DESIGNING A SUSTAINABLE PRODUCT FROM ELECTRONIC PLASTIC WASTE

– A study in how an environmentally friendly product can be developed with a discarded material as the starting point

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This master thesis was written during the spring 2014 at Linköping’s University, as the final part in the master of science program in Design and Product Development. The focus of the thesis have been sustainability, recycling and eco-design and represents a work on 30 ECTS. Kerstin Johansen have been the examiner and David Eklöf supervisor.

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The aim of the thesis was to show that it is possible to develop a sustainable product of a discarded material and provide a framework for how to do that. A great amount of discarded material is today put on landfill due to its low value and difficulties to use. But putting the waste on landfill is the least preferred way of handling it, especially when the resources in the world are not infinite. It is therefore of importance that we find another way of handling the discarded material, which is why this thesis was written.

During the work has a quote by McDonough and Braungart (2002) been kept in mind, reminding us, as product designers, of the responsibility we have for future generations well-being.

“How can we love the children of all species—not just our own—for all time?”
McDonough and Braungart. 2002. Remaking the way we want things, pp 168

This thesis consisted of three phases. In phase 1 the plastic WEEEBR (a recycled plastic blend from waste from electrical and electronic equipment) was evaluated and a suitable product for it was found. Phase 2 started with a market research trying to find a market opportunity for that product. Thereafter several concepts for the product was developed. The last phase, phase 3, analyzed and evaluated the two previous phases in order to summarize the process and develop a method for how to put requirements on future products.

Phase 1 and 2 are shortly described, thereafter follows the analysis of them. The proposed method are exemplified with concepts and results from phase 1 and 2. The result of the thesis was a method based on following 6 steps:

1. Agree to the company’s vision
2. Evaluate what available material you have
3. Evaluate your technical possibilities with the material
4. Highlight a market possibility
5. Set product requirements
6. Develop the concept

This method is generic and shall be used as a guide when developing sustainable products. Developing sustainable products include thinking about what material you have. It is worth thinking about if the product shall be produced locally, with local material and also how the material should be handled after it is used and at last where it ends up.
To facilitate for the reader this guide is provided.

First, do you know all the theory needed to understand the decisions made during the project? These are the areas you need to be familiar with:
• How a product is developed
• Different approaches to sustainable production
• Electrical and electronic equipment
• The material WEEE BR
(chapter 2, 3, 4 and 5)

The second part describes the process used to answer the questions of the thesis. That process is also discussed and several conclusions are drawn. (chapter 6 and 7)

The third part is where the proposed method is presented to the reader. First by a short overview of the generic method. Followed by a review of each step where implemented methods are explained and motivated. (chapter 8)

The stages in the method are then followed through and explained with examples of the requirements and concepts that was found during the project. (Chapter 9)

The next part includes a discussion of the proposed method and an overall discussion of the project. This also includes recommendations for further studies. (chapter 10)

To summon the conclusions there is a last chapter where the questions of the thesis are answered. (chapter 11)

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1. Introduction

This first chapter will give the reader an introduction to the subject of the thesis and explain the purpose of the work. The aim will be described and also delimitations and the questions of the thesis will be stated.

Some hundred years ago people thought that the earth had a shape of a thin plate. Today we all know that that is not the case. 200 years ago the industrial revolution started and things we had never imagined were developed. The society went from being based on agriculture to being based on industry. Only some decades ago people started to realize and explore how the industrial revolution is affecting our environment and all the now living creatures. Humans need development and maybe it’s now time for another change in how we see things.

Some months ago, a lecture was held on Kungliga Tekniska Högskolan (KTH) in Stockholm, Sweden. Ellen MacArthur was invited by Cradle-Net, to talk about her work on a circular economy. And most recently, the EWEEK (Environment, Economy and Evolution) was held at Linköping University (LiU), a week of seminars and lectures with the theme “Circular Economy”.

One might ask why this is happening now, universities and researchers are discussing a new way of looking at the economy. Do the rising threats of climate change have something to do with the increasing interest of a more sustainable and circular working society? Is there once again something that has to change in the way we look at society? A lot of people would agree to this (McDonough and Braungart. 2002, Ellen MacArthur Foundation. 2012).

One of the main ideas that a circular economy is based on is Cradle to Cradle’s (C2C) principle “waste equals food”. When material that earlier were classified as waste changes to something useful it is possible to close the loop of a product’s life, as to say, the material goes from cradle to cradle. The economy is then dependent on the flow of material and on keeping it in the loop instead of letting the material lose its value and be turned to waste. (McDonough and Braungart. 2002)

McDonough and Braungart (2002) writes that since the resources of the world aren’t infinite, changes in our way of living have to be done. Studies show that if we were to continue to live in the same way that we are now living, especially when countries as Brasil, Russia, India and China (BRIC-countries) are growing rapidly we will face some great challenges in only a couple of years. (Global energy assessment. 2012). Countries are therefore developing legislation to encourage sustainable solutions and new, conscious companies work hard to live up to the legislation and to develop products that suit the customers’ demands. Recycling companies are growing and take care of our increasing amount of old products through sorting and recycling.

A Swedish example of recycling companies is the company Stena Recycling
that has been working with handling and recycling of material since 1939. Stena is today handling about 2.5 millions of tonnes of waste material. They handle all kinds of waste, but mainly metal, paper and plastics. Most of it they are selling back to the material manufacturers, as an around 90 % clean and sorted material. (Stenvall et al. 2014, Flink. 2014)

Even though Stena is working hard with developing different ways of sorting and handling the waste to turn it into usable material (i.e. turning waste into food) there are some wastes they classify as problematic. These problematic fractions do not have the economic value and the materials end up at landfills or are incinerated instead of being sold to manufacturer. Waste from electronic and electrical equipment (WEEE) is one very complex fraction since it consists of a lot of different plastics, metals and other, sometimes hazardous, components. The metals are possible to sort out to a sufficiently clean material but the plastic fraction comes in grand variety of quality. Today there is no easy and feasible way of sorting out the different materials in the plastic fraction, called WEEE Plastic, leaving this fraction without any value and a lot of this plastic fraction ends up at landfills in Sweden or other countries, or is used as energy recovery. (Flink. 2014) Additionally, the WEEE is one of the fastest growing waste fractions of today and will, due to a growing population, increase even more in the near future. (Stenvall. 2013)

During many years the recycling industry and the product manufacturers have been separated. But to actually build this circular economy and close the material loops these two industries have to work closer together. This will require both parts to adjust their processes and way of working. The reality of the recyclers have to meet the vision of a circular economy if we want to create a sustainable society. So how shall this be done? Well, a lot of the responsibility will be on the product developers. Products in a circular economy will have other requirements to fulfil than today’s products. These requirements might be both commercial (business - how shall the product be sold? How shall it be kept in the circular economy?), aesthetic (human - how shall the human perceive the product?) and technical (functions - what are the functions of the product?).

This master thesis, written the spring 2014 at Linköping University and in collaboration with Chalmers, will bring up solutions on how product developers can design future products to adjust them to both the recycling industry and a circular economy. In order to answer the questions above one discarded material will be used as example. A discarded material is referred to as the waste material that has been put on landfill because of its lack of value. This thesis will try to find solutions on how the discarded material WEEE Plastic can be brought back into the loop and stay there. A method will be developed and proposed for
future work.

The thesis is a part of a bigger project called Waste to Design (W2D) where experts from Stena Recycling, Semcon (consulting agency) and product developers and material experts from Chalmers are included. Also the master student of material engineering, Ze Yu, was during the spring involved in the project as he evaluated how aging and recycling affect the WEEE Plastic.

The W2D project runs over three years and give students from the field of design a product development an opportunity to develop a product out of waste. W2D itself is part of a MISTRA initiative called Closing the loop.

1.1. Aim and purpose
The aim of this project has been to show how an environmentally friendly product can be developed starting with the discarded material WEEE Plastic. A guide for how sustainable products can be developed and an example of how it is used were the expected results. The purpose was to reduce the discarded material on landfill and to show how future products may have to be designed to suit a sustainable society. This was done with the discarded material as the starting point of the development process.

Thesis questions:
1. How does the development process change when developing from discarded material?
2. Do we have to put other requirements on the products in the future, in order to achieve a sustainable society?
3. What product could be designed when starting with the given material WEEE Plastic?
4. What requirements have to be added to that product?

1.2. Delimitations
This project will not try to come up with a totally new product from the WEEE Plastic but rather replace an existing material in a known product. The product will then be modified according to the properties of the discarded material but it will not focus on developing new functions of the product unless it is necessary for the concept. This will also lead to that focus will be laid on the functions of the product that are mostly affected by the material’s properties. Functions of the product that are not affected by the chosen material will not be further developed.

While searching for possible product areas the manufacturing process will be kept to the recommended process. Injection molding is the process that has been
used by the material researchers during early experiments with the material. The experiments were done at the material laboratory at Chalmers University and with equipment available at that time. Other manufacturing processes (e.g. extrusion) may be possible to use but will not be looked further into in this project.

The work will focus on the material with the properties existing in the beginning of the project. Since the material student Ze Yu is evaluating the properties in his master thesis they might be improved in the final product. The project will be kept in the area of engineering and of technical products and therefore not be looking closer to marketing and business systems unless it is of great importance for the concept.
2. A product is developed

This chapter will explain different approaches and methods that can be used when developing a product. First will a very general process be described, then methods that can be used throughout the process. Thereafter will an agile method called Scrum be explained. Finally some human values will be described.

2.1. The product development process

Ulrich & Eppinger (2008) are often referred to when talking about product development. The process they recommend includes following generic steps.

- Market research
- Setting requirements
- Concept generation
- Concept election
- Detail design

These five steps are iterated several times until the best solution is found. For every step are different methods recommended. To mention some of them; lead users, work shops, market analyses and concept screening matrixes.

Depending on the starting point the process will vary. Technology-push products are driven by new technology and starts off by planning for what market the technology should be used. For creating a successful technology-pushed product the new technology should have a clear competitive advantage and alternative technologies should be difficult or impossible to utilize for competitors. To prevent the project from failing it is recommended to compare the concept with other competitives on a regular basis. (Ulrich and Eppinger. 2008)

Platform products, often mentioned as consumer electronics, computers and printers, assumes an already proven and well-known technology platform. Products including a high-risk need an early and continuous identification of these. The risks are related to technology (will the product work properly?), the market (what will the customer think of the product?) and budget and time (will the product be completed at given time and budget?). Because of the early risks they recommend to push the decision of concept forward allowing it to be tested with prototypes and evaluated as early as possible. Another way for avoiding large risks are to create multiple solutions that can be examined parallel. (Ulrich & Eppinger. 2008)

When innovating new products a very important success factor is the understanding of the users demand and needs. According to Creusen et al (2012) this is done during the Fuzzy Front End (FFE). The FFE is described as the uncertain first phase of the product development, where opportunities are found, ideas generated and concepts developed. Information of the consumers is especially important in the so called FFE. In the end of the FFE a go/no go decision is made, deciding whether it’s worth continuing with the concept or not. Creus-
en et al (2012) mentions a couple of common methods used during the FFE. These are the same methods brought up by Ulrich and Eppinger (2008) and are, amongst others; interviews, focus groups and questionnaire surveys. The aim of using these methods can vary, either they are used for idea generation, concept testing, collecting customer needs or understanding the context of the product. In early stages of FFE image boards, questionnaires and internet communities are often used to gain information about the demands of customers, problems with existing products and the context. Later in the FFE it is more common with interviews, focus groups and observational research in order to testify the concept. (Creusen et al. 2012)

2.2. Choosing material

Johannesson et al (2005) claims that the choice of material should be done in balance with the decision of geometry, function and manufacturing process. Also, it has to be kept in mind early in the designing process. They illustrates the relation between these choices in a figure. (see figure 1)

When changing one material to another it is important to evaluate these so no unexpected failure arises. A failure can be harmful for the reputation of the company and it is therefore of great importance to make sure the new replaced material is good enough. Johannesson et al (2005) brings up several factors to base the material decision on. These are mechanical properties, physical properties, assembling methods, the external factors during the product’s life, recyclability, cost and demand for coatings.

However, van Kesteren et al (2007) states, the user’s experience of the material is hardly considered in the material choice. van Kesteren (2007) claims that the users impression are getting more important since products are getting more similar to each other. The products have the same main functions but differs in appearance and usability.

Johannesson et al (2005) explain several ways of comparing the technical properties in order to help the designers choosing the right material. But as van Kesteren et al (2007) mentions the aesthetic aspects (user experience) of the material are not included. The designers also lack confidence for the material advices given to them and van Kesteren et al (2007) recommends a closer relation between the material data source and the developers.

![Figure 1. This figure explains the relation between the different issues of a product that needs to be taken into account during the developing process. (Johannesson et al. 2005)]
2.3. Methods and tools to find product requirements

These are methods that are used to find the requirements and demands of the customers and users and thereafter combine them into a final specification of requirements. It is very important to find all the demands on the product to be able to develop a successful solution. (Ulrich and Eppinger. 2008)

**Literature studies** - Literature studies are used to gather information about a specific area. Some knowledge might be of great importance and literature studies is a good way to increase the developer’s expertise.

**Market research** - Market researching is a good method to get an overview of the competitors’ products and solutions. Other companies’ products are looked into and analyzed to see what the basic functions of the product are and what are the additional extra functions. Extra functions are added to distinguish the product to gain customers. (Ulrich and Eppinger. 2008).

**Semi-structured interviews** - There are three types of interviews, structured, semi-structured and unstructured. A structured interview requires well prepared questions and no questions or answers outside of these will be taken into account. An unstructured interview is in contrast very open and reminds of a regular conversation, the interviewer and the interviewed together decides in what direction the interview is leading. A mixture of these two is described as a semi-structured. (Gillblom and Toivonen. 2011, Creusen et al. 2012)

**Focus group** - A focus group consists of around 6 to 10 persons discussing a certain topics or products. The people involved in the focus group are often very engaged and interested in the discussed area. (Creusen et al. 2012).

**Survey** - A survey is a quick way of collecting information from a wide amount of people. Surveys are however not recommended by Ulrich and Eppinger (2008) in the beginning of the process. But they are often used later on in the process to gather a large and statistically good data. (Ulrich and Eppinger. 2008)

**Lead users** - A lead user is described as a person with either personal needs of the developed product or as someone with very advanced knowledge of the subject. (Creusen et al. 2012).

**Specification of requirements** - A specification of requirement is used to specify the demands of a product. The specification includes demands from custom-
ers, assemblers, regulations and the company itself amongst other. The demands are found through workshops, surveys or other information gathering methods. (Ulrich and Eppinger. 2008, Johannesson et al. 2005)

2.4. Methods and tools for generating ideas

Idea generation is normally referred to as when a wide range of solutions are being developed with the intention of solving the given problem. The generating process can be helped by different creative methods to increase the numbers of solutions. Idea generation also includes combining ideas with each other in a complementary way. (Ulrich and Eppinger. 2008)

**Brainstorming** - The purpose of brainstorming is to come up with as many ideas as possible. Important is to start by setting some boundaries of what the idea will solve. Several ideas is then sketched down rapidly. Some ideas are being combined and built on to creating a wide number of different solutions. (Ulrich and Eppinger. 2008, Gillblom and Toivonen. 2011)

**Mindmaps** - Mindmaps is a way of mapping up all the ideas to put them in relation to each other. It gives the user a quick overview of what parts that are missing and where to focus next. (Ulrich and Eppinger. 2008)

**Imageboard** - Imageboards are used to collect and put together a lot of inspirational material. This gives the user inspiration and a direction of how the ideas and concepts might look. The collected material can be pictures words, design expressions or competitive products. (Ulrich and Eppinger. 2008, Johannesson et al. 2005)

2.5. Methods and tools to choose the best concept

To evaluate and eliminate concepts that are the most versus least feasible concept screenings and scorings are commonly used. These two methods are objectively analyzing the concepts based on the specification of requirements. SWOT-analysis is a more subjective way of analyzing concepts. (Ulrich and Eppinger. 2008)

**Concept screening** - Concept screening is a concrete method where requirements and possible concepts are being weight to each other. One concept is chosen as referral concept and is set to 0. Other concepts are then being compared to the referral concept, giving a “+1” if better, a “-1” if seen as worse and a “0” if it is supposed to be equal. The points of the concepts are summarized and the concept with highest score win. Often, that winning concept is chosen as referral
concept and the screening is made once again to secure the results. (Ulrich and Eppinger, 2008).

**SWOT-analysis** - A SWOT-analysis is a way of observing a product’s strengths (S), weaknesses (W), opportunities (O) and threats (T). SWOT-analyses are subjective and based on the user’s earlier knowledge. (Johannesson et al. 2005).

