A sensitivity analysis was made on the remanufacturing procedure and in the form of a breakeven analysis between the concept and the reference filter.

7.1 Remanufacturing

The idea in this part of the sensitivity analysis was to increase consumption of all resources needed during the remanufacturing process, including transports, since the very nature of the concept builds on remanufacturing. The remanufacturing procedure was not described in detail in the report "*Preparing for tomorrow: exploring design adaptations on a wheel loader in a circular business model"* and the amount of ingoing resources was considered needed to be tested to understand where the limit was if the procedure would be developed. This was done by multiplying the remanufacturing process with 2 and 10. This way a doubling of needed resources was represented with 80 washings instead of 40 and an increase with 10 times the amount was represented by 400 washes. Since transportation was also included it would represent that the distance to the remanufacturing facility would double in the first case and tenfold in the second.

7.1.1 Global warming potential

Figure 16 shows that even if all the factors in the remanufacturing process were multiplied by 10, which includes energy consumption, transport, water use, spare parts and soap, the concept filter is still better for the environment in terms of global warming potential. This is a good indication for that the remanufacturing process is a better solution than disposable filters.

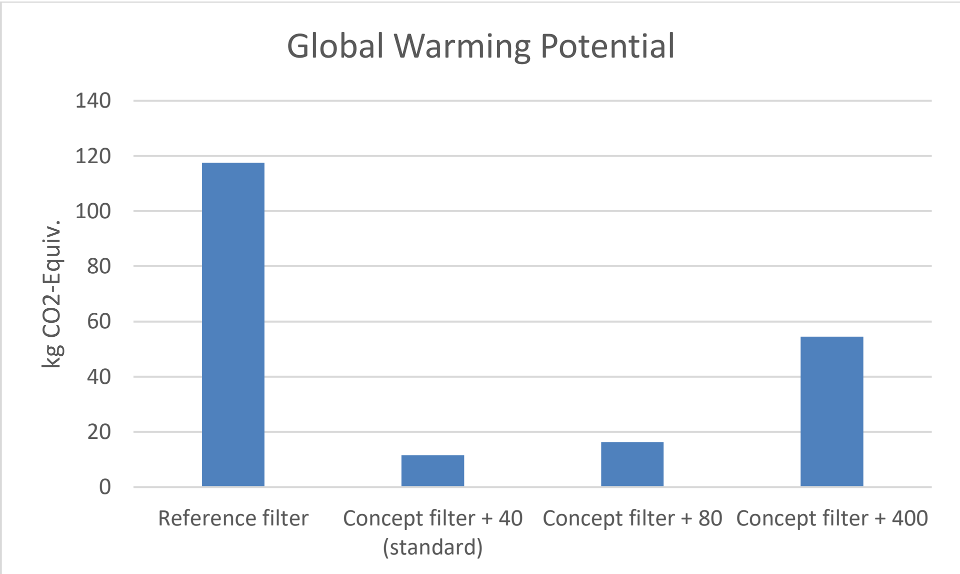


Figure 16. Graph showing how the global warming potential is affected when the parameters of remanufacturing are changed.

The biggest change between times two and ten is that the rubber production passes the production of steel spare parts in terms of emissions. This indicates two things, the remanufacturing procedure itself is not a large source of pollution and the amount of spare parts needs to be kept low.

7.1.2 Acidification potential

When it comes to acidification, as shown in figure 17, the relative difference is not as big as for global warming potential.