### 2.6. SCRUM - an agile development process

An agile process includes a short-term planning and is described by Highsmith (2004) as a process where each iteration add some information or functionality to the final product. A widespread agile process mostly used for software development is called Scrum. (Schwaber and Sutherland, 2013)

The first thing to do when using Scrum is to develop the product backlog. The product backlog is the core document with all the requirements of the project. The product backlog is developed and modified throughout the whole project and is considered as a dynamic and always changing document. The requirements, features, functions and enhancements are listed in the product backlog and these will be changing as long as the product exists. The development is divided in a specific number of iterations, called sprints. During a sprint is one part of the product chosen to be focused on. Every sprint starts of with a planning meeting where the sprint backlog is created. The sprint backlog includes a sprint goal and some specifically chosen requirements that will be kept in focus during the sprint. During the sprint the sprint backlog changes when new requirements are added and some are removed. The result of the sprint is a document called increment. The increment corresponds to the final sprint backlog when all changes has been done. (Schwaber and Sutherland, 2013)

### 2.7. Human values

For people in general one could say that there are some things in life that we all need. Basic needs can of course be associated with food and water. In a semi-structured interview with a designer at Linköping’s University were other human values explored. Eklöf (2014) argues that these needs are not the only ones. There are also needs that are more subjective and vague. For example, all people needs to be acknowledged and noticed by others in their surroundings. Eklöf (2014) claims that a good product is the one fulfilling these subjective human demands. Following figure (figure 2) summarizes these seven basic subjective needs brought up by Eklöf (2014). Each of the needs are symbolized as patterns that exist in nature. Cracks in the earth symbolize the safety that people need in their life. The stripes on a zebra symbolize visualisation and the importance of
getting attention. People feel happy if other people listen to them, their thoughts and demands. Bubbles are seen as the importance of meetings between people or meetings between people and technology for example. Everyone wants to feel that they contribute. Spirals in shells are used to exemplify the development a human does during her life. The chaos exists everywhere in the world and so does it in human lifes. We need to feel uncertainty sometimes in order to feel certain in other situations. Symmetric shapes are used to symbolize the balance people need in their lifes. Finally are waves and sand dunes used to exemplify the feeling of unifying that we all need. People does want to be a part of something, for example a community or a family. (Eklöf. 2014)

![Diagram of seven human values](image-url)

*Figure 2. Explains the seven human values proposed by Eklöf (2014). These are durability, visualization, contribution, development, uncertainty, balance and unify.*
3. Different approaches to a sustainable production

This chapter will explain some ways of how the production can be sustainable. It will bring up how a product's energy can be lowered, how to avoid unnecessary waste and prevent the surrounding from hazardous material. Finally will this chapter also bring up how these ways can be combined and developed to create a sustainable society.

The vision of a sustainable society has been growing during the last couple of years. It's a very wide area and sustainability touches upon everything from economical, societal and environmental aspects. Many new theories and methods have evolved because of the increasing interest of reaching a sustainable society.

Traditional and more classic approaches include waste treatment, recycling and energy consumption. To achieve less waste can the waste management hierarchy from EU be used. To facilitate recycling can the method design for disassembling or design for recycling be used and with a life cycle assessment (LCA) can the energy consumption for a product's phases be calculated. (Ulrich and Eppinger. 2008, Bevilacqua et al. 2007)

A more innovative approach is the Cradle to Cradle-thinking. That not yet have any specific method to use but can be used as a vision when using a mixture of several other eco-design methods.

3.1. Lower a product’s energy use

One approach to improve a product’s environmental impact has for a long time been related to lower its energy consumption. To do this was the EU directive on eco-design introduced in 2005, that prohibit the products with the largest energy consumption. The eco-design directive applies to all energy-related products being produced in more than 200.000 units a year. (Energimyndigheten (a). 2013, Directive 2009/125/EG). To encourage companies to further decrease the energy consumption on their products was also energy labels introduced. The energy labels allow customers to compare the energy consumption of different products in order to guide them to buy the best one. (Energimyndigheten (b). 2013).

To calculate a product’s energy consumption is often the method LCA used. The LCA is an analysis and evaluation of the product’s total environmental impact during the whole life cycle, including production, distribution, use, disposal or material recycling and reuse. The LCA is often focused on energy consumption but may also be used to calculate CO₂-emissions or the water usage. The analysis is done in a comparative way in order to chose the least affecting option and to identify problem areas. For doing the comparison a great range of data needs to be collected which may cause some problem and also be very time con-
suming. Normally, the LCA differs between active and passive products. Active products have largest impact on the environment during their usage phase (e.g. car, lightning) and the passive have a greater impact during the manufacturing (e.g. packages, disposable products). (Ulrich and Eppinger. 2008)

Disadvantages with LCA is that it is a very time consuming method and it is necessary to collect a very large amount of values. A less demanding method is the environmental effect analysis (EEA). The EEA is a more subjective method based on the users earlier knowledge and thoughts. It should be used early in the development and takes into account legislation, environmental policy and the markets opinion about the product’s environmental impact. Thanks to this the actual impacts can be judged and the best solution be chosen. (Ulrich and Eppinger. 2008)

3.2. Preventing waste

One of the most well-known EU directives might be the waste management hierarchy (see figure 3). It gives guidelines about how the growing amount of waste shall be handled. The most preferable way of handling waste is in the top and the worst-case scenario is in the bottom. The first step is of course to prevent the waste to even be produced. The second till the fifth step describes how to handle the already produced waste. The second step is to reuse the waste, the third to recycle the waste, the fourth to recover the waste (often heat recovery) and the last and fifth step is to disposal the waste. (Directive 2008/98/EC).

A clarification need to be done between the second and the third step since the word recycling is commonly used also for remanufactured and reused products. There are many ways of reusing or recycling components and materials.

Ordoñez and Rahe (2012) are in their article interviewing designers in five different countries to put together five categories of recycled, remanufactured and reused products made of waste material (WM). These categories are: material recycling, new materials from waste, redistribution, new products from waste and design for end-of-life.

![Figure 3. EU’s waste hierarchy. Reduce, reuse and recycle are the steps preferred. The recovery and disposal steps are tried to be avoided. (Directive 2008/98/EC)](image)
The material recycling includes paper, glass, aluminium, metal, PET and other plastics. These materials are industrially re-manufactured and the material is used to produce new similar products as before the manufacturing. This way of recycling is well known and is, to various extents, a part of the society and the countries system to handle waste. (Ordoñez and Rahe. 2012).

Material recycling allows large-scale production and is an easy way for taking care of disposals, both for recycling companies and for users, as it doesn’t require so much of the users. The problem Ordoñez and Rahe (2012) mention is that material often gets down-cycled. Down-cycled here means the material loses its properties because of the re-processing and sometimes blending with other materials. Of course, material recycling is in many cases better than using new raw material, given that the process of recycling is not more energy consuming than the extraction of the raw material. (Ordoñez and Rahe. 2012).

The new materials from waste are often composite materials, which means they contain a mixture of different materials. They mention an example, Polyplank, a material made of recovered thermoplastics mixed with wood fiber from a wood-mill. (Ordoñez and Rahe. 2012)

These products are, in difference to products made from recycled material, possible to use in new product areas (Ordoñez and Rahe. 2012). Ordoñez and Rahe (2012) write that the “eco-friendliness” of the new materials from waste can be discussed but that it does provide an alternative for material disposal.

Redistributed products is often connected with repositioning the products on new markets, for example second hand shops or charity organizations. Sometimes this also includes repairing or modifying the products in some way. The repairing and redistribution of products results in a more time consuming and specific process and takes away the advantages of industrialized, large-scale processes. The authors of the article also raise the question of whether this will reduce the need of new produced products. Additionally, one could not be sure of what will happen to the products once they have been bought from the second hand shop etc. (Ordoñez and Rahe. 2012)

One could also argue for the fact that this kind of redistribution only works for some product areas. Many people find it okay to buy clothes and furniture from second hand shops, since the age adds value to the product (i.e. vintage) but not as many people would buy a computer from the early 90’s.

The authors refer to the new products from waste as upcycled products. This category contains the products made out of waste to create a whole new type of products. They mention bags made of woven used magnetic tape and cups made of rest material from production as two good examples. But Ordoñez and Rahe (2012) also points out a problem with this kind of products; they are normally
only produced in a small scale and very often hand-made. This resulting in difficulties if you want to be able to handle the large amount of existing waste.

In **products designed for end-of-life** the designers have taken into account the end-of-life (EOL) stage of the product, planning for it during the product development process. This hopefully leads to less caused waste. However, the design for EOL is a very wide expression and may include both design for material recycling, remanufacturing or a product that is biodegradable. Ordoñez and Rahe (2012) come to the conclusion that design for EOL not will solve the already growing amount of waste but may reduce the problem in the future.

To two first definitions “material recycling” and “new material from waste” are claimed to belong to the third step in the waste management hierarchy, recycling. This does not require the products to be designed in any specific way since the products in this step first are shredded in the recycling process and then separated into different material streams. Almost all of today’s products can be, and are being, recycled in this way. Except of course products containing prohibited and hazardous substances.

The later three definitions are claimed to belong to the second step in the hierarchy, reuse. Depending on how good the products was designed from the beginning they can be handled different. To design for reuse one can use the tool Design for X. Where X can stand for environment (E), disassembling (D) or recycling (R). Basically, DfX follows these general steps:

- Gather and present information about processes and products
- Analyze and explain the relationships between these processes and products
- Measure performance
- Highlight the strengths and weaknesses of the these
- Evaluate the reasons for the weaknesses and strengths
- Provide a solution for how to improve the design
- Predict the effects of the redesign
- Carry out the redesign and its improvements
- Iterate the decisions throughout the process

(Gillblom and Toivonen. 2011)

Preferably, the products that should be designed for reuse are reused. In many cases though this do not happen. Since the amount of waste today is huge and still growing it is impossible for the recycling facilities to handle every product separate to disassemble it. Products designed for disassembling often require manual handling. That requires a lot of time and is not feasible for the recycling companies, resulting in that the products designed for manual disassembling instead are shredded to save time and money. For example, the famous chair from Herman Miller are designed so that all parts can be manually separated
from each other but in reality this does not happen. When the chair gets to the recycling facilities it is shredded together with other products. (Gillblom and Toivonen. 2011, Flinck. 2014). It can therefore be discussed whether the products shall be designed for disassembling or designed for material recycling and shredding.

However, in the automotive area are some parts, for example the windows, removed before shredding and material recycling to facilitate for the mechanical sorting. A project called Realize, that is a part of the MISTRA Closing the loop initiative, is evaluating if further separating the parts will give better and more homogenous waste fractions after the mechanical sorting. If that would be the case then it can be claimed that it is good to design for disassembling, even if the parts in the end are being material recycled instead of reused. They have shown that through changing the aim of the disassembling they can reduce a lot of time. Instead of separating the parts in the car for remanufacture and reuse, during one and a half hours, they separate them for the shredding, in four to five minutes. The reason for the decreased time is that if the components are being shredded, they can be handled more roughly during the disassembling. (Cullbrand. 2014)

3.3. Recycling companies and product developers

To avoid that products are being designed for disassembling and later material recycled – as in the case of the Herman Miller chair – Stena is working on informing designers on how the recycling process looks like. Gillblom and Toivonen (2011) proposed a service where manufacturers can get their product evaluated by Stena and then make it more suitable for recycling. The relation is described in figure 4.

Figure 4. Proposal on how manufacturers and the recycling company Stena could cooperate. (Gillblom and Toivonen. 2011. pp. 12)
3.4. Reducing hazardous and critical substances

Since we get more knowledge about how different substances are affecting the nature and the humans some materials we used to use are now prohibited. Research are done continuously on all materials, both new and old ones to see how the impact us. Materials that are stated as hazardous are being restricted by some EU directives. The RoHS (restriction of hazardous substances) and REACH (registration, evaluation, authorisation and restriction of chemicals) are two. The RoHS-directive was introduced by EU in 2006 and prohibits the use of EEE with more than 1 promille of Hg, Pb, hexavalent chrome (Cr6+), polybrominated biphenyls (PBB), polybrominated diphenyl ethers (PBDE) and 0.1 promille of Cd of the weight of the product. Companies distributing EEE are responsible for not introducing products that exceeds these limits. (Kemikalieinspektionen. 2012).

REACH set standards on how chemicals shall be registered in order to be allowed. All substances corresponding to more than 2 % of a product’s weight or to 1 ton material a year must be registered. To register a substance the company has to attach a description and classification of the usage, manufacturing and possible emissions. Chemicals should be evaluated depending on their affectance on human health, physical and chemical risk, environment and content of bioaccumulative substances as PBT. Important factors for the evaluation are the risk of bioaccumulation, exposure of material and the amount of the substance. Hazardous substances are defined as: explosives, oxidizing, flammable, toxic, health damaging, corrosive and irritating substances. Many plastics are considered flammable since they easily catch fire and continues to burn when the source of is removed. (Regulation 1907/2006.)

Other restricted materials are the materials brought up on EU’s critical raw material list. These are, among others, antimony, indium, cobalt and magnesium. These 41 materials are restricted due to their limited availability and their affectance on the world economy. (Raw material supply group at the european commission. 2010)

3.5. Cradle to Cradle’s vision

Cradle to cradle (C2C) defines a society built together with nature, instead of working against nature as something that needs to be conquered. Ever since the industrialization humans have tried to overcome the nature itself resulting in a decreasing amount of resources, a destroyed nature and a growing amount of waste. In 2002 McDonough and Braungart released their book “Cradle to Cradle: Remaking the Way We Make Things” where they launched the expression C2C. With the vision of C2C they go from the industrialized society built on
eco-efficiency and defines a society based on eco-effectiveness. They mean that the commonly used expression eco-efficiency only makes things less bad, for example, a car is designed to emit less CO$_2$, the result is that the car still will emit CO$_2$ and therefore be no good. In comparison, eco-effectiveness is when you do something that is 100 % good. 100 % good is defined as a product with no environmental impact, for example, if you develop a bike instead of a car. Or even better, a product with a positive environmental impact, for example develop a car that emits fresh air to the surroundings. (McDonough and Braungart. 2002). See figure 5.

With the intention of doing 100 % good they also introduce the expression “waste equals food” meaning that nothing is waste. Everything must be designed for another lifecycle, going from cradle to cradle. To make this possible, every material we use need to be defined as a technical or biological nutrient. These nutrients belong in two separated spheres, see figure 6. (McDonough and Braungart. 2002)

To the technical sphere can the plastics, metals, chemicals and other non-biodegradable materials be counted. To the biological sphere belong the biodegradable materials, such as wood, paper and biodegradable plastics. The technical nutrients will be recycled over and over and the biological nutrients will degrade to soil over and over again. These spheres of material should not be mixed, or the material will risk to be down-cycled. Down-cycling means that the material loses its good properties and decreases in quality. In contrast, up-cycling, is defined as when the material can be used with the same quality or even better compared to before the recycling. Another important principle of C2C is the use of renew-

Figure 5. The upcycle chart explaining how a product can be improved. An existing product is being investigated and then optimized in order to create a positive impact of the surroundings. (MBDC. C2C Framework. 2013)
able energy, and the importance of linking the economy, environment and social fairness together. (McDonough and Braungart. 2002)

In the book “The upcycle” by McDonough and Braungart (2013), they go even deeper in how it will be possible for companies to achieve the upcycling. Here they define 6 steps when developing a concept.

1. Establish the values for your company
2. Establish the principles of your company
3. Develop goals to realize the values
4. Develop strategies to meet the goals
5. Develop tactics to execute the strategies
6. Develop metrics to measure the effectiveness of the tactics

They draw attention to the values within the company by saying that if you don’t start with the values, it’s easy to forget them. The measurements will be done eventually, since you always have to measure how things goes but without stating a value from the beginning the best solution might not be found.

The C2C Products Innovation Institute is certifying products that fulfil the requirements of C2C. The criterias for C2C are attached in appendix A. For this they have five standards, Basic, Bronze, Silver, Gold and Platinum. For receiving a standard the product has to be evaluated in the five categories: material health, material reutilization, renewable energy and carbon management, water stewardship and social fairness. For all levels the materials included in the product have to be separated in biological and technical nutrients. Nutrients from each sphere shall be easy to disassemble from each other to facilitate recycling. A list
of banned chemicals are being used to guide the development team when choosing materials. A material containing more than 1000 ppm of the banned material should be phased out to achieve the preferred eco-effectiveness. This is important since the C2C vision is based on ecological, economical and social fairness, meaning that neither the workers and the users nor the environment (animals, water, air) should be exposed for these banned materials if the product is 100% good. (C2C Products Innovation Institute (a). 2011, C2C Products Innovation Institute (b). 2011)

A problem brought up by van der Grinten (2008) is that concept of C2C are often being too much of a vision. This is also claimed by recycling companies who are the ones working with the materials in the two spheres in the reality. (Flink. 2014)
4. Electrical and electronic equipment

In this chapter will electrical and electronic equipment be treated. How it is recycled and certified will be brought up as well as some examples on how computers, one of the most common products, are affecting the environment and how we can affect them.

The European Union (EU) has defined electrical and electronic equipment (EEE) as "equipment which is dependent on electric currents or electromagnetic fields in order to work properly" (Directive 2012/19/EU, pp. L 197/43). EEE could be everything from vacuum cleaners and computers to electrical tools, garden equipment or kitchen devices. All EEE must have a visible label describing preferred use voltage, for example 230 V~50 Hz, and maximum effect output. In some cases must also the international protection rating (IP) be attached. IP is a safety directive for dust and water. (Elsäkerhetsverket. 2013)

When the EEE does not work or are thrown away by other reasons by its user it’s referred to as waste electrical and electronic equipment (WEEE). (Directive 2012/19/EU). Of the total plastic waste in Europe the EEE generates around 5-6 %. (Plastics Europe. 2012).

4.1. Recycling EEE

Stena Recycling, one of the leading recycling companies in Europe, take care of 2,5 millions tones of waste every year, collected from companies, authorities and organizations. Of course, they are also handling the WEEE. (Stena Recycling. 2011).

The WEEE arrives at Stena's facilities in a large stream of different and unsorted products. The first step in the process is the decontamination where all hazardous material is removed, for example the batteries in computers, oil, lead and toners. The LCD-screens are handled separate and one by one because of lamps containing mercury. The main stream of waste goes through the precious metal recycling (PMR) and the plastics recycling center (PRC). The entire waste stream goes through a shredder to be divided in smaller material fractions. A magnet drum is used to separate copper and ferrous from other fractions, the copper is later sorted out by hand from the ferrous. The other fractions are separated from each other by size and goes then to an eddy current separator that takes away aluminium and boards from the main stream. The aluminium and boards go through an optical separator. The main stream now mostly contains different plastic fractions; these are separated from each other by flotation. In the flotation the plastic with high density sinks while the one with low stays on the edge of the water. This process results in one stream of recyclable plastic, one with brominated plastic and one fraction with several plastics that can not be separated. The fraction that can not be separated is called WEEE Plastic. In the end of the recycling process the WEEE has been divided into ferrous, copper,
aluminium, circuit boards, precious metals (inclusive copper), recyclable plastics, brominated plastics and the WEEE Plastic. (Stena Recycling. 2013. Stenvall. 2013)

The mechanical sorting can’t provide a 100 % pure material and the rest fractions end up in the WEEE Plastic. The WEEE Plastic mostly contains of different plastics but may also contain other materials as copper, lead, cadmium and tin. It is more feasible for the recycling companies to try to sort out pure metals than pure plastic, resulting in this plastic fractions with small amounts of metals in them. The price for selling recycled plastic is really low and may be compared to the prize of biofuels and fuel oils. (Stockholmsregionen avfallsråd. 2010, Stenvall. 2013, Flink. 2014)

For the EEE it is therefore seen to be an increasing market for standardized plastic housings which facilitates for recycling and disassembling, resulting in better quality for both metals and plastics. One example is computers designed in a grey-scale ABS plastic for easy disassembling which would be very suitable for a recycling industry. (Stockholmsregionen avfallsråd. 2010). Other existing products are plastic details in the automotive industry made out of 60 % recycled plastics. These details are being produced by the company Luxus and sold to several huge car companies. (Engineering materials. 2013).

4.2. Product certifications for electronics

To facilitate for the customers when deciding what EEE to buy several certifications have evolved. Two well-known and widely used certifications are EPEAT and TCO Certification. (EPEAT (a). 2014, TCO Development (a). 2014)

EPEAT, stands for Electronic Products Environmental Assessment Tool (2014), was initiated in the beginning of 2000 in order to help procurement officials when choosing environmentally friendly electronic equipment. It is a globally used tool and is today used in 42 countries. To be registered to EPEAT the product has to fulfill all the required criterias, this will give the product a Bronze certification. In order to gain a Silver or Gold certification the product also has to fulfill some optional criterias. For the Silver level 50 % of the optional criterias have to be reached and for the Gold it is 75 %. The criterias are divided in following 8 categories including 24 criterias.

- Reduction/elimination of environmentally sensitive materials
- Material selection
- Design for end of life
- Product longevity/life extension
- Energy conservation
- End-of-life management
• Corporate performance
• Packaging

The 24 specific criterias can be seen in appendix B and a clarifications of the criterias may be found on the EPEAT homepage. (EPEAT (a). 2014)

The criterias includes both very specific issues as “the product does not consist of cadmium” and wider issues as “the manufacturer needs to publicly demonstrate a policy consistent with ISO 14001”. The EPEAT criterias also evaluates service-related issues, as possibilities of take back products and recycling. Energy Star, a global energy program is also included in the EPEAT certification. On the homepage of EPEAT one can also find information about every certified product and get access to their criteria scorings. (EPEAT (a). 2014, Energy star. 2012)

TCO Development (2014) is a part of the Swedish union TCO (The Swedish Confederation for Professional Employees) and has since 1992 worked with labels for EEE. It is a label similar to the EPEAT but includes requirements of ergonomics, safety and radiation. One of their latest certifications, for computer displays, also consider the use of recycled plastics. The display should consist of at least 85 % recycled plastic, have a halogen free display and additionally fulfill some ergonomic requirements as “have a cable cover or an integrated cable holder”. (TCO Development (a). 2014)

4.3. Computers

Computers and other ICT (Information and Communication Technology) are often associated with a fast growing market and a rapid development of new technologies. Due to the large quantities of computers that are produced every year the ICTs are causing several environmental and sustainability problems. From extraction of “conflict” minerals and usage of a huge demand of energy to resource loss since only a small part of the computers are recycled. Lately, a lot of articles have been written about the environmental impact of the computers. Fitzpatrick et al (2014) bring in their latest article up the problem of only looking into the energy consumption or global warming potential when analysing the impact. The loss of resources are however not looked in to, resulting in a distorted picture of the computers’ total impact.

They point out some decision points in a computer’s life cycle where, depending on what decision is taken, the environmental impact can vary widely. In figure 7, the decision points, the decision makers and the preferred decision can be seen.

The first important decision is based on the user’s satisfaction with the computer. The longer the computer stays with one user the better. This time can be
increased by offering services to the user and by letting the user get an emotional attachment to the computer. When the user decides to buy a new computer a decision of whether give it away or store it has to be done. Preferable, the user give it away to a collecting facility where it can be fixed and passed on to a second user. To help the user make the right decision, information could be provided from any formal channel.

The second decision point is the responsibility of the collecting facility, they have to decide whether the computer should be refurbished, sorted as waste and recycled or sent to disposal. Refurbishment or possibly recycling is the preferred choices here. Fitzpatrick et al (2014) writes that if there is technically, economically, environmentally, socially and legally desirable to recycle the product then it will be. It is therefore important to keep these factors in mind when designing the product, for example through using the design principles of DfE.

If the refurbish site decides to refurbish the computer, then, should it be made manually or mechanically? To manually disassemble the materials are stated to be much more effective, resulting in higher amounts of clean materials. But, as mentioned earlier in the thesis, this might not be commercially possible when it comes to such large quantities as WEEE.

Another of the decision points are based on the market potential of the recycled material. If the recycled material doesn't have a potential to be sold, such as the plastic fraction from the housings, the recycling facilities do not see any reason for taking care of the material. (Fitzpatrick et al. 2014).

If the decision makers (user, collecting facility and recycling facility) can be guided on how to make the right decisions, a lot can be won in environmental
impact. Fitzpatrick et al (2014) states some design principles that might affect the decision makers and help them do the right choice. These principles are:

- Emotionally durable design
- Service offerings
- Easy to upgrade, refurbish
- Easy to disassemble
- Minimal negative value fractions

Where the first two corresponds to the first decision maker (the user) the third to the second decision maker (the collecting facility) and the last two corresponds to the third decision maker (the recycling facility). (Fitzpatrick et al. 2014).

The five principles are used when analyzing a small personal computer and its inner components. A normal stationary computer consists of 8 components, a processor (CPU), motherboard, memory (RAM), power supply unit, hard drive, cooler, optical drive and a computer case. The processor is the one part deciding the performance of the computer, depending of what it shall be used for. A compatible motherboard is then chosen. Thereafter can the other components be decided, these have to be compatible with the motherboard. See figure 8 below.

The computer stores every data that the user needs on the local hard drive. Depending on the CPU the computer can handle heavier CAD-programs and games or simpler text handling programs as Word or Excel. Normally the stationary computers have better CPUs than laptops for example. (Kjell&Company. 2013) Since the normal user only need simple programs, laptops are being seen as a growing market. Advantages with laptops are their easy handling and flexible use since they are not as large and heavy as the stationary computers. Additionally, lot of people prefer the thin and simple design, free from cables and easy to keep clean. (PC Online. 2013).
5. The material WEEEBR

Researchers at Chalmers University in Gothenburg have come up with a new type of material made out of the discarded material WEEE Plastic. The material is in the beginning of the developing stage and is still under evaluation. Here follows a description of the material and its properties as it was in the beginning of this project.

Further information about the WEEEBR can be found in “Influence of repeated recycling and aging effects on mechanical performance of WEEEBR (waste electrical and electronic equipment blend recycled)” by Yu (2014) and the thesis “Electronic Waste Plastics Characterisation and recycling by Melt-processing” by Stenvall (2013).

WEEEBR stands for a plastic made from the Blended and Recycled Waste from the plastic fraction coming from Electrical and Electronic Equipment. Like other plastics the WEEEBR consist of polymers. The polymers are mainly produced by crude oil, primarily in Asia, and seen as a non-renewable resource. But producing plastics from agriculture, bioplastics, in order to make them renewable are under development. (Ashby. 2013, Bruder. 2012)

To manufacture WEEEBR the first step is to sort out the waste plastic from electrical and electronic equipment (WEEE Plastic) from the WEEE (all waste from electrical and electronic equipment) at Stena’s facilities. The WEEE Plastic, that comes out of the industrial large-scale recycling process is then further treated by Chalmers. The manufacturing at Chalmers have until now been done in a small-scale laboratory environment. Data on industrial processes for that treatment was therefore not available. However, the WEEE Plastic was melt-filtered and large incorrect pieces (e.g. metallic pieces) sort-

![Figure 9. A flowchart showing how the material from electrical and electronic equipment passes through the sorting process at Stena’s facility resulting in the problematic plastic fraction. The plastic fraction is then further sorted, washed and then melt-blended resulting in the new material WEEEBR. WEEEBR can be used as other plastics, for example by being injection moulded.]

...
ed out. The blended plastic pieces was then melt-blended and processed to small pellets that can be used as virgin plastics. See the flowchart of the plastic in figure 9. (Stenvall. 2013, Stenvall et al. 2014)

The WEEE Plastic from Stena may vary depending on the input material. But the content of the fraction being analyzed in the thesis written by Stenvall (2013) is presented in figure 10. The WEEE Plastic can generally be said to consist of 42 % HIPS, 38 % ABS and 10 % PP. The rest 10 % are divided between another 5 % mixed plastics and the last 5 % are represented by various metals and other materials.

![Figure 10. Describes the consisting part in the analyzed fraction of WEEE Plastic. The fraction consists of 42.2 % HIPS, 38 % ABS, 10.4 % PP and the last 9.5 % are divided between several different materials. (Stenvall et al. 2013. pp 75).](image)

It is calculated roughly that for one kilo plastic, two kilos of crude oil is needed. So, one could argue that even though the recycled plastics loses some properties it is known to be better and more energy efficient than producing new plastic. (Stockholmsregionens avfallsråd. 2010) Additionally, the CO₂-emission also decreases when recycling plastics. One kilo recycled plastic causes two kilos less emitted CO₂. (Lunds renhållningsverk. 2009).

By doing some rough calculations it was found that this was true also for WEEE BR. The CO₂ emission for WEEE BR was 1.3 kgCO₂/kgWEEE BR and the energy consumption was 32 MJ/kgWEEE BR. Compared to ABS that emits around 3 kgCO₂/kgABS and has an embodied energy at 95 MJ/kgABS.

Additionally was the price for WEEE BR calculated to around 12 SEK/kg. Virgin ABS costs around 20 SEK/kg. The calculations can be seen in appendix C.

WEEE BR is a thermoplastic and are like other thermoplastics easy to manufacture and may be remelted more than one time. (Ashby. 2013, Bruder. 2012). How well WEEE BR will work in a second recycling loop is however not known.
Nor is the aging of WEEEBR and its impact investigated.

Other technical properties are under evaluation in the parallel thesis written in by Ze Yu (2014) a student in material engineering. Some properties are however summarized in appendix D. The same properties for ABS are included to make it easy to compare the two materials.

As can be seen in the material sheet for WEEEBR it is, as other recycled materials, not as resistant as virgin materials. The properties have degraded because of the recycling process and are not as technically good as virgin materials. WEEEBR is more sensitive to mechanical fatigue and impacts, UV-light and chemicals.

WEEEBR has a service temperature on around 60 to 80°C, that compared to other plastics is very normal. The plastics HIPS, ABS and PP are normally not used in temperatures higher than this and neither should the WEEEBR be.

The colour of the WEEEBR is dark grey. Uncertainty of the input material also causes a slight uncertainty and variation of the colour of WEEEBR. The colour might be possible to modify but this would need further investigation, which was not done during the time of this project.

WEEEBR does not consist of any of the prohibited materials in RoHS. But some low amounts of Antimony (Sb) were observed. Sb is one of the materials mentioned on the list of critical raw materials proposed by EU. (Kemikalieinspektionen. 2012, Stenvall. 2013). Around 1000 ppm PVC have been observed. PVC is a material that is banned by C2C. (C2C). A total list of the materials can be found in appendix E.

The material WEEEBR is based on the input of WEEE Plastic. Around 5 - 6 % of the produced plastic in the world goes to EEE. (Plastics Europe. 2012). Exactly how much of this plastic that is recycled are not known but in Europe is about 26 % of all the produced plastic recycled. To keep producing WEEEBR there must be a continuous flow of old EEE to the recycling companies. But since both plastic production and EEE are growing industries there should not be a problem getting new input material. (Plastics Europe. 2012, Stenvall. 2013).

Material recycling has during the last years increased in importance. It is one way of handling the growing amount of waste. The material recycling is supposed to reduce extraction of raw material, to save energy when processing already existing material instead of raw material and to reduce the difficult and sometimes hazardous disposal of existing material. Processing of recycled material is also said to emission less air pollutants. An example from the metal sector shows that a recycled aluminium can releases 20 times less air pollutants than the process of producing a new one. (Lunds renhållningsverk. 2009).

Since the thermoplastics can be re-melted they are good for material recy-
cling and can be reused when making new plastic. Unfortunately the recycling cannot be made an infinite number of times since the material loses some of the properties during the process. (Bruder. 2012, Lunds renhållningsverk. 2009)

WEEE BR can as other thermoplastics be further treated and processed by injection moulding, blow moulding or extrusion. (Stenvall et al. 2014)
6. Implemented process

This chapter will explain the methods that have been used to fulfil the aim of this thesis. The project was divided in three phases. The first two phases are quite experimental, where the author develops a product based on WEEE BR by mixing well-known development methods. The third phase is where the author analyzes the development process and creates a recommended generic method for future products based on a material.

During the writing of this theses the process seen in figure 11 have been applied. The project started with a startup meeting for all involved and was followed by a planning phase (not included in figure 11).

The aim of phase 1 was to choose a type of product and the aim of phase 2 to develop that to a final product. Phase 3 was an analysis made over phase 1 and 2 to find out where the largest challenges were during the development process. The conclusions from that analysis, phase 3, was summarized in a proposed method.

The first phase was based on the development method called Scrum and the second on Ulrich & Eppinger’s (2008) product development process. A mixture of methods and tools have been used many times during the phases resulting in a very iterative working progress.

In a typical product development process the main purpose of what is going to be designed is known in the beginning of the project. (Ulrich and Eppinger, 2008, Johannesson et al. 2005) In this case is only the material known and not a demand on the market. Established methods for this kind of processes do not exist, which has allowed an experimental and creative attitude throughout the first phase of the project. As in Scrum was phase 1 in this project divided in three
sprints. Figure 12 shows the three sprint goals (pink) and the different methods used to realize each sprint goal. The final result is a specification of requirements for the chosen product. A more specific description of phase 1 is attached in appendix F.

Phase 2 was similar to a normal product development process described by Ulrich & Eppinger (2008), see figure 13. However, not all steps were included in the project. The result from phase 1, a specified type of product, was carried through the first three parts of the process. First a market research, then were the requirements specified and at last were concepts developed. The concepts were not eliminated to one final concept, instead were several concepts kept and used as examples in phase 3. Neither was a final detail design done.

Figure 12. A schematic figure showing the methods used during the first phase in order to find a suitable concept for the WEEEBr.

Figure 13. Describes the five stages included in the product development process proposed by Ulrich and Eppinger (2008). This project was carried through the first three parts during phase 2.
Phase 3 included an analyze of phase 1 and 2. The challenges that was met during the development process were questioned and conclusions were summarized in a generic flow chart with guidelines on how to avoid the previous challenges.

6.1. Methods used during the project
The methods that have been used throughout the project’s process are explained here.

Studying literature - Phase 1 and 2
Most of the literature, books and articles were found through searching the databases of Linköping and Chalmers University. Words and phrases that have been used brought up following areas:

- Environmentally friendly products, computers, electronics
- Cradle to Cradle
- Choice of material
- Plastics
- Recycling processes
- Electrical and electronic equipment
- Certifications for electronics and ecolabels
- Eco design and product development

The material database CES was used for collecting information about specific material properties. CES can be found on the computers of Chalmers and Linköping Universities. Material safety data sheets (MSDS) were searched for when researching material properties.

Research and analysis of existing market for plastics - Phase 1
The market research were done through searching openly on internet and through studying existing companies’ range of products. The swedish household companies Clas Ohlson and SIBA were the companies used for a more thoroughly evaluation on their product range. The products were compared to eachother both by price, marketing strategies, functions and how well they fulfilled some specific certification criterias. SWOT-analyses were used as a tool when making the analyze.

Analysing the properties of WEEEBR - Phase 1
The properties of the WEEEBR were analyzed due to environmental impact, technical avantages and disadvantages and human impression. The environmental impact was calculated and the result compared to ABS. The technical
properties was primarily compared using values from the material database CES available at Chalmers University. MSDS from plastic companies were used to see where and how other plastics are used today. Human impression was also included as van Kesteren et al (2007) brought up the increasing importance of these factors when designing new products. SWOT-analyses were used as a tool to summon up the comparison. The theories of the design strategy C2C was used inspirational and held in mind while doing the analyses.

Analyzing the WEEEBR from a company’s point of view - Phase 1
The WEEEBR was analyzed trying to imagine how a plastic company would react if they were offered to replace their existing plastic production with WEEEBR. Since ABS was the material assumed to have most in common with WEEEBR that was chosen as a reference material.

Contacting stakeholders and other professionals - Phase 1 and 2
Semi-structured interviews have been held with professionals from companies, universities and other stakeholders. The interviews were mostly done by phone after a short introducing email that explained the purpose of the interview during which notes were taken. Contact by e-mail have also been used to gather specific information. A list of the people that have been contacted is found in appendix G. The main part of the interviews were held in phase 1 with the purpose of getting a better understanding of EEE industry and the material.

Discussions with the project group - Phase 1 and 2
Discussions with the four project members, Erik Stenvall, Isabel Ordoñez, Sandra Tostar and Ze Yu, were held on a regularly basis which might be compared to a focus group. The discussions regarded new findings in the project and problems that might have come up. During the interviews and discussions notes were made and the most important issues were summarized. The decisions made during the meetings were taken in consensus or by the author of the thesis.