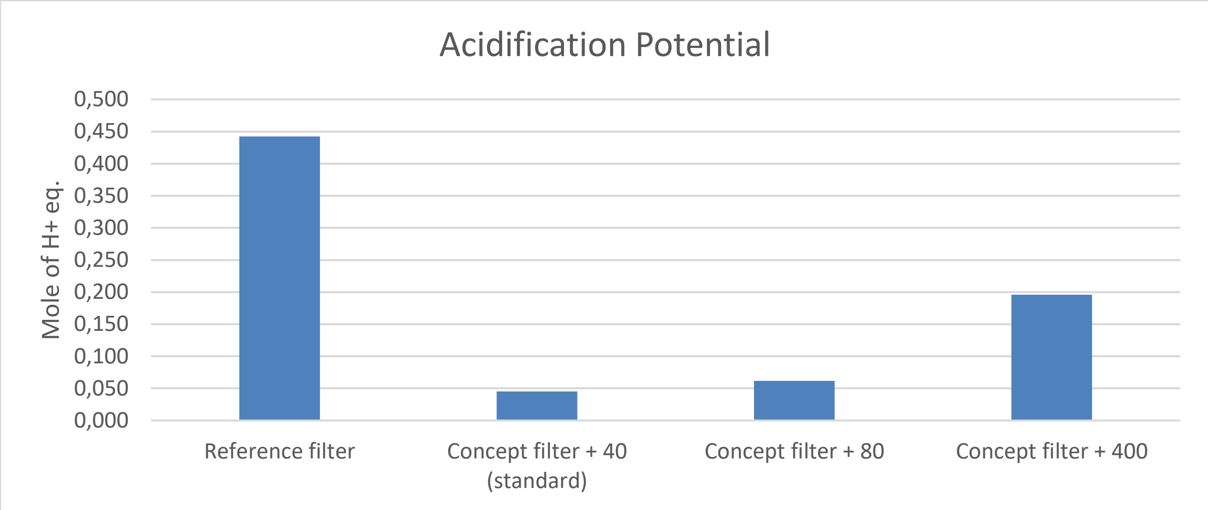


Figure 17. Graph showing how the acidification potential is affected when the parameters of remanufacturing are changed.

The biggest contributors are rubber and steel parts production and soap production. They are causing emissions in the form of Sulphur dioxide and nitrogen oxides.

7.1.3 Eutrophication potential

Figure 18 shows that even with a ten folding of everything consumed in the remanufacturing process, the eutrophication potential of the reference concept is still bigger. Nearly all the damage of eutrophication can be avoided with the concept solution.

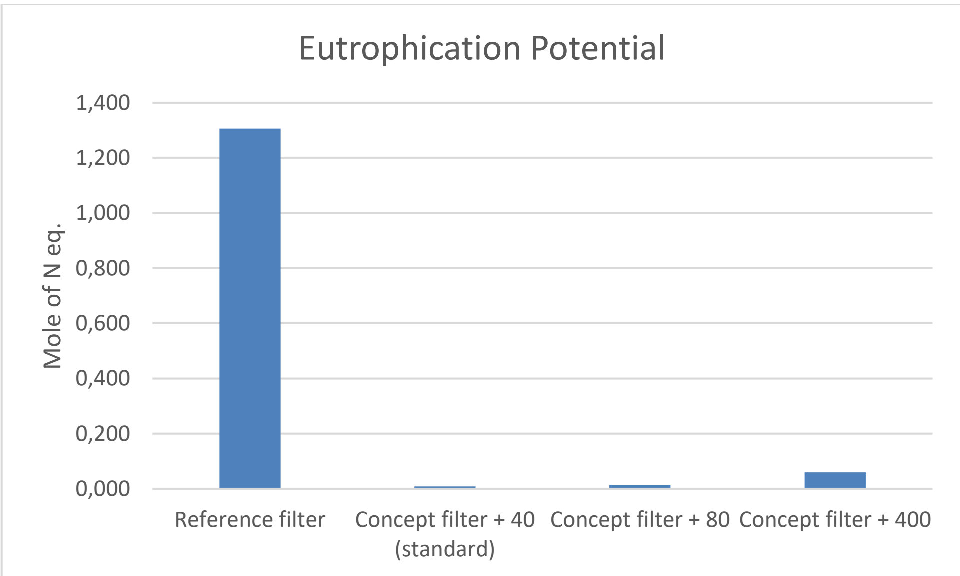


Figure 18. Graph showing how the eutrophication potential is affected when the parameters of remanufacturing are changed.

7.1.4 Resource depletion

Figure 19 shows that the concept filter with its remanufacturing process saves resources.

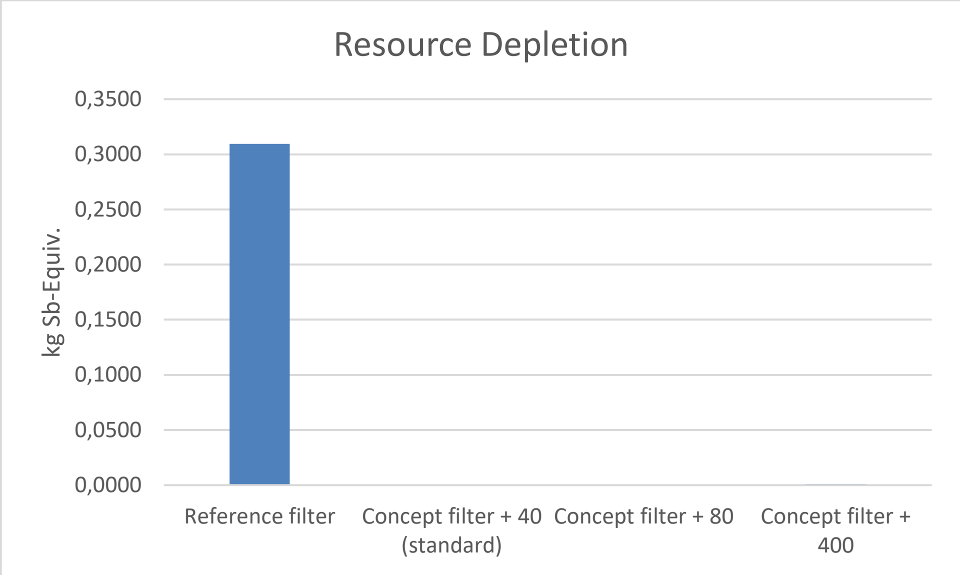


Figure 19.Graph showing how the resource potential is affected when the parameters of the remanufacturing process are changed.

A conclusion from figure 19 is also that the remanufacturing process for each filter consumes almost no resources compared to the currently used disposable reference filters. This is still true if the input parameters are ten folded. The remanufacture procedure has little impact on resource consumption compared to new production of filters.

7.1.6 Analysis

The remanufacturing process was the biggest area of uncertainty in the model over the concept due to the readiness of the concept. Values for what was thought to be needed were estimated and because of that, it was interesting to see how the results developed when the used amount was multiplied. However, some of the factors multiplied by 400 are not likely to be that big such as water use and spare parts. On the other hand, it gave a good indication of what is most important to think about when the remanufacturing process is developed.

It is definitely worth refining the filter design until it requires as little spare parts as possible to keep the environmental impact minimum. There is a lot of potential to develop a remanufacturing facility which can allow for low impact if principles of reuse are implemented, for example, could left-over heat from the washing and drying of filters be used in the factory.

7.2 Breakeven

A breakeven analysis was made to see how many times the concept filter needs to be reused before it was a better option than the reference filter in terms of greenhouse gases emitted.

7.2.1 Breakeven

Figure 20 shows the result from the breakeven analysis. The concept filter has a much higher amount of initial emissions (5.9 kg) but the remanufacturing process emits very little. Due to this, the concept filter has soon paid off its initial emissions and the reference filter, which emits 2.64 kg per each, is the less good option already after three replacements. To make the comparison more interesting, the high resource consuming (times ten from previous figure) remanufacturing concept was also included in the breakeven analysis (green line). If the remanufacturing process is that expensive, resource wise, it will take five replacements to breakeven.

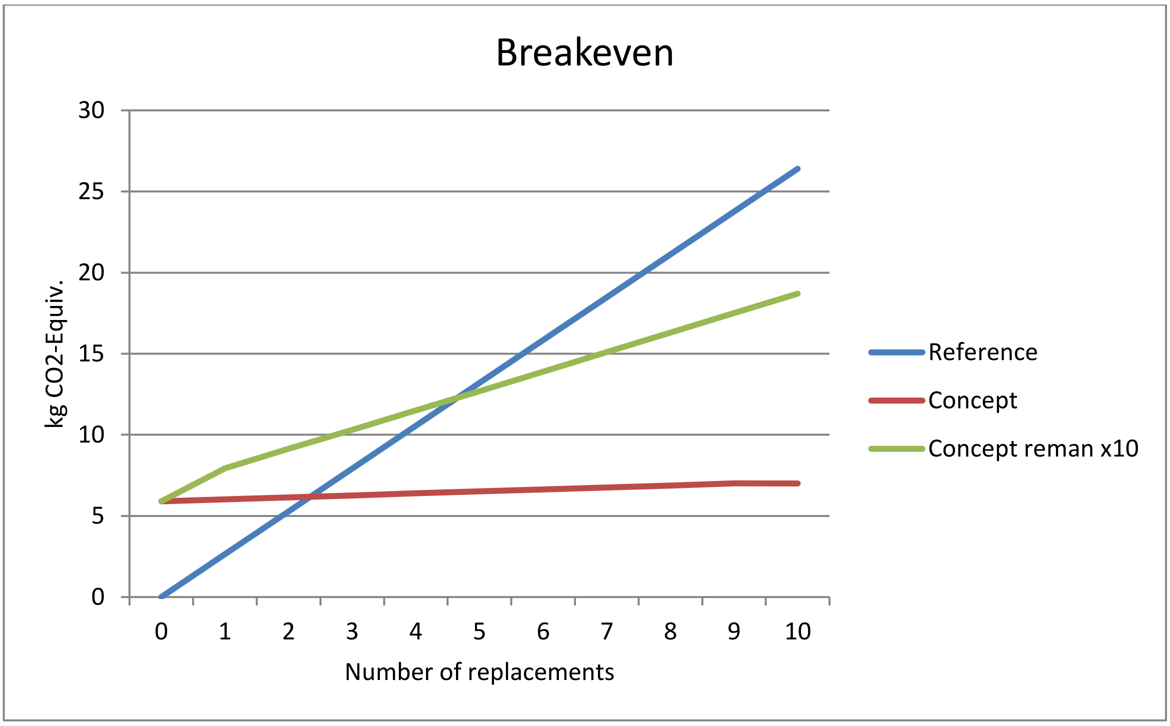


Figure 20. Showing breakeven point between the concept filter, concept filter with resources for remanufacturing multiplied with 10 and the reference filter. It can be seen that the concept breaks even at 3 disposable filters but that it takes 5to break even with a more resource consuming remanufacturing (reman) process.