Study visit at Stena Recycling - Phase 1
A study visit at Stena’s recycling facility was done to gather information about the processes. During the visit photographs were taken to document.

Student survey - Phase 1 and 2
The site “Surveymonkey.com” was used to send out surveys to students at Linköpings university. The students studied mechanical engineering and around 300 students were contacted. The aim of the survey was to guide the decision of product and touched upon how the students experienced four different types of
products and their environmental impact. The survey was sent out in the end of phase 1 and collected in the beginning of phase 2.

**Contact with lead users - Phase 2**
Lead users were found on internet forums as “Sweclockers” and were used to gain information about their specific needs and to get information about trends. An account were created at the forum and some questions for discussions were announced. The people that answered were anonymous or writing with pseudonyms. The lead users were contacted in phase 2, when a product was chosen.

**Market research for green products - Phase 2**
A market research was done to compare and find opportunities for the type of product. That market research was divided in three parts, green products, green computers and green casings. The products found were compared due to their price, function, how they were branded as green and also how well they fulfilled some certifications’ criterias.

**Backlog and specification of limitations - Phase 1**
The product backlog were developed during phase 1 and used to limit the types of products suitable for WEEEBR. In Scrum is the product backlog set together to a specification of requirements but in this case it was rather used as specification of limitations. When products had been eliminated based on the backlog were there one winning type of product left.

**Specification of requirements - Phase 2**
Based on the functions and requirements of the type of product was a specification of requirements put together. The functions were decided based on previous market research and on lead users’ thoughts. Human values and environmental aspects were also included. Two specifications were made, one for a more holistic view of the concept and one specified on the type of product and its functions.

**Generating ideas - Phase 2**
Several imageboards were created throughout the project. These were filled with inspirational pictures and ideas about how to solve different problems. These were used as inspiration when doing the brainstorming. The brainstorming was done by the author using papers and sketching materials. The brainstorming sessions varied in time. Mind maps were often used to summarize the solutions. Mainly was the generation done in phase 2 but some ideas also came up earlier in phase 1 when doing the comparison and the research.
7. Analysis of the implemented process

This chapter will discuss the first two phases and evaluate what challenges that were met. Conclusions drawn from the phases and the development of a product of WEEEBR are presented. The analysis was later used as a base for developing the proposed method.

When developing a product from WEEE Plastic, in order to put the material back to the loop, the author met some challenges.

The first phase went on quite good and the information available was enough for choosing what type of product that was supposed to be developed. Using Scrum as an inspiration was a good decision since it was easy to see how to move forward. Scaling down from whole industries to possible products in that industry to a certain type of product worked as good limitations. Scrum worked in a structured way and it would have been difficult to take the step from the WEEEBR to a casing without doing it in different steps (sprints).

Sometimes it was hard to know how much information about the material that actually was relevant. The approach of analyzing the material in a companies point of view, seeing how they would feel about replacing an already existing material was good. That analyze brought up the material’s advantages and disadvantages in a good way making it easier to know what to focus on. Comparing the material in a wider perspective than only the technical properties was also good. From that could conclusions be drawn on why the WEEE Plastic was a material with low value. It was claimed that it is important to know why the material was discarded if you want to bring it back to the loop. The WEEE Plastic was not used because it did not have any technical advantages and it was therefore decided that human values and environmental values should be focused on. The reason for its low technical value was that it had been recycled, degraded and that several materials were mixed together in one. That was one important aspect when designing the final product, to avoid this to happen again.

The backlog was first thought to be used as a specification of requirements but was later seen more as a specification of limitations. After scaling down to the decision of developing a casing the properties of the material was difficult to relate to.

The backlog put together in phase 1 was therefore hardly used in phase 2. One reason for this was that the properties that had been used in phase 1 for choosing product type were not relevant when designing a casing. The casing would be possible to make with the WEEEBR. The question changed from “Is it possible to develop any type of product out of WEEEBR?” to “How will that product look like?”

The second question was much wider and provided several solutions. The solutions were not based only on the properties of the material. Therefore was the focus changed and the backlog used in the first phase put away. To realize
how the focus had to change took a long time. Hopefully can this be avoided in further projects by making it clear how and when the focus should to change. It would be important to clarify the difference between the technical possibilities of the material and where the material would provide the largest market possibility.

After the change of focus one can say that phase 2 started – the normal product development process. Phase 2 was supposed to be the easiest part since the process was known. In reality that was the more difficult part of the project. There was no given direction of how the product should be developed, no focus group, no given market, only a will of reducing the amount of the problematic material. The large amount of the WEEEBR was partly used as a starting point, and the author tried to find a market that corresponded to that amount. Another starting point was the environmental advantage that came with using the WEEEBR.

The environmental advantage was assumed very early in the project, already in the decision of choosing a discarded material and putting it back in the loop. One could argue that there existed a vision already in phase 0 – making the world a better place. As McDonough and Braungart (2002) mentions it is important to decide values for the company, to know in what direction to go. To facilitate for similar projects it was therefore recommended to set a vision for the project in the first stage. Additionally was the environmental advantage of WEEEBR the main focus when doing the market research.

The market research was done widely which was good. It gave a lot of inspiration to the author of how things could be solved. The market research generated a lot of requirements and the setting of requirement worked out well. The only challenge there were keeping the part made of WEEEBR apart from the whole product. It was the whole concept that answered the earlier mentioned question “How will that product look like?”. The material WEEEBR was only a small part of that concept. But this project was decided to focus on the part with the WEEEBR, putting it back in the loop, which was the main aim of the W2D project. In the end was it decided that only the requirements that would differ the casing from other products because of the choice of WEEEBR would be focused on. For example was ventilation not supposed to differ because of the brittleness of the WEEEBR. In opposite was the assembling and disassembling methods supposed to be very different to other similar products. The human impression of the product was assumed to be different, as were the system the product would be sold in. It was also assumed that these will play a role in future products developed from a material. For a product like this it was suggested to set requirements in three groups.

It was claimed that it in future products will be important to have require-
ments also on the system the product is working in. Either focusing on how the product shall be adjusted to the already existing system, thinking about recycling processes, or on how the product shall help the development of another better designed system. At a recent theme-day held at Chalmers University several lectures brought up the same way of thinking. They claimed that it is important to include more than only the product’s environmental impact, the product has to be set in a system. The importance of the product developers and their responsibility were as well mentioned. (Swerea. 2014). The author of this thesis therefore claims that it is important for future developers to add this kind of requirements when they design products.

That the human impression will be important in future products, as van Kesteren et al (2007) claims, was a conclusion drawn also in this project.

The requirements set in phase 2 differed to requirements set in a normal product development process. Partly because they didn’t include any demands of a target group but a wide range of environmental and businesslike demands. The concept development process was however similar to a normal process and not dependent on the requirements.

The concept development was the last thing done in phase 2. The detail design and the concept elecction was skipped. The greatest challenge found during the development phase was to develop a concept that was achievable in reality.

Even though there was a thoroughly cooperation with people knowing the material the author often felt a lack of information. There were a lot of data available on technical properties, such as strength and brittleness, even though some of these properties were available first in the end of the thesis. But it was hard to get a feeling of how these properties would affect the product and how the material would react in different designs. There were not enough material to build a prototype and since a lot of time had been spent on chosing type of product and evaluation of the material there were not enough time to build a model in CATIA. Additionally, since only some of the functions of the product were focused on it was difficult to create a model of the whole concept. That would have been necessary to evaluate for example the assembling.

When a material is chosen depending on the product the way of assembling and disassembling are already decided. The assembling and disassembling methods are then chosen by other reasons and the material is only adjusted to it.

One could argue that the difficulties in the end of phase 2 was to eliminate concepts and choose which ideas that should be combined into one single product. The ideas were many but it was challenging to make decisions based on how the material would react. This project was chosen to not be taken any further. In a product development process there is generally time in the beginning to research
the product’s specialized functions. In this case it would have been the assem-
bling and disassembling function of the product that would distuingish it the
most. Time for evaluating a prototype made with different assembling methods
could have been one way to help making the decisions.

The conclusions from phase 1 and 2 resulted in the guidelines presented in
chapter 7.
8. Proposed method

The developed method for how to go from a given material to a sustainable product is described in following chapter. Each step in the method correlates to a result which can be reached by using several methods. The purpose and reason for the steps will be explained as will also the methods used.

The method can be seen in the flowchart presented in figure 14. At all stages the user is recommended to answer some questions. The questions are there to help the user reach the result of the step. To do this it is recommended to put up some requirements on the product after each step. These requirements are summarized in step 5. When the wanted result is achieved the user moves on to next step.

1. AGREE TO THE COMPANY’S VISION
   What is important for your company?
   How can your company make the world a better place?
   — Vision

2. EVALUATE WHAT MATERIAL YOU HAVE
   What material does your company have?
   How can you use what you have?
   — A material

3. EVALUATE YOUR TECHNICAL POSSIBILITIES WITH THE MATERIAL
   What can you make of the material?
   What are the advantages and disadvantages with the material?
   — Type of product

4. HIGHLIGHT A MARKET POSSIBILITY
   How can you fulfill your vision?
   Is there any place your material has an advantage?
   What shall your material be used for?
   — Business concept

5. SET PRODUCT REQUIREMENTS
   What are the functions of the product?
   How shall the product be sold?
   How shall the product be seen by the user?
   — Specification of requirements

6. DEVELOP THE CONCEPT
   How does the product meet the requirements?
   — Final concept

Figure 14. Flow chart describing the 6 steps in the method for developing a product starting with a given material.
8.1. Agree to the company’s vision

In the first stage it is important to decide on the company’s (project’s) vision. This was stated by McDonough and Braungart (2013) in their book “The Upcycle”. They claim that it is of great importance that all the involved in the project agrees to the vision.

It is getting more important to include a wide range of sustainability aspects to successfully gain the customers’ attention. As C2C certifications are getting more popular and other eco-labels are starting to include more criterias in their certification all these aspects have to be thought of in the beginning of a project. C2C and circular economy is a popular subject on many recent hold seminars and conferences, for example when Ellen MacArthur from Cradle-Net talked on Kungliga Tekniska Högskolan (KTH), the EWEEK (Environment, Economy and Evolution) at Linköping University focused on a “circular economy” which was also one of the subjects on the Sustainability Day in Gothenburg. (Cradlenet. 2013, Cleantech Östergötland et al. 2014, Miljöaktuellt. 2014). Chalmers University was also arranging a day for discussing resource efficient products and MISTRA Innovation started up the project called “Closing the loop”. (Swerea. 2014, Mistra. 2014).

The C2C Innovation Institute have developed their own labeling system and are launching new C2C certified products every day. (C2C Products Innovation Institute (a). 2011). Other more conventional eco-labels are also developing their criterias, increasing the limits and adding new requirements. For example, the TCO Development recently proposed an increased amount of recycled plastic in computer screens, where 85 % must be recycled plastic. (TCO Development (b). 2014).

Fitzpatrick et al (2014) states that 75 % of the market belongs to customers that are sustainable mainstream, meaning that they will buy a sustainable and green alternative as long as it is not cutting down the quality of the functions. Another 15 % are noticed to be highly engaged in buying sustainable technology even though the functions are being compromised.

To distinguish a company by being greener than the competitors is therefore claimed to be good in many ways. You will stay ahead of many new legislations, you will get more customers and you will create a sustainable society.

Methods used in this project to answer the questions:

• What is important for your company?
• How can your company make the world a better place?

To answer the questions were a lot of theory was used. The theory touched upon sustainability, upcycling and C2C. The aim of the “Closing the loop”-program
was also included in this part.

8.2. Evaluate what you have

This step was included in order to remind the developers that the earths resources are not infinite. Furthermore, what you have is something that should be valued and it was claimed that keeping the materials inside the company was good. A problem brought up by McDonough and Braungart (2002) is that the more global the production gets the less attention is payed to the its local environmental impact. As an example they take the textile industry. The colouring process have been shown to cause problems to water supplies and the local nature but since this production is passed away to other countries neither the customers nor the employees notices it. If you instead move the production more locally it is easier to see the direct effects of the production processes and also to do something about it. Evaluating what you have is a way of keeping the production local by observing the local environment and try to come up with ways to use it.

It was claimed that the local resources are adding values just by being local. McDonough and Braungart (2002) gave a lot of examples on how problems have been solved by looking on what they have.

Related to this was to develop a concept on how to keep what you already have. It was stated that if your company wants to go from waste to design the better would be not to produce any waste. That also follows the steps of the waste hierarchy set by EU. (Directive 2008/98/EC). Going from waste to design is good but if that waste was never produced, then you could go from design to design.

This step is important because it prevents further downcycling of materials. The aim of the step must also be to keep what you have in a good shape. If you do not keep what you have in a good quality it means someone else will have to handle it as waste, which is what we want to avoid.

Methods used in this project to answer the questions:

- What material does your company have?
- How can you use that material?

This step included a quick decision since the WEEE BR was already handed to the project. An evaluation of other possible available materials were not done. A larger examination of the WEEE BR was done trying to find requirements on how the WEEE BR should be used to avoid further material downcycling.

8.3. Evaluate your technical possibilities

Always when it comes to changing materials it is important to evaluate how
the change will affect the product. (Johannesson et al. 2005). Johannesson et al (2005) are highlighting methods for evaluating technical properties, such as FEM-analyses amongst others. But as van Kesteren et al (2007) mention the aesthetic properties of a material are also important.

Because the fact that WEEEBR is a recycled material it was assumed that its technical properties were inferior virgin materials’. It was therefore claimed that aesthetic properties and the user experience was even more important when changing from ABS to WEEEBR. Additionally, the aesthetic properties of a recycled material are often mentioned as worse than a virgin material. Recycled materials have a rumour around them of having a low qualitative surface and of existing in less colours, which are partly true for the WEEEBR.

From this step you should go on with a product chosen by technical requirements or limitations. It corresponds to the backlog produced during phase 1, where products were eliminated step by step.

Methods used in this project to answer the questions:

- What can you make of the material?
- What are the advantages and disadvantages?

Since WEEEBR was a new material its areas of use were not known. An analysis of the main materials in WEEEBR (HIPS, ABS and PP) and were to find them in today’s market were done to get an overview of possible products within the plastic industry. A comparative analysis between ABS and WEEEBR were done, based on that these two material have the most similar properties and that it was most likely to exchange ABS with WEEEBR. This analysis were done from a company’s point of view, subjectively looking at advantages and disadvantages for the company when replacing the materials. The properties of WEEEBR contributed with limitations to avoid areas where it would not be feasible. By using concept screening matrixes iteratively the most suitable product could be chosen.

8.4. Highlight a market possibility

In order to succeed when introducing the product there must be a market opportunity. As in a normal product development process you need to know how to distinguish the product from competitors. Since the discarded material in many cases are putting limits on the concept it might be even more important to find a place where there actually is a demand of the product. The material itself, as it is discarded because of its lack of “good” properties, will not contribute to the finding of a market possibility. It is therefore maybe even more important to find a hole on the market where competitive products do not exist.

Requirements from this step regard ways of distinguishing the product. Since
the recycled material might have difficulties living up to other virgin materials, focus shall not be on technical requirements but on finding ways of using the product in a way that fulfils the vision.

**Methods used in this project to answer the questions:**

- How can you fulfil your vision?
- Is there any place your material has an advantage?
- What shall your material be used for?

When the casing was decided to be the most suitable product for WEEE BR a market analysis was done to find out how the casing should be used. Since the vision of the project was to develop a product that creates a sustainable society a research was done on how other competitive products did this. There were also a survey sent out to see how their impression of different products were.

**8.5. Set product requirements**

Setting product requirements is done in every development project. Normally the requirements are based mainly on the users demand on how the product is supposed to function. (Ulrich and Eppinger. 2008). Setting requirements on a product made for a circular economy is claimed to demand a wider view than that. Requirements on the system will be needed because of the take back of the product, in order to keep the material in a closed loop. Higher responsibility will be put on the manufacture company to actually control were the products ends up after their usage phase. One could argue that the “polluter pays principle” will have to be extended to not only include hazardous material but all material. The company should be responsible for taking care of all produced material, not only the hazardous.

Aesthetic requirements will also increase in importance. As van Kesteren et al (2007) writes, the aesthetic properties of a material play a greater role in the product development when the functions of the products are getting more similar. Adding other (than the material’s) aesthetic values to the product will further raise its competitiveness.

Furthermore, since the material already has been chosen there will be some requirements based on the material’s properties. All in all the requirements on the product can be divided in three categories:

- Requirements on the function of the product - how will these differ because of the choice of material?
- Requirements on the system the product will function in
- Requirements on how the user will experience the product, aesthetic requirements
Methods used in this project to answer the questions:

• What is the function of the product?
• How shall the product be sold?
• How shall the product be seen by its users?

To set these requirements on the functions were several methods used, for example function trees to map the different functions or methods to gather information about user needs. The requirements on the system were more vague. It might be difficult to know whether the system itself shall change or if the product shall adjust to the system. These requirements are primarily based on the vision of the project, in step 1, but also on the human values explained by Eklöf (2014). The question “What’s next?” often asked by McDonough and Braungart (2013) was also used as a helping hand when setting the requirements on the system. The requirements based on the material were set earlier, in step 2, to make it possible to choose type of product. All requirements that had been found out in the previous steps were summarized and put together in the three categories mentioned earlier.

The human values are also used when deciding on the aesthetic requirements on the product. Deciding which requirements that are the most important can be difficult. But generally can the stated vision be used as a start.

8.6. Develop the concept

This step is the one most similar to the one in the common product development process. The concept is based on how it fulfills the requirement. Both when brainstorming and when eliminating concepts, the requirements are the starting point leading the direction for the project. To base the decisions when choosing concept it is also good to have a vision set from the beginning. Although, the time for the development might increase since there are more aspects that have to been taken into account. If we before only designed the products with the users’ demand we now have to start design with the environment in mind.

Methods used in this project to answer the questions:

• How does the product meet the requirements?

Developing the concept included brainstorming, mindmapping and a lot of sketching. Some concepts were eliminated and some were taken to further development. Concept screenings are used in the same way as for other products.
9. Validation of proposed method

This chapter will highlight examples on how the proposed method can be implemented, in order to validate it. The examples are taken from the development process in phase 1 and 2. Some of the concepts are modified to better suit the explanation.

9.1. The vision of the project

With C2C and the Mistra program “Closing the loop” in mind the vision was set to create a product that was 100 % good. With 100 % good means that the product has none environmental impact at all, or in the best case, a good environmental impact. It was a highly set aim but worked well as inspiration and the later decisions was to a large extent based on this. As a part of this the C2C certification was examined and a goal of creating a product with the Basic C2C level was set. The Basic level includes good working conditions for the employees and requires a well-known material content. All material shall be defined as biological or technical and the energy shall to a large extent be renewable. C2C speaks about eco-effectiveness instead of eco-efficiency and therefore was the amount of energy used during production and the product’s using phase not that important.

More related to the “Closing the loop”-initiative and the W2D-project was to turn something less valuable into something with high value. This is also brought up by C2C referred to as waste equals food.

Included in the development of a 100 % good product is of course the users’ experience. The human values mentioned by Eklöf (2014) seemed to match the aim of a 100 % good product. These were therefore also included early in the design process in an attempt to encourage the user to live in a sustainable society. Some overall requirements on the product are explained below.

The product must:
• Fulfill the criterias of C2C Basic level
• Be sold in a sustainable way
• Be included in a closed material loop
• Aim to be 100 % good
• Encourage the user to create a sustainable society

9.2. WEEEBR the material

This project started with a material called WEEEBR. WEEEBR is made of the recycled plastic fraction from WEEE and solves the problem of putting problematic waste material on landfills. It also decreases extraction of new raw material as it puts the material back in the loop.

The W2D-project had a goal of closing the loop and raise the value of the problematic materials provided by Stena. The problematic material that was giv-
en in this project came from the plastic fraction from WEEE. This plastic fraction is problematic because it contains a mixture of different plastics (mostly HIPS, ABS and PP) but also some rest materials such as metals and wood. Stena are today either selling this material to further sorting or sending it to landfill. Further sorting are expensive and the most economically feasible is to send it to landfill.

Fortunately, researchers at Chalmers university have come up with the idea of melt-blending this waste fraction. The result is the material called WEEE-BR which this project is based on. The material properties can be found in the theoretical chapter “5. The material WEEE-BR”. From a C2C point of view the WEEE-BR can be discussed. The WEEE-BR is first, to some extent, mixing materials from both the technical (plastics and metals) and the biological (wood, paper rests) loop. This is very difficult to change since Stena already are making the best they can to sort out clean material fractions. The sorting can provide an around 90 % clean material but the cleaner it is the more expensive are the processes. (Stenvall et al. 2014, Flink. 2014). If the biological nutrients were possible to sort out to 100 % it would still be possible to argue against the mixing of different plastics. By melting them together you make it a one-way decision. It will never again be possible to sort out the ABS, the HIPS or the PP by themselves and their specific properties are lost. Additionally, the market of bioplastics are increasing and how this will affect the properties of recycled plastics are being evaluated. (Mistra. 2014)

However, since the sorting includes way too many steps to be feasible the melt-blending of the problematic plastic fraction is a good solution. And by defining WEEE-BR as a new material from waste (Ordoñez and Rahe. 2012) the mixture of technical nutrients could be overseen. It was claimed that it was a difference between seeing WEEE-BR as a new developed material with other properties and requirements and seeing WEEE-BR as a mixed blend of materials and their decreased properties.

The use of WEEE-BR, as a new material, will in many ways result in products with less environmental impact. The production of WEEE-BR requires the same energy as other recycled materials and it causes the same low CO₂-emissions (see appendix C).

To fulfill the requirement of being kept in a close loop it was decided that the developed product must be defined as EEE.

By keeping the WEEE-BR in the loop, see figure 15, it does not require any new extraction of raw material such as non renewable oil which is normally the case for plastic production.

A problem by creating this loop is that recycled plastic always loses some of its
properties. Plastics are made of polymers which is why they normally only can be recycled up to seven times. (Ashby. 2013, Bruder. 2012, Lunds renhållningsverk. 2009). Therefore was the work of Yu (2014) important, where he is examining how the newly developed WEEEBR is affected by several aging and recycle loops. Yu (2014) showed that the properties of WEEEBR strongly degrade after already two years. The life-time for the product the material is used in should therefore not be longer than two years.

The possibility to recycle WEEEBR together with other plastics was something that was assumed to be working. It was also assumed that since there always will be some kind of waste fraction, no matter how many recycling steps the fractions are taken through, there will always be waste material to manufacture WEEEBR from.

To keep to the vision of the project more requirements were added on the product. Old requirements are written in italic.

The product must:

- *Fulfill the criterias of C2C Basic level*
- *Be sold in a sustainable way*
- *Be included in a closed material loop*  
  - Be included in the loop of EEE
  - Be produced based on the material WEEEBR
- *Aim to be 100 % good*
  - Decrease the amount of waste on landfills

**Figure 15.** Show the loop for the material WEEEBR. It starts within the EEE that then becomes waste (WEEE), that is sorted out to WEEE Plastic. Thereafter is WEEEBR manufactured and finally can the material WEEEBR be used again in EEE.
• Encourage the user to create a sustainable society
• Encourage the user to send back the WEEEBR

9.3. The type of product possible for WEEEBR

The type of product best suitable for the WEEEBR is within the EEE, preferably in a casing for small electronic equipment. By evaluating the advantages and disadvantages of the WEEEBR could a type of product be chosen. To get a feeling of what the WEEEBR can be used for it was compared to other similar materials. Screening methods was used to evaluate different products suitability.

The suitable product found for WEEEBR was a casing. The materials that WEEEBR are mainly made of (HIPS, ABS and PP) are often used in similar applications, see appendix H. A summary of the properties similar to WEEEBR can be seen in appendix I.

According to the limiting properties of WEEEBR casings are one of the better suitable. The limiting properties can be seen in appendix J. and the screenings where other areas, industries and products were eliminated can be seen in appendix K.

To fulfill the criterias of the WEEEBR the casing have to be used in smaller applications placed indoors and preferably on a static quite hidden place. These could for example be computer devices, switches, measurement equipment, fire alarms etc. See figure 16.

The result of when the replacement of ABS with WEEEBR was discussed from a company’s point of view can be seen in appendix L.

Four proposals on how the WEEEBR could be used were developed after visiting a swedish store for household electronics.

Housing for a green vacuum cleaner - The WEEE-
BR could be used producing a casing for a vacuum cleaner. See figure 17. This kind of product does already exist on the market. That casing is made of 50% recycled plastic. The new developed vacuum cleaner would have a casing made of 100% recycled plastic, WEEEBR. The dark colour of WEEEBR and the risk of that vacuum cleaner might not be carefully handled could be a disadvantage.

**Digital box** - The existing digital boxes often have a front in shiny high qualitative plastics and a backside made of one less qualitative plastic. The backside plastic could be replaced by the cheaper material WEEEBR and at the same time adding a green image. An advantage of this is the lack of green alternatives on the market for digital boxes. See figure 18.

**Backside of a TV screen** - As for the digital boxes the TVs of today often have a more high qualitative plastic in the front and another material on the backside. See figure 19. This concept was based on replacing every backside of a screen with WEEEBR. That would represent a very large market share if it could be done in a clever way. Same concept could also be used in computer screens. An advantage of this concept is the probably upcoming legislation requiring the use of recycled plastics, similar the one introduced by TCO Development regarding computer screens. (TCO Development (a). 2014)

**Small stationary computer** - The WEEEBR could also be used as the casing for stationary computers. See figure 20. The casings today are often made of plastics and some of them with metals in the back. There are some green computers on the market but these are at most made of 50% recycled plastics which is why WEEEBR would be a good replacement.

**9.4. The market opportunity for a casing made of WEEEBR**

The technical possibility that offered most opportunities for WEEEBR was to develop a casing to a small consumer electronic product. To find what electronic product that had the greatest possibility to success several market analyses were
Market for green products

Green products is a growing market and many companies are today claiming their products to be green. During a long time these green labels have only taking into account the energy consumption and CO₂ emissions, as are common in a LCA. But as these new sustainable visions of C2C and circular economy are becoming more familiar to the customers higher requirements are put on the products. One example is the recently launched phone “Fairphone” that not only includes smaller packages and replaceable batteries but also conflict-free minerals, an openly showed pricing and good working conditions. Fairphone is also cooperating with a foundation called “Closing the loop” in order to develop a phone made of only recycled materials in the future. (Fairphone. 2014). See figure 21.

No other EEE product was found that payed so much attention to all these factors. Although, a computer made by some students at Standford University. Developed a computer consisting of several easy disassembled parts. (See figure 22). But in this case working conditions and conflict-free minerals were not included. (Inhabitat. 2010)

Another green product is the vacuum cleaner created by Electrolux. The vacuum cleaner is produced to have a lower energy consumption and comes with larger vacuum cleaner bags in order to increase the lifetime of the bags. It is also quieter than its competitors. Additionally, the housing for it is made of 50 % of recycled plastics.

A survey for students at LiU showed that they thought computers were the product with greatest negative environmental impact (the less green product) out of the four alternatives TV, digital box, vacuum cleaner and stationary computer. (see appendix M).

But in the contrary to this result, many computers are branded as green. Apple’s computers for example are often highlighted as environmentally friendly. A conclusion drawn from this is that there actually exists a demand on the market.
for green computers, why would companies otherwise brand their computers as green? But the computers are not sufficiently green to convince the customers. Since the study showed that computers not yet had been designed to keep all these aspects in mind, as in the Fairphone, designing a computer that actually is green showed a good possibility. (Fairphone. 2014)

**Market for green computers**

Most of the computers today are labelled with the EPEAT or TCO Development certification. They are also sold with packages in recycled material and some of them have casings that are recyclable. For example is Apple’s Mac Book Pro made of a recyclable aluminium casing. But apart from that the analysis of green computers showed that nearly all the stationary computers lacked the EPEAT criteria of being produced with recycled material. (EPEAT (b). 2014) (see appendix N).

When talking to lead users at the Sweclockers forum they mentioned thin clients as the most environmentally friendly solution for companies. (Sweclockers. 2014). Thin clients are also mentioned when talking to IT-departments on several companies. At Stena for example, about 50 % of the employees use laptops, 25 % stationary computers and the rest 25 % use thin clients. (Stena Recycling IT-department. 2014, Stockholm Stad IT-department. 2014).

A thin client, also called slim client or zero client, makes it possible for several users to share the same server. In opposite to a thick client, or stationary computer, where each user has its own server. In a thin client there is no need of CPU or hard drive, these components are put in a larger server. This means that the thin client only handles the information needed for that specific moment and

![Figure 23. A schematic figure of how a thin client works, sending the signals from the server to the screen where the user make an active choice, sending back signals to the server. (Leverstock. 2012)](image)
the rest is stored in the server. (Sweclockers. 2014, Webopedia. 2010, Wisegeek. 2014) See figure below (figure 23).

Advantages with thin clients are that they are cheaper, more energy efficient, offer better security for companies, is quicker and easier to fix when broken and normally have longer life-time. (Hewlett-Packard Development Company. 2014, Sweclockers. 2014). The reason why they are more energy efficient and have a longer life-time is that they does not include any CPU nor any moving parts. This requires less cooling and save energy. The existing parts don't break as easily and therefore have a longer life-time. To update the software only one server has to be updated, instead of several servers for each computer. Same argument may be used for when a thin client breaks down, instead of buying a new computer only a new thin client is needed. This saves money and time since the thin client does not need any installation of programmes. HP means that a saving of 48 % of the total cost of ownership (TCO) can be done if a company decides to invest in thin clients. (Hewlett-Packard Development Company. 2014)

Disadvantages with thin clients are the need of more units, since both a server and thin clients are needed. In a stationary computer the thin client and the server are in the same unit. If a place for servers does not exist this will require a large one time investment for the company. Another disadvantage could be that many clients lack of input/output ports and therefore can not be connected to other devices (e.g. printer or speakers). Nor can they be used for playing CD's or DVD's. (Sweclockers. 2014, Wisegeek. 2014)

A study of the market for thin clients showed that they normally are marketed as money saving and secure. Hardly none of the thin clients were branded as environmentally friendly nor did they consist of any recycled material. A thin client designed for being as green as possible could therefore offer a good market possibility.

Market for green casings
When looking for computer casings a lot of variations were found. Many people

Figure 24. Examples on different casings for computers. (Recompute. 2014, Computerbild. 2011, Rusbiz. 2009)
have been trying to build their own casings using LEGO bricks, wood, old furniture, cardboard etc. (See figure 24)

Some of them were stated as green and environmentally friendly, as for example the aluminium casing for the Apple Mac Book Pro that is 100 % recyclable. Other green casings were made out of cardboard or wooden planks, these were however not so well-known on the market. The aluminium casing by Apple is not recycled but recyclable. It is not known from where the aluminium comes from nor how it will be handled in its end of life. The cardboard casing is branded as eco-friendly but will not be appreciated by the recycling industry. As C2C states the biological and technical nutrients shall be separated. But since manual disassembling do not exist to that extent, the cardboard will cause more trouble than it will help.

Casings made out of recycled plastics were not very common. And to use the WEEEBR as the casing material was seen as a good opportunity to fulfill the EPEAT criteria “Higher content of postconsumer recycled plastic” (EPEAT (b). 2014). Additionally, since the TCO Development recently launched their new criteria for recycled material in computer screens the use of 100 % recycled material in a computer casing seemed like a good decision.

Conclusions from the market analyses
Conclusions drawn from the market analyses:

• Hardly none of the computers included social fairness, as conflict-free materials or fair working conditions
• None of the computer companies had an open pricing such as fairphone have
• None of the computer companies included demands on changing to renewable energy nor controlled water usage
• None of the computers fulfilled the EPEAT criteria about recycled material
• None of the green computers had any other advantages than being energy efficient
• None of the thin clients were sold as a green product
• None of the green casings were made of recycled plastics
• Hardly none of the green casings were adapted to how the recycling industry actually works
• All the green computers had smaller, recyclable packages
• All the green computers fulfilled around 20/24 points at the EPEAT criteria
• Many of the thin clients were sold or leased to companies

Based on these conclusions a market possibility was found. It resulted in a business concept which included an environmentally friendly thin client with the
casing made of WEEEBR. The main concept was to develop a computer similar to the fairphone. The primary customers should be small and medium enterprises (SME) with a desire to have a green image.

9.5. Requirements on the thin client

Due to a normal product development process a list of the functions were put together. Since the given material, WEEEBR, only will affect the function of the casing the requirements on the thin client itself will not be focused on, nor will the package be highlighted. The inner parts to which the casing is adapted are chosen by the computer service Inet and are described thoroughly in appendix O. Basically the casing need to be adjusted to the CPU and the motherboard as these are the large components in the thin client. The CPU chosen by Inet is 100 x 125 x 64 mm and weigh 1,4 kg. The motherboard is 170 x 170 mm and has a weight of 0,75 kg. Furthermore, only the functions affected by the material will be looked further into. This resulted in not changing the basic shape of the casing – traditionally a box – nor how the ventilation worked.

The three types of requirements were specified further.

- Requirements on the function of the product
- Requirements on the system the product will function in
- Requirements on how the user will experience the product, aesthetic requirements

Requirements on the function of the product

To fulfill the users' demands on a casing for a thin client following requirements should be fulfilled.

The casing shall:

- Protect inner components
- Facilitate reutilization and recycling of inner components
- Keeping the thin client together
- Protect the user from electrical parts
- Facilitate cooling of the inner parts
- Connect to other clients
- Communicate with the user
- Ergonomically facilitate for the user
- Guide the user to its functions

The main functions are specified further, that can be seen in appendix P. The C2C requirements are attached in appendix A.

The functional requirements were marked as mandatory (M) and some as optional (O). The properties of the plastic WEEEBR will affect some of the
requirements. These will have an impact of the function of the case and be the reason to why it differs from other cases made in other materials. The requirements that will be affected are following:

**Have a long lifetime (> 5 years) (M)** - The lifetime for the thin client was recommended to be more than five years. This is not possible since the properties of WEEEBR will start to degrade after two years. Two years is a short lifetime compared to other plastics. The WEEEBR might affect the lifetime in a negative way.

**Have a reasonable price (M)** - The price of WEEEBR was assumed to be lower than for ABS. The WEEEBR will therefore affect the price of the thin client in a positive way.

**Keep the thin client together (M)** - The WEEEBR is brittle and assembling methods may be a problem. Normal assembling methods are screwing and “click”-solutions. It might be difficult to screw in the WEEEBR. The WEEEBR is also technically weaker than other plastics and it will be difficult to fix the inner components by only using the plastic.

**Protect the user from electrical shocks (M)** - The content of WEEEBR could vary, which could be a safety problem. This can not be looked in to further in this project.

The functions that seemed to be most affected by the WEEEBR was the “keep the thin client together” and “have a long lifetime”. Secondly, the WEEEBR will affect how the user experiences the product’s surface. These three mandatory functions was focused on in the brainstorming.

The optional requirements were weighed to each other in order to decide which were the most important. See appendix Q. These are shown below in ascending order. Each scoring is shown in parenthesis behind the corresponding requirement.