7.2.2 Analysis

It might be surprising that the breakeven point is reached after so few exchanges. Though, considering that the concept filter only weights slightly more, it is more understandable. It has already been shown that the impact for both filters is in the production phase and that even if a concept filter is remanufactured 400 times during 20 000 h it is still a better option. This indicates that the remanufacturing process is not very resource intensive.

8. Discussion

Assessing a concept with LCA comes with a lot of challenges and might at first sight seem contradictory to the very nature of an LCA. A concept is lose and sketchy, not much is decided and even less is known compared to how it is needed to be in an LCA where every process, material and matter of transportation needs to be known in detail. However, involving LCA in the product development process also comes with a lot of second thinking of materials choices, thicknesses and the need of extra details.

8.1 Concept filter

During the product development process of the concept fuel filter some assumptions where needed to be made only for the sake of the LCA. For example the different manufacturing processes the location of the remanufacturing facility and the weights of each component. Normally the product would be prototyped and tested before such parameters would be decided; manufacturing strategies would be developed by someone with special competence in such technologies. It was not the case in this study, simply because it was out of scope for the project. But the result is not useless, quite the opposite. There is a reference and a base to start from when developing a manufacturing lane for this filter saying how to avoid huge environmental impacts.

The choices of datasets in GaBi were made based on what seemed to correspond to the process that was decided to be needed for the concept filter future production, use and end of life. They might all be different in the final product. But in this LCA an indication is given to where most attention should be put when further development is used. One example is the fact that the spare parts contributed so much to the emissions in the remanufacturing process, to reduce them is therefore important in the development of the concept.

8.2 Reference filter

The modelling of the reference filter was more based on measured and collected data compared to the concept filter. The data was then approximated with processes in GaBi and might not give the whole truth. However, the accuracy of the both LCAs are quite similar and it made them more suitable for comparison. Where the same material and manufacturing technique were used in both filters the same data sets have been used to make the comparison more accurate. The biggest reason for that the reference filter stood out as the lesser option in the comparison was the large amount of materials used. A change in the choice of processes in GaBi would not have affected that fact and the results are therefore to be seen as useful.

8.3 Transports

The distances and means of transportation have been a data gap for the reference filter. To come around this issue the same nodes, trucks and transportation routes were estimated for both the concept filter and the reference to make the comparison as fair as possible. If additional information had been found, the same changes would have been applied to both filters and would not have had any significant impact on the end result. The matter of transportation was estimated to a 5 ton truck with an emission standard of Euro 0-5 mix. This should be seen as a conservative assumption. Most trucks have a class 5 emission standard today and the way the filters are transported might not be with such a big truck. This indicates robustness in the remanufacturing model; it does not have to increase transports and it saves materials.

The location of and transport to the remanufacturing facility are both unknowns but the values used here could be seen as a base scenario in which parameters could be modified to find a good solution.

8.4 Choice of datasets

Since production of both filters was decided to be located in Germany the datasets were chosen accordingly which in this case meant that EU-27 processes were chosen as often as possible. The impact from an EU-27 process is an average value of the impact of similar processes in 27 different EU countries. If an "agg" process was chosen (no input datasets needed) the European or German datasets were preferred to create a model that corresponded as well as possible to a real manufacturing scenario in Europe. By doing so, it is likely that the production in both cases can be considered an average scenario when it comes to emissions. The processes should not be considered either the best or the worst case.

8.5 The bigger picture

The result from the LCA is in line with the idea of circular economy: by rethinking the system a product is part of, the product's or the service's environmental impact can be decreased. (Ellen MacArthur Foundation, 2015) The concept in this study was developed with design for environment strategies and a product development process that was concerned about the environmental aspects, which paid off in terms of less environmental impact.

The concept development focus was to decrease the amount of materials used and reuse what was already extracted. This is supported by Miljömålsberedningen (2016) which writes in the report *En klimat- och luftvårdsstrategi för Sverige, Del 1* that raw materials extraction is accountable for 19% of the total amount of emitted greenhouse gases globally and waste management is accountable for 3%. In this study, the focus was metal, which is positive since the extracted amount of ores increased with 133% between 1980 and 2008 according to OECD (8.2 Gt year 2008).

9. Conclusion

The study showed that a fuel filter designed to fit into a circular business model and developed with design for the environment strategies is better for the environment in all impact categories used. A remanufactureable solution also decreases the amount of transportations needed if the remanufacturing facility is placed closer where the filters are used than where the manufacturing site is located.

The majority of the environmental savings came from the 95% reduction in used materials. From this it can be concluded that by focusing on reducing materials in a product many positive side gains can be achieved from an environmental perspective.

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