1. Show if it’s on/off (10)
2. Encourage a long life-time (7,5)
3. Show that it is made of recycled material (7,5)
4. Encourage to recycling (6,5)
5. Be easy to disassemble (5,5)
6. Encourage the user to switch it off when not in use (5,5)
7. Be ergonomic and facilitate for reaching the ports (3)
8. Show internet connection (2)
9. Keep the inner cables on their right place (1)
10. Lower annoying sound (0)

From the optional requirements were the ones related to user experience (number 1, 2, 3, 4 and 6) also highlighted during brainstorming. Number 2 “encourage a long lifetime” was mainly directed to the customer and how long time the customer would like to keep the product. In opposite was the earlier “have a long lifetime (> 5 years)” focused on the technical lifetime and at what time the product would break. Number 5 “be easy to disassemble” seemed to relate to the mandatory function regarding assembling and was also included.

These requirements, and the one from the mandatory ones, were taken further to the concept development phase.

The casing shall:
- Keep the thin client together (M)
- Have a long lifetime (> 5 years)
- Facilitate the reuse/recycling of the inner components (O)
  - Easy reach the inner components
  - Not destroy the inner components
- Be able to be material recycled (O)
  - Not break down into too small pieces (not dust)
  - Not have any coatings or glue attached

Requirements on the system the product will function in

The demands on the product from a system’s point of view were primarily based on the vision of the project. These requirements are following:

The thin client shall:
- Fulfill the criterias of C2C Basic level
- Be sold in a sustainable way
- Be included in a closed material loop
- Be produced based on the material WEEE
- Be included in the loop of EEE
- Aim to be 100 % good
- Decrease the amount of waste on landfills

To further specify the requirement of being 100 % good were the design principles explained by Fitzpatrick et al (2014) used. Fitzpatrick et al (2014) first specifies which decisions that will have the greatest environmental impact and then uses the design principles to avoid the worst decisions to be made. To suit this project were one of the original five principles modified and two new principles added. The principles were also translated to requirements.
The requirements are listed below depending on who they will affect.

User:
• The product shall have a low energy consumption (New)
• The product shall have an emotionally durable design
• The product shall have an emotionally green design (New)
• The user shall be offered service

Collecting facility:
• The product shall be easy to upgrade and remanufacture
• The product shall be easy to disassemble

Recycling facility:
• The product shall facilitate the closing of the loop of the less valuable fractions (Modified)

Fitzpatrick et al (2014) did not include the way the computer is being used. Their observation started when the user had to make the decision of throwing the computer away. Since computers and other technology is known to have a high energy consumption during its use (e.i. referred to active products in LCA by Johannesson et al (2005)) it is important to also include the usage phase. The requirement “the product shall have a low energy consumption” was therefore added. When talking about the requirements “the product shall have an emotionally durable design” and “the product shall be sold in a sustainable way” is a long lifetime often desired. The short lifetime of WEEE BR was therefore thought to affect the system negative, not only the product. In a linear economy system is a long lifetime supposed to be good from an environmental point of view. In a circular economy, that does not have to be the case.

The requirement “the product shall have an emotionally green design” was added to raise the user’s awareness of how her handling with the computer will impact the environment.

The principle “minimal negative value fractions” by Fitzpatrick et al (2014) was replaced with the requirement “the product shall facilitate the closing of the loop of the less valuable fractions” to match this thesis’ purpose. Instead of minimizing the difficult materials, try to upcycle them. Referring to C2C, the first principle would be described as making a product gain eco-efficiency and the second allows the product be eco-efficient. Note that the later requirement also encourage to creativity and development, it could also be written as “create a potential market for the negative value fractions”.

Some of the mentioned decision points was eliminated due to the involvement of Stena Recycling. In this thesis, the recycling facility was known, including the recycling processes. Fitzpatrick et al (2014) brought up some points of importance where the recycling facilities take the decisions. In this case, it is
known that Stena uses shredding as recycling method. It is also known that some products (e.g. LCD-screens) are taken care of separately and that the process are carried through under control.

**Requirements on how the user will experience the product, aesthetic requirements**

The aesthetic demands were to some extent based on the requirements developed for the system. The two requirements “the product shall have an emotionally durable design” and “the product shall have an emotionally green design” are both directed to the user’s experience. Using these following seven human values could the two requirements be extended to another seven.

**Human values:**

*Durability, Visualization, Contribution, Development, Uncertainty, Unify and Balance.*

- The casing shall be used in a durable way and give the user a feeling of durability and infinity
- The casing shall make the inner components and their purpose visible to the user
- The casing should highlight the user's role and responsibility to recycle, to save energy and to use renewable energy
- The casing shall contribute with knowledge
- The casing shall let the users develop
- The casing should let the technology develop
- The casing shall unify the users

**9.6. Concept proposals**

From the requirements in step 5 were several concepts developed in order to solve these demands. Sketches can be seen in appendix R.

From the functional requirements were the “the casing shall keep the thin client together”, “the casing shall facilitate the reuse/recycling of the inner components” and “the casing shall be able to be material recycled” focused on. The requirement regarding the product's lifetime was moved to only be included in the requirements for the system instead. The other functional requirements were assumed to be solved in similar ways as for existing thin clients. For example “show if it is on/off” was supposed to be solved by a small lamp. However, together with the requirements “the thin client shall be included in the loop of EEE”, “the thin client shall decrease the amount of waste on landfill”, “the product shall be easy to disassemble” and the more human based requirements “the casing shall let the users develop” and “the casing should let the technology develop” was four concepts developed.
All the four concepts are based on the decision to material recycle the casing of WEEE BR. It was claimed that it might not be worth to reuse or remanufacture the casing due to the high probability of breaking it during disassembling. Casings were also claimed to be one of the components mostly affected by trends and fashion and that the customer therefore would demand a newly produced casing, after material recycling of course. Additionally, the short lifetime of the WEEE BR affected the decision of material recycling the casing after the usage time. It is also worth to mention that the casing in an electric equipment causes the least environmental impact and is least valuable, compared to the motherboard or the CPU which contain a lot of different materials and therefore should be reused.

The design was therefore focused on how the casing could be disassembled in an easy way, keeping in mind that the casing should be material recycled. As was seen in the research made by Cullbrand (2014) a lot of time could be saved when disassembling for material recycling rather than remanufacturing and the concepts were developed with this as inspiration. Though, the inner components have to be working and taking away the casing shall not ruin the inner components.

Additionally, none of the concepts require a covering or coating since that will ruin the material recycling.

**The first concept** is based on a cubic shape of the thin client (see figure 25). Two triangular sides are assembled on to the middle part through tracks in the casing. The CPU are assembled in one of the triangles. That triangle are assembled last and the weight of the CPU (~1 kg) will hold the three parts together. It is easy to disassemble the parts and change the inner components. The motherboard lies on the bottom at the middle part with small plastic plugs to fix its position.

![Figure 25. Cube with triangles assembled by tracks in the casing.](image)

**The second concept** has as the previous one the shape of a cube. The triangular sides are fixed on an inner skeleton made of steel, see figure 26. This concept is
kept together better than the first but also more time consuming when disassembling. The one disassembling the case will need some basic knowledge on how to open up the casing. The CPU and the motherboard are placed on the same place as in concept 1.

The third concept has the shape of a rectangular and reminds of existing thin clients, see figure 27. The upper part is fixed to the under thanks to tracks in the plastic. Both the CPU and the motherboard are fixed in the under part. This concept is more conventional and does only consist of two parts. Depending on how fixed the inner parts are the user can choose to keep the thin client lying or standing, making it easier to adjust.

The fourth concept is based on snap-fits, see figure 28. The snap-fits can only be used once because of the fragile plastic but because of the thought material recycling that was not seen as a problem. To disassemble the upper lid the snap-fits have to break. To facilitate and specify where the fracture shall be two tracks are done. This concept makes it clear that the casing not shall be used again. Though, this is the concept where the inner components might be hurt during disassembling.
Of these four concept was the fourth the one most adapted to the properties of the material. Yu (2014) have been evaluating how the aging affects the WEEE BR and analyses show that the material will degrade greatly after already two years. Designing a casing that is meant to break after two years will take advantage of that property. The casing will then be seen as a single-use product.

A system based on leasing the thin client to companies were created (see figure 29). The customer was a innovative small medium enterprise (SME) wanting to have a green image. The users were employed at the company, working 6 hours a day with easier programs. All data was stored on the “cloud” or at local servers

Figure 28. Rectangle assembled with snap-fits.

Figure 29. A schematic figure on how the concept based on a leasing system could work.
connected to the thin clients which allows the user to log in wherever there is a free thin client. The user was also interested in sustainability and was willing to adapt green solutions if the functions are the same (sustainable mainstream).

When the thin client breaks the company will send it to service. The service will disassemble the thin client and decide which of the inner parts that are possible to reuse and remanufacture. The service will also assemble the old functionable parts in new casings and send them back to the users. All the incoming casings will be material recycled because of the brittleness of the WEEEBR.

The WEEEBR-casing will be brought back to Stena Recycling and sorted in their existing system to WEEE Plastic. The WEEE Plastic can thereafter be further treated to be used once again as WEEEBR in casings for thin clients or other equipment.

The manufacturing can be done either (as many other plastic products) in Asia or manufactured locally in a facility in Sweden.

Through the leasing system proposed in figure 29 the following requirements will be fulfilled “the casing shall be used in a durable way and give the user a feeling of durability and infinity”, “be sold in a sustainable way”, “be included in a closed material loop”, “be produced based on the material WEEEBR”, “be included in the loop of EEE” and “decrease the amount of waste on landfills”. Advantages with this concept are:

• Creates jobs locally if the casings are manufactured, assembled and served in Sweden were the recycled plastic comes from
• Less transportations causing less CO₂ emissions
• Locally produced casings giving better control of the materials. Resulting in that environmental problems will be noticed earlier and not sent away to other places. It is for example easier to control the used materials so that they are not from conflict areas.
• Creates relations between the recycling facility and other stakeholders
• Secured material stream for the WEEEBR as the old casings always are handed back to the factory
• Closes the loop of the problematic materials - creates a market for the earlier downstream material
• Large market potential, 90 % of the market want to buy sustainable technology. Companies need great amounts of computers and are therefore having a big environmental impact. It is important that they take their responsability.

This can be compared to the single use cameras that was popular some years ago. They were send back to the factory to be disassembled and working parts was combined with other working parts to new cameras. The film and photos from the camera was send back to the customer, which was also the reason for
why the customer sent back the camera to the factory in the first time. In this case would the reason for why the customer sent the thin client back be the breaking casing. The customer would be guaranteed an update of the software and the inner components after two years and that would be the time when the casing would break.

Two examples on how the human values can be included in the thin client’s casing were developed. The first one, see figure 30, includes the requirements “The casing shall make the inner components and their purpose visible to the user” and “The casing shall contribute with knowledge”.

The concept combines the holes for ventilation with the aesthetic values by informing the user of its inner components.

The valuable components in a thin client are the motherboard and the power supply. These are also the materials that contains the highest amount hazardous material, critical raw material, “bad” extracted materials and non-renewable materials. Additionally, these components are the active ones that use energy during the usage phase. The less valuable components are the housing and packaging. One could ask why these inner components with high negative impact on the nature are hidden from the user. Through creating casings with ventilation holes in the pattern of a motherboard the user will be aware of the valuable inside. A comparison can be drawn to an existing casing with the pattern of a flower.

The second example, see figure 31, on how human values can be added in the thin client is fulfilling the requirements “the casing should highlight the users role and responsibility to recycle, save energy and use renewable energy” and “the casing shall unify the users”. That concept is based on a competition where each user can see the energy use for the thin client. Depending on how good the user is to switch it off during breaks the energy will vary. Given that there is a company

Figure 30. Visualize the valuable motherboard. Wikipedia (b). 2014.
buying the thin clients, users around the same table can compete with other tables creating a team spirit.

Because the casing is made of WEEEBR, its colour might vary depending on the input WEEE Plastic. This will further increase the user’s experience of it being recycled. The WEEEBR will also result in a higher EPEAT certification than competitive computers and thin clients. A decision to not allow any coatings on the thin client was based on the requirement “be able to be material recycled”.

Figure 31. Encourage the users to save energy.
10. Discussion

In this chapter is the new developed method discussed. Advantages and disadvantages are highlighted and it will be discussed whether the method can be used generically.

Following this method makes it easy to motivate many of the decisions taken during the process. One reason was the vision that was defined early in the project. Comparing to phase 1 and 2 were the vision not defined as clearly. The vision made it easier to back up later decisions in the developing phase.

In this case the vision was to create a sustainable society based on a circular economy. So why was this vision chosen? First, in order to develop a product out of a discarded material one cannot avoid reflecting over why the material is discarded. Since we live in a linear economy, we are used to products that are going from being worth something to products without a value – waste. Discarded material is a part of a linear economy and it is a result of products designed to go out of fashion. So if a product shall be designed from a discarded material then, preferably, that product shall be designed to not cause any new disposed material. Otherwise will the new product made from discarded material cause even more material (probably even less valuable than the first discarded material) in the end. This is why the vision of a circular economy was stated.

Since many of today’s companies are greenwashed (claiming they are green but they are not) it can also be of importance to decide upon a vision. (Dahl. 2010). Around 75 % of the customers belong to the sustainable mainstream and another 15 % chooses a green product even if it lack some functions and it is therefore claimed that it is possible for companies to go for even greener products without risking too much. (Fitzpatrick et al. 2014). Observing general trends shows that even more people are getting involved and interested in the environment and in buying sustainable products. Google is one company that for example recently stated the importance of a vision through investing in solar plants and renewable energy. (International business times. 2014)

The second step is important also if not working with a discarded material but in every development project. To start with the local materials may be discussed. Why should we not start to import materials from other countries? To what extent can we import and export our materials? Transportations stands for a very large part of the emitted CO₂ in the world and reducing transports would be good in that point. But it might also be good in some cases, for example, to import good materials rather than using a bad or hazardous material. In this thesis however was this step already given since the aim of the W2D project was to develop a product from a material.

The aim of the W2D project also laid the ground for step three. If the WEEE Plastic would not have been chosen the development process would have been
different. However, starting with the technical properties is recommended. To limit the amount of products by the technical properties was the best way to start. The environmental advantages and the human values of the material are more subjective and will not limit the choice of product to the same extent.

Step 4, evaluate the market possibilities, is important for every new product. As is mentioned by Ulrich and Eppinger (2008) it is more important for some types of products. When developing technology-pushed products, the first thing to do is to make a market plan and decide for who the product shall be developed for. They also recommend to do regular comparisons between the own product and competitors. This is to find a clear advantage for the developed product.

This process started with an evaluation of the plastic market, then evaluated the market for casings and later for green products, green computers and green casings. Both the product and the material was compared to similar products in several steps to make it possible to find advantages for it and decide how it should be distinguished.

In the evaluation of the method was examples from the “test”-development process (phase 1 and 2) used. Critically, one could say that the proposed method never was used to develop a product. Seeing the validation more of a way of clarifying how the method should be used could therefore be good. During phase 1 and 2 was however all these challenges found and with the proposed method can these hopefully be avoided or handled in a better way.

It could also be worth mentioning that there has not been any external revision of the method. The method have been developed and used by only the author of the thesis and it is recommended to do some further validation.

The method does not pay so much attention to the economical aspects of the product development. However, in the fourth step, market research is included and it is obvious that the developers here have to examine also the economical feasibility of the product.

One could argue that using a new material is a kind of new technology. If using the definitions from Ordoñez and Rahe (2012) is the material WEEEBR a new material developed from waste. Ulrich and Eppinger (2008) bring up risks related to technology, the market (what will the customer think of the product?) and budget and time (will the product be completed at given time and budget?). For this project has the technology been the main issue, questioning for example how the WEEEBR will stand external impacts, since it is so brittle? The market risk has also been important, what will the customer think about a product made of recycled material? Throughout the project focus have been on convincing the customer that, even if the material itself is brittle and give the impression of having been recycled, the product is good. The greatest risk, was due to the author,
when the detail design was to be done and the final concept chosen. A product of WEEEBR have never been produced before and doing that would require some prototypes and tests before deciding on the final concept. Because there were no possibility to build a prototype the decision was to end the developing phase before a final concept had been chosen. As Ulrich and Eppinger (2008) mentions, large risks can be avoided by developing multiple solutions that are evaluated parallel. This was one of the intentions when developing several concepts for the disassembling (see page 63-64). The disassembling should be examined before taking the project further.

Creusen et al (2012) talks about the fuzzy front end (FFE). It is claimed that the FFE in this project came in two stages. First, when starting the project (Phase 0) and then around step 4 when the market opportunity should be found and the way of distinguishing the product was set. In the FFE the customers thoughts are important, which is something that could have been included more in this project. A survey to companies could have been sent out to get input on their thoughts about a thin client.

However, the FFE lasted for a long time and one of the reasons might have been the lack of customer connection. In a normal product development project the customers are often known from before since the product is developed for a specific company. In this case there were no company to provide the author with information or guidelines of the design of the product. It would have been good to find a company producing, assembling or selling thin clients but this was difficult since they were not included in the beginning of the project. A cooperation with a company developing thin clients could have provided the project with more specific requirements and a target group. The company could also have been used to validate the product’s possibility on market and also to validate the use of WEEEBR in the casing. It could have been interesting to investigate more in how they work during the choice of material. Overall could the choice of materials been investigated more in the theoretical framework.

Step 5 and 6, setting the requirements and developing concepts were, as was mentioned earlier, the two steps most similar to the normal product development process. They will be modified depending on the vision and the material but will work in the same way as for other products.

Overall, this method can be recommended for future developing projects where the aim is to develop a sustainable product. The materials will have to play a greater role in future products, due the the decreasing amount of virgin material, and it might be better to start designing with this in mind before it is a must.

Using the method if developing a “normal” product might be exaggerated. If your company already are selling products then are the materials already known,
as are the market possibilities and the customers. For that kind of development would the proposed method be very time consuming and it might be better to continue as always. But, if you do want to come up with something new and innovative then it might be helpful to use this method. Say for example that the vision is to earn a lot of money, then you could start to think about what you have in your neighborhood. That might be, a lot of water, then you could start to technically evaluate how you could use it in the most efficient way. Maybe that is to use it for harvesting. You might see a big market potential in selling food, because that is something people always need and you can start to develop your business.

Then, if you did this right, you will have used your local material in an innovative way and earned a lot of money.

Additionally, even if this method might not be the exact way of how to design future products it is important to design in a more holistic view and it is important to design resource efficient products. Hopefully can this project be used as a guideline for future studies.

### 10.1. Recommended further studies

For taking this project even further it could as mentioned in the discussion, be interesting to build prototypes of the concepts. The concept could also be built up in a CAD-program to decide on details. It would also be interesting to have discussions with companies producing plastic details or selling technology. They could give good inputs on the manufacturing of the product, the design and the leasing system. It is important to remember that the concepts developed in this project are very conceptual and were mainly developed as inspiration.

Another thing that could be recommended to bring forward to further research is the change from phase 1 to phase 2. How can this be done better? How do we know when the best product is found and ready to implement? Maybe it is very hard to answer that, which is why the products are developing every day.

Additionally, it would be good to include a company working with products that are similar to the product that is chosen to develop. This would be helpful during the designing phase and it would hopefully be easier to take the development process one step further and maybe also take the product to final production.

Further studies could also involve products designed for a circular economy. Products that are sold in a “circular way”, for example with a leasing system, are today mainly normal products that are leased. Not many products are designed from scratch to suit in a circular economy, obviously because we do not have a
circular economy yet. But as the thought of changing system becomes more real the developers have to adjust, maybe first of all, to that new system.

How this design for a circular economy could look like we do not know. It would maybe have to be more modular, like the upcoming phone, Phonebloks, build by blocks. Or we might have to encourage the user to care more about her products. Can we even tell our users something new when they are using the product?

These are complex questions but they will hopefully be investigated further in the future.
11. Conclusion

In this chapter the conclusions drawn from the project are described. The questions stated in the beginning of the thesis are being answered and recommendations for further studies are given.

The aim of this thesis was to show how an environmentally friendly product can be developed with a discarded material as starting point. Through analyzing how a product, made of WEEE Plastic, could be developed following steps was proposed;

1. Agree to the company’s vision
2. Evaluate what available material you have
3. Evaluate your technical possibilities with the material
4. Highlight a market possibility
5. Set product requirements
6. Develop the concept

These six steps may be followed in order to develop a green and environmentally friendly product. To validate this proposed method were concepts on a casing for an environmentally friendly thin client developed.

Conclusions drawn from this project was that the development process changes in some ways when starting from a given, discarded material instead of a customer demand. In order to persuade companies to even start working with discarded materials, they need a good reason for it, which is why the first step in the method was included.

If the aim is to develop an environmentally friendly product it is important to expand the role of material selection. Products should be designed while taking into account the properties of the materials, adapting the product to the materials. Step 2 and 3 reminds the developers to evaluate the materials in their proximity.

It was also found that in order to actually develop an environmentally friendly product the specification of requirements should be set in a wider context. Requirements on how the product acts in the society, how it is treated and handled, should be included. The human interaction with the product does also play a large role and human values should therefore also be counted in as product requirements. Step 4 and 5 in the method were developed to consider these conclusions. The development of concepts, done after setting the requirements, will however be made similar to a normal product development process.

As mentioned, a casing for an environmentally friendly product was developed to validate the steps in the proposed method. Through deciding the vision – develop a sustainable product – it was easy to make decisions that otherwise would have been difficult to motivate, without any customer or a company be-
hind. The use of WEEE Plastic, in fact the mixed blend called WEEEBR, was an easy decision in many ways. There was a great amount of material available and the reuse of it would prevent the otherwise only (and least preferred) solution – putting it on landfill. Technically was the WEEEBR best suited to be used in a casing and it was seen that thin clients would be a good environmentally friendly product. Concepts of how the thin client would interact with the larger system – our society – and with the people within it were developed.

The expected result, a guide of how an environmentally friendly product can be developed and an example of doing so have been presented in this thesis. Finally, the aim of the thesis is fulfilled; it is shown how a sustainable product could be developed from a discarded material and a framework for doing so is given.
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Here is the demanded requirements for achieving the C2C certification.

**C2C certification for Basic Level**
- The product shall be produced with fair conditions
- Product is 100% characterized by generic materials
- No banned list chemicals based on supplier declarations
  - Less than 1000 ppm of PVC, PVCD, CPVC, polychloroprene
  - Less than 1000 ppm of arsenic, cadmium, chromium VI, mercury, lead
  - Less than 1000 ppm of HBCD, PBDEs, TBBPA, TDCPP
  - Less than 1000 ppm of DEHP, BBP, DBP
  - Less than 1000 ppm of chlorobenzenes, PCBs, short-chained chlorinated paraffins
  - Less than 1000 ppm of pentachlorophenol
  - Less than 1000 ppm of nonylphenol, octaphenol, nonaphenol ethoxylates, octaphenol ethoxylates
  - Less than 1000 ppm of organotins
  - Less than 1000 ppm of PTFE
  - Less than 1000 ppm of PFOA, PFOS
  - Less than 1000 ppm of PAHs
- Intended metabolism identified for each material (biological or technical nutrient)
- Purchased electricity and direct on-site emissions associated with final manufacturing stage are quantified
- No significant discharge permit violations
- Local, business-specific water issues characterized and mitigation action plan developed
- Self-audit conducted and management plan developed

**C2C certification for Bronze Level**
- Chemicals identified and assessed in 75% (TNs) or 100% (BNs) of materials (by weight) using ABC-X ratings
  - Phase-out strategy developed for X-assessed materials
  - Renewable energy and carbon management strategy developed
  - Facility-wide water audit is completed
  - Full self-audit is completed and impact strategy developed

**C2C certification for Silver Level**
- Chemicals identified and assessed in 95% (TNs) or 100% (BNs) of materi-
als (by weight) using ABC-X ratings

• No carcinogens, mutagens, or reproductive toxins
• Material reutilization score ≥ 50
• 5% of purchased electricity and direct on-site emissions are renewably sourced or offset (for final manufacturing stage only)
  • Product-related process chemicals in effluent characterized and assessed
    OR
  • Supply chain water issues for 20% of Tier 1 suppliers characterized; positive impact strategy developed
  • Material-specific or issue-related audit or certification relevant to a minimum of 25% of product materials
    OR
  • Supply chain social issues investigated; impact strategy developed
    OR
  • Conducting innovative social project
Appendix B - EPEAT certification

Reduction/elimination of environmentally sensitive materials

- R Compliance with provisions of European RoHS Directive upon its effective date
  - O Elimination of intentionally added cadmium
  - R Reporting on amount of mercury used in light sources (mg)
  - O Low threshold for amount of mercury used in light sources
  - O Elimination of intentionally added mercury used in light sources
  - O Elimination of intentionally added lead in certain applications
  - O Elimination of intentionally added hexavalent chromium
  - R Elimination of intentionally added SCCP flame retardants and plasticizers in certain applications
  - O Batteries free of lead, cadmium and mercury
  - O Large plastic parts free of PVC

Materials selection

- R Declaration of postconsumer recycled plastic content (%)
  - O Minimum content of postconsumer recycled plastic
  - O Higher content of postconsumer recycled plastic
  - R Declaration of renewable/bio-based plastic materials content (%)
  - O Minimum content of renewable/bio-based plastic material
  - R Declaration of product weight (lbs)

Design for end of life

- R Identification of materials with special handling needs
  - R Elimination of paints or coatings that are not compatible with recycling or reuse
  - R Easy disassembly of external enclosure
  - R Marking of plastic components
  - R Identification and removal of components containing hazardous materials
  - O Reduced number of plastic material types
  - O Molded/glued in metal eliminated or removable
  - R Minimum 65 percent reusable/recyclable
  - O Minimum 90 percent reusable/recyclable
  - O Manual separation of plastics
  - O Marking of plastics

Product longevity/life cycle extension
• R Availability of additional three year warranty or service agreement
• R Upgradeable with common tools
• O Modular design
• O Availability of replacement parts

Energy conservation
• R ENERGY STAR®
• O Early adoption of new ENERGY STAR® specification
• O Renewable energy accessory available
• O Renewable energy accessory standard

End of life management
• R Provision of product take-back service
• O Auditing of recycling vendors
• R Provision of rechargeable battery take-back service

Corporate performance
• R Demonstration of corporate environmental policy consistent with ISO 14001
• R Self-certified environmental management system for design and manufacturing organizations
  • O Third-party certified environmental management system for design and manufacturing organizations
• R Corporate report consistent with Performance Track or GRI
• O Corporate report based on GRI

Packaging
• R Reduction/elimination of intentionally added toxics in packaging
• R Separable packing materials
• O Packaging 90% recyclable and plastics labeled
• R Declaration of recycled content in packaging
• O Minimum postconsumer content guidelines
• O Provision of take-back program for packaging
• O Documentation of reusable packaging
Appendix C - Calculations for WEEEBR

Rough calculations for the energy needed when producing the WEEEBR were done. The calculations were based on data from HIPS, ABS and PP. An assumption that the last 10% consisted of equal parts of HIPS, ABS and PP was done to simplify the calculation.

**Embodied energy**

*Average embodied energy for producing recycled HIPS, ABS and PP:*

\[
E_{\text{HIPSrecycled}} = \frac{31,3 + 34,6}{2} = 32,95 \text{MJ/kg}
\]

\[
m_{\text{HIPSrecycled}} = 42\% = 0,42
\]

\[
E_{\text{ABScycled}} = \frac{30,7 + 33,9}{2} = 32,3 \text{MJ/kg}
\]

\[
m_{\text{ABScycled}} = 38\% = 0,38
\]

\[
E_{\text{PPrecycled}} = \frac{25,7 + 28,4}{2} = 27,05 \text{MJ/kg}
\]

\[
m_{\text{PPrecycled}} = 10\% = 0,10
\]

*Assumption that the last 10% are represented by a mixture of HIPS, ABS and PP:*

\[
E_{\text{mixedrecycled}} = \frac{E_{\text{HIPSrecycled}} + E_{\text{ABScycled}} + E_{\text{PPrecycled}}}{3} = \frac{32,95 + 32,3 + 27,05}{3}
\]

\[
m_{\text{mixedrecycled}} = 10\% = 0,10
\]

*Embodied energy for producing WEEEBR:*

\[
E_{\text{WEEEBR}} = E_{\text{HIPSrecycled}} \times m_{\text{HIPSrecycled}} + E_{\text{ABScycled}} \times m_{\text{ABScycled}} + E_{\text{PPrecycled}} \times m_{\text{PPrecycled}} + E_{\text{mixedrecycled}} \times m_{\text{mixedrecycled}}
\]

\[
E_{\text{WEEEBR}} = (32,95 \times 0,42) + (32,3 \times 0,38) + (27,05 \times 0,10) + (30,76 \times 0,10)
\]

\[
E_{\text{WEEEBR}} = 13,839 + 12,274 + 2,705 + 3,076 = 31,894 \text{ MJ/kg}
\]

**The embodied energy for WEEEBR was 32 MJ/kg according to the made calculations. This value could only be used as a guidance since proper calculations would require more information about the process. Information that was not available since the manufacturing only have been done in small-scale laboratory. However, it was possible to compare the result to the embodied energy in virgin plastic.**

*Embodied energy for producing virgin HIPS, ABS and PP:*

\[
E_{\text{HIPSvirgin}} = \frac{92,1 + 102}{2} = 97,05 \text{MJ/kg}
\]

\[
E_{\text{ABSVirgin}} = \frac{90,3 + 99,9}{2} = 95,1 \text{MJ/kg}
\]

\[
E_{\text{PPvirgin}} = \frac{75,7 + 83,7}{2} = 79,7 \text{MJ/kg}
\]

The WEEEBR require around 30% of the energy for HIPS and ABS and 40% of the energy needed for producing PP. Still, the energy is supposed to increase when
adding the energy consumption for manually separating and washing the WEEE-
BR that was not included in these calculations. Anyhow, it is obvious that WEEE-
BR can be counted for at least half of the energy consumption compared to a virgin
material. This result is in line with Stockholmsregionens avfallsråd (2010) claiming
that recycled plastic is causing less environmental impact than newly produced.

Same can be said about the CO2 emissions when manufacturing virgin material
compared to recycled material. Lunds renhållningsverk (2009) states that recycled
plastic causes two kilos less emissions per kilo plastic than raw material. Calcula-
tions shows that the CO2 emission for WEEEBR is 1,3 kgCO2/kgWEEEBR. That is
2,5kg less than virgin HIPS and ABS 2kg less than PP.

**CO2 emission**

**CO2 emission when producing virgin HIPS, ABS and PP:**
\[
E_{\text{HIPS virgin}} = \frac{(3.61 + 3.99)}{2} = 3.8 \text{ kg CO2/kg WEEEBR}
\]
\[
E_{\text{ABS virgin}} = \frac{(3.64 + 4.03)}{2} = 3.835 \text{ kg CO2/kg WEEEBR}
\]
\[
E_{\text{PP virgin}} = \frac{(2.96 + 3.97)}{2} = 3.465 \text{ kg CO2/kg WEEEBR}
\]

**CO2 emission when producing recycled HIPS, ABS and PP:**
\[
E_{\text{HIPS recycled}} = \frac{(1.23 + 1.35)}{2} = 1.29 \text{ kg CO2/kg WEEEBR}
\]
\[
E_{\text{ABS recycled}} = \frac{(1.24 + 1.37)}{2} = 1.305 \text{ kg CO2/kg WEEEBR}
\]
\[
E_{\text{PP recycled}} = \frac{(1 + 1.11)}{2} = 1.055 \text{ kg CO2/kg WEEEBR}
\]

**Assumption that 10 % is the average of HIPS, PP and ABS.**
\[
(1.29 + 1.305 + 1.055)/3 = 1.217 \text{ kg CO2/kg WEEEBR}
\]

**CO2 emission when producing WEEEBR:**
\[
E_{\text{WEEEBR}} = (1.29*0.42) + (1.305*0.38) + (1.055*0.10) + (1.217*0.10)
\]
\[
E_{\text{WEEEBR}} = 0.542 + 0.496 + 0.1055 + 0.1217 = 1.2652 \text{ kg CO2/kg WEEEBR}
\]
\[
E_{\text{WEEEBR}} = \text{CO2 emission for WEEEBR} = 1.3 \text{ kg CO2/kg WEEEBR}
\]

**Water usage**

Water usage when producing the WEEEBR could not be calculated since the
laboratory process lack available data.

**Price**

One main issue to highlight when speaking of the processes is the price of the
material. The selling price for one kilo virgin ABS is around 20 SEK, 25 SEK for
HIPS and 15 SEK for PP. The price for WEEEBR has been estimated with help
from the plastic company Rondo.
Manufacture WEEE Plastic to WEEE BR:
It is assumed that washing and regranulating are done at the same facility.

Washing: 1,5 SEK/kg
Regranulating: 3,25 SEK/kg
Transportation: 0,8 SEK/kg

Cost to produce WEEE BR from WEEE Plastic = 1,5 + 0,8 + 3,25 + 0,8 = 6,35 SEK/kg

The price for the manufacturing process is 6,35 SEK/kg. If the WEEE Plastic can be assumed to be bought from recycling facilities for around 6 SEK/kg will the total price be around 12 SEK/kg. That is a very good advantage compared to the other three materials.
Appendix D - MSDS for WEEEBR and ABS

A MSDS shows the technical properties of WEEEBR compared to the properties of ABS.

<table>
<thead>
<tr>
<th>Properties</th>
<th>ABS</th>
<th>WEEEBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer type</td>
<td>ABS</td>
<td>HIPS (~42 %), ABS (~38 %), PP (~10 %) other plastics (~5 %) other material (~4 %)</td>
</tr>
<tr>
<td>Recycled fraction (%)</td>
<td>3.8 - 4.2</td>
<td>100</td>
</tr>
<tr>
<td>Density (kg/m3)</td>
<td>1040 - 1070</td>
<td>~1018</td>
</tr>
<tr>
<td>Price (SEK/kg)</td>
<td>19 - 21</td>
<td>~10</td>
</tr>
<tr>
<td>Colour</td>
<td>Varied</td>
<td>Dark grey</td>
</tr>
<tr>
<td>Young’s modulus (GPa)</td>
<td>2.21 - 2.62</td>
<td></td>
</tr>
<tr>
<td>Yield strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum service temperature (°C)</td>
<td>63 - 77</td>
<td>60 - 80</td>
</tr>
<tr>
<td>Durability: acids</td>
<td>Acceptable</td>
<td>Limited use</td>
</tr>
<tr>
<td>Durability: water</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Durability: UV radiation</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Embodied energy, primary production (MJ/kg)</td>
<td>90.3 - 99.9</td>
<td>~32</td>
</tr>
<tr>
<td>CO₂ footprint, primary production (kg/kg)</td>
<td>3.64 - 4.03</td>
<td>~ 1.3</td>
</tr>
<tr>
<td>Water usage, primary production</td>
<td>167 - 185</td>
<td></td>
</tr>
<tr>
<td>A renewable resource</td>
<td>False</td>
<td>True*</td>
</tr>
</tbody>
</table>

*Not entirely true. Depends on how good the WEEEBR is to recycle and the input flow of other plastics
## Appendix E - List of chemicals and substances in WEEEBR

### C2C's Banned list of chemicals

<table>
<thead>
<tr>
<th>Metals</th>
<th>Content in WEEEP (ppm)</th>
<th>Passed?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Chromium V (Cr)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Flame retardants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hexabromocyclododecane (HBCD)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Penta-BDE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Octa-BDE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Deca-BDE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Polybrominated Diphenyl Ethers (PBD)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Tetrabromobisphenol A</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Tris(1,3-dichloro-2-propyl)phosphate</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Phthalates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bis(2-ethylhexyl)phthalate</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Butyl benzyl phthalate (BBP)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Dibutyl phthalate (DBP)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Halogenated Polymers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyvinyl chloride (PVC)</td>
<td>~1000</td>
<td></td>
</tr>
<tr>
<td>Polyvinylidenechloride (PVDC)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Chlorinated polyvinyl chloride (CPVC)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Polychloroprene</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1,2-Dichlorobenzene (ODCB)</td>
<td>0</td>
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<td>Perfluorooctane sulfonic acid (PFOS)</td>
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<tr>
<td>Perfluorooctanoic acid (PFOS)</td>
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The number is uncertain since only a few experiments and tests have been carried out on a small amount of the WEEEP.
EU's critical raw material

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<td>Beryllium (Be)</td>
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Amount of material is <<1000ppm
Amount of material is <1000ppm
Amount of material is ~1000ppm
Amount of material is >1000ppm
Appendix F - Applied working process in phase 1

The applied working process in phase one followed the picture below. The picture corresponds to picture X in the chapter “Method” in the report.

First sprint - Kind of industry (green)

The first sprint touched upon what kind of industry that matched the properties of WEEE BR.

1. What are the properties of WEEE BR? theoretical

Phase 1 started with a very general gathering of information about the WEEE BR and other similar plastics. Information found is described in the chapter “Theory”. The gathering was made through literature studies and through discussions with the members of the project group. The literature studies included written articles about the WEEE BR, general knowledge about plastics and their areas of use, basic information about C2C and recycling. The properties of WEEE BR were also found through looking at the similar materials HIPS, ABS and PP. This was summarized in a specification of requirements for the industry.

The specification of requirements was a growing document, where new information was added throughout the process. The specification may be compared to the “increment” in the scrum method, as the growing document where all new
achievements from each sprint are added.

2. In what areas are similar plastics used? idea generation
This information settled the base for demands and criteria that the industry had
to fulfil. Through comparing the WEEEBR to other plastics (HIPS, ABS and
PP) and their areas of use an idea generation of possible industries could be
made. Other types of industries were searched for on search engines as “google”.

3. What area of use/industry suits the WEEEBR? evaluation
The specification of requirements for the industry and the list of existing indus-
tries were screened to each other with a concept screening matrix (Ulrich & Ep-
pinger. 2008). The winning industries were later discussed and compared within
the project group and a decision was taken by consensus. The decision was based
on the intention of keeping the material “in the loop”.

Second sprint - Kind of product, within EEE (green-blue)
The second sprint goal was to decide what specific product or product type that
was suitable for the porperties of WEEEBR.

4. What is EEE and WEEE? theoretical
When the industry was chosen more information needed to be gathered about
the specific industry and its requirements of the material. Like, what prop-
ties of the material is important for the EEE? An interview was held with a
professional in WEEE, Kristoffer Elo, discussing pros and cons with using the
WEEEBR in EEE. This contributed to the growing specification of require-
ments.

Information about the recycling of EEE was also studied, both by reading
literature about the recycling process but also when going on study visit to Stena
Technoworld in Halmstad. During the study visit a semi-structured interview
were held with Sven Bång, production manager WEEE. Additionally, a visit was
made to the laboratory where the WEEEBR is produced. This was to gain a bet-
ter understanding about the material itself.

5. In what kinds of EEE are plastics used? idea generation
For the idea generation the EU-directive (Europaparlamentet WEEE. 2003) for
WEEE was used to define EEE and specify product categories. The categories
are used by EU to specify the different waste fractions of EEE and was in this
project used to make sure no products were missed.

A market research was made, categorizing existing products made by similar
plastics. The research was based on a large Swedish technology company, Clas
Ohslon, and based on their range of products. General searching on sites as "google" were also done with the key words “EEE”, “electronics”, “plastics” etc. Additionally, some open brainstorming sessions where done to try to come up with totally new products in EEE.

The market research and the results from the EU-directive were put together in a list with possible products.

6. What EEE suits the WEEEBR? evaluation

The extended specification of requirements were screened twice to the product types included in EEE by a concept screening matrix (Ulrich & Eppinger. 2008). The first screening reminded to the screening made in the first sprint, the proposed products were compared to mechanical properties of WEEEBR. The products that continued to the second screening were screened to requirements as “being a low voltage product” (Europaparlamentet LVD. XXX) and “price”. Also here was a discussion held with the members of the project group to approve the decisions taken.

Third sprint - Kind of concept (blue)

Next achievement was to specify the concept and how it should be matched with the properties and values of WEEEBR.

7. What is the values of WEEEBR? theoretical

The values of the WEEEBR were studied with the gathered literature from earlier steps still in mind. More information about the principles in C2C and environmentally good products were studied. This was done by literature studies. Information about “eco-labels” were also studied as well as the criterias from EU-directives. The banned list of chemicals from C2C’s certification was also studied to see what is important in creating an C2C-certificated product (C2C Innovation Institute....). The found values added more requirements to the specification of requirements.

8. What other products takes advantages of these values and how do the do that? idea generation

In this stage ideas that corresponds to C2C and other “eco-labels” were studied, as were products made of recycled material. Also ideas that corresponds to WEEEBR’s second value, the low price, were generated. The aim was to figure out how they were designed and branded and possible marketing methods were analysed. Furthermore, a visit on a Swedish store for consumer electronics (SIBA) were done to investigate possible parts to use the WEEEBR in. Thereaf-
ter a brainstorming was done to come up with ideas of products that take advantage of the values and that have a possible market. The idea generation resulted in 4 concepts.

9. How can you best take advantage of the values of WEEEBR? evaluation

The values found in the WEEEBR was used as a base when doing a SWOT-analysis for the 4 concepts. The analysis was followed by a discussion and a decision were taken. A survey was sent out to around 500 students at Linköping university to see what they were thinking about the concepts and their environmental impact.

Final concept

Finally, a specification of requirements could be formulated for the concept. The specification followed the model presented by Ulrich & Eppinger (2008), only based on material properties and values instead of customers’ or a company’s demands. The concept was then moved further to phase 2.
Appendix G - List of people that have been contacted

Kristofer Elo - LiU
Taina Flinck - Stena Recycling
Sven Bång - Stena Recycling
Mikael Lindén - Inet (computer store)
Klas Cullbrand - Closing the loop (car recycling)
Patric Svensson - Semcon
Mårten Sundin - El-kretsen (market responsible, recycling)
Eva Sandberg - Zenterio (digitalbox company)
Marcus Svensson - Rondo (plastic company)
## Appendix H - Comparing materials, MSDS

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<th>Properties</th>
<th>ABS</th>
<th>HIPS</th>
<th>PP</th>
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<td>Polymer name</td>
<td>Acrylonitrile butadiene styrene</td>
<td>Polystyrene, high impact</td>
<td>Polypropylene copolymer</td>
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<tr>
<td>Recycled fraction (%)</td>
<td>3,8 - 4,2</td>
<td>5,7 - 6,3</td>
<td>5,26 - 5,81</td>
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<td>Density (kg/m³)</td>
<td>1040 - 1070</td>
<td>1030 - 1060</td>
<td>897 - 906</td>
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<tr>
<td>Price (SEK/kg)</td>
<td>19 - 21</td>
<td>23,3 - 25,6</td>
<td>14,2 - 16,4</td>
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<td>Young's modulus (GPa)</td>
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<td>1,16 - 2,55</td>
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<td>Varied</td>
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<td>Varied</td>
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<td>Varied</td>
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<td>63 - 77</td>
<td>70 - 90</td>
<td>69,4 - 86,8</td>
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<td>Durability: acids</td>
<td>Limited use</td>
<td>Limited use</td>
<td>Excellent</td>
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<tr>
<td>Durability: water</td>
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<td>Excellent</td>
<td>Excellent</td>
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<tr>
<td>Durability: UV radiation</td>
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<td>Embodied energy, primary production (MJ/kg)</td>
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<td>CO² footprint, primary production (kg/kg)</td>
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<td>3,61 - 3,99</td>
<td>2,96 - 3,97</td>
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<td>Water usage, primary production (L/kg)</td>
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<td>132 - 146</td>
<td>37,2 - 41,2</td>
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<td>Embodied energy, recycling (MJ/kg)</td>
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<td>31,3 - 34,6</td>
<td>25,7 - 28,4</td>
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<td>CO² footprint, recycling (kg/kg)</td>
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<td>A renewable resource</td>
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103
<table>
<thead>
<tr>
<th>Properties</th>
<th>ABS</th>
<th>HIPS</th>
<th>PP</th>
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</table>
| Areas of use | • Machine housings, guards, and covers  
• Instrument panels  
• Point-of-purchase displays  
• Models and prototypes  
• Thermoformed trays and tote bins | • Point-of-purchase displays  
• Printed advertising graphics  
• Models and prototypes  
• Thermoformed machine housings  
• Point-of-purchase displays  
• Printed advertising graphics  
• Thermoformed parts  
• Prototypes  
• Shelves  
• Kiosks  
• Fixtures | • Chemical tanks  
• Plating tanks  
• Fire truck water tanks (copolymer)  
• Cutting boards for food preparation  
• Semiconductor equipment cabinets and work surfaces  
• Orthotics and prosthetics |
| Key characteristics | • Outstanding impact resistance  
• Good machinability  
• Easy to thermoform  
• Easy to bond with adhesives  
• Strong and stiff  
• Low cost  
• Flame retardant grades available  
• Available in a wide variety of colours and textures | • Low cost  
• Easy to paint or print on  
• Easy to assemble with adhesives or solvents  
• Outstanding thermoforming characteristics  
• Good machinability  
• High impact strength  
• FDA compliant grades available  
• Available in a wide variety of colours and textures | • Easy to weld using thermoplastic welding equipment  
• Low moisture absorption  
• Good chemical resistance  
• Low cost  
• Extremely tough (copolymer)  
• Excellent aesthetic properties  
• Easy to fabricate  
• FDA compliant grades available |
Appendix I - Summary WEEEBR

Applications
• Models and prototypes ($HIPS+ABS$)
• Machine housings, guards, and covers ($ABS$)
• Instrument panels ($ABS$)
• Models and prototypes ($ABS$)
• Thermoformed trays and tote bins ($ABS$)
• Semiconductor equipment cabinets and work surfaces ($PP$)

Key characteristics
• Easy to assemble with adhesives or solvents ($HIPS$)
• Outstanding thermoforming characteristics ($HIPS$)
• Easy to thermoform ($ABS$)
• Easy to bond with adhesives ($ABS$)
• Low cost ($ABS+HIPS+PP$)
• Easy to weld using thermoplastic welding equipment ($PP$)
• Easy to fabricate
The product areas where WEEEBR shall be used were supposed to include products that:

**Not require a wide range of different colours** - the WEEEBR will have the colour of dark grey and it will need further investigation of the material if other colours than dark grey are needed. Additionally, the colour may vary a little since the consistent depends on the input material in Stena's recycling loop.

**Have soft edges** - it was decided early on in the project that injection moulding was the prefered manufacturing method. Of course, other methods may be used but this thesis will only look into products manufactured by injection moulding.

**Have surfaces thicker than 0,1 mm** - because of the chosen manufacturing process, injection moulding, it is impossible to create surfaces thicker than 0,1 mm.

**Are used in less than 60°C** - the mechanical properties of WEEEBR will change largely if the material is used in temperatures above 60°C. Since the material is recently developed the changing of properties hasn't been evaluated enough and to secure the result of this thesis temperatures above the critical 60°C will be avoided.

**Not are exposed for daily mechanical fatigue** - the WEEEBR is very brittle and should therefore be avoided in products that are exposed for a lot of mechanical impacts such as vibrations, shocks and fatigue.

**Not are exposed for chemicals** - the WEEEBR has not been evaluated in how good it resists chemicals but as the consisting plastics (especially …) should be avoided in contact with chemicals this was expected to be the same with WEEEBR.

**Not are exposed for UV-light** - the WEEEBR does not resist sunlight and should therefore be used in indoor products.

**Not are in contact with food, health care, children etc** - since the WEEEBR is recycled plastics it has a level of uncertainty regarding its consistence. A possible case is that a hazardous substance gets in to the material without knowing, causing troubles for the users. This might be especially important because the waste idnsustry is an area where new legislations is developed frequently.
**Not require parts bigger than 1m²** - because of the mechanical properties and the injection moulding process products that are bigger than 1m² should be avoided.

**Can be recycled in an existing recycling process** - since the WEEEBR is recycled material its existence depends on the input on new plastics. It is therefore said to be of importance that the material is coming back to where it came from, to secure the quantity. This is important since it is difficult to imagine developing a product starting from a material if the stream of new material is decreasing.
Appendix K - Screening

List of industries

A list of the industries/areas of use that has been looked at is presented below.
• Machinery manufacturing
• Automotive industry
• Ship building industry
• Electrical and electronic equipment (EEE)
• Textile industry
• Paper industry
• Steel works
• Chemical industry
• Building industry
• Furniture industry
• Food industry
• Healthcare
• Agriculture industry
•
Appendix K - Screening

Specification of requirements - Industry

The requirements for the industry. These were made into questions (see below) that was answered during the concept screening:

• Not require a wide range of different colours (Have the colour of WEEE: dark grey, black)
• Have soft edges (because of injection moulding and material properties)
• Have surfaces thicker than 0,1 mm (because of injection moulding and material properties)
• Be used in less than 60°C
• Have a lifetime of 2-3 years
• Have a reasonable price
• Not be exposed for daily mechanical fatigue
• Not be exposed for chemicals
• Not be exposed for UV-light (be used indoors)
• Can be recycled in an existing recycling process (or preferable manually?)
• Not be in contact with food, health care, children etc
• Not require parts bigger than 1m2

Explanation

1. Questions that were answered when evaluating the industries.
2. Heat exposure, is the industry exposed to temperatures >60°C
3. Material thickness, does the industry require a thickness thinner than 0,1mm
4. Mechanical fatigue, is the material exposed for daily fatigue?
5. Chemical exposure, is the material exposed for chemicals?
6. Numbers of colours, is the colour of the material important? How many different colours are needed?
7. Cleanliness, does the industry require a clean (hygienic) material?
8. Size, does the industry require products bigger than 1m²?
9. UV-light, is the material used outdoors?
10. Recycling possibilities, is there a existing recycling process for the material/industry?
### Appendix K - Screening Industry Selection criteria

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**Concept screening**. Furniture industry is used as reference concept. (Electrical equipment = EEE)
## Appendix K - Screening

Concept screening 2 Industry. Result with EEE as reference

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Concept screening. Electrical electronic equipment (EEE) is used as reference concept.
Appendix K - Screening

Concept screening Industry. Result

Continue?
1. EEE
2. Furniture industry
3. Building industry*
4. Automotive industry**

*Building industry is recomended by Ze. It may be possible to increase the strength properties of the material to suit buildings. Though, none of the members of the project have studied architecture and more knowledge in this area would be needed.

**The plastic parts in automotive are probably carefully designed plastic details and therefore the automotive industry is decided to be too complex for continuos work. More knowledge about the car industry would be needed.
Appendix K - Screening

List of products

- Sound/picture
- Photo/video
- Computer devices
- Tablets, I pads etc
- Mobile phones
- Fixed telephony
- Heat/cold/ventilation
- Instalation material
- Switches/outlets/plugs
- Cables/multiple sockets
- Timers
- Lightning
- Solar panels
- Measurement equipment
- Batteries/chargers
- Torches
- Alarm/safety
- Thermometers/
- weather stations
- Watches
- Electrical hand tools
- Statitionary tools
- Handtools*
- Painting*
- Glue/tape/chemicals*
- Protection*
- Storage/garage*
- Padlock/key cabinet*
- Interior/furniture
- Windows/doors/
- hanging*
- Screws etc*
- Wheels*
- Water/sewage
- Small kitchen devices
- Kitchen equipment*
- Set the table*
- Cleaning equipment
- Clothes care*
- Storage*
- Body/health*
- Dentalcare
- Haircare
- Office*
- Garden
- Forest/firewood
- Outdoor life
- Bicycle*
- Boat
- Large household
- appliances (food)
- Large household
- appliances (washing)
- Automatical
- dispensers
- Sport equipment
Appendix K - Screening

Specification of requirements - Product

This appendix shows the requirements for the products. Same requirements have been used (italic) as in the specification for Industry and then another requirements have been added (normal). These requirements were used in two screenings.

The product shall

• Not require a wide range of different colours (Have the colour of WEEEP: dark grey, black)
• Have soft edges (because of injection moulding and material properties)
• Have surfaces thicker than 0,1 mm (because of injection moulding and material properties)
• Be used in less than 60°C
• Have a lifetime of 2-3 years
• Not be exposed for daily mechanical fatigue
• Not be exposed for chemicals
• Not be exposed for UV-light (be used indoors)
• Can be recycled in an existing recycling process (or preferable manually?)
• Not be in contact with food, health care, children etc
• Not require parts bigger than 1m2
• Is included in electrical and electronic equipment (EEE)
• Not be exposed for high pressure
• Not be exposed for water (since it’s electronic equipment)
• Is included in the low voltage directive (LVD)
• Is produced in a quantity suitable to the amount of WEEE/BR
• Is produced in a quantity that corresponds to the amount required in the Ecodesign directive (200.000 pieces/year)
• Takes advantage of the values of WEEE/BR (price and environmentally friendly)
• There is a growing market for green products
• Price is reasonable and suits the price category of WEEE/BR
• Be designed for easy disassembling
• Be made of materials that are easy to recycle

Fulfil the requirements of the C2C Certification, level Basic
Appendix K - Screening

**The product should**
- Be able to material recycle two til five times without loosing it’s material properties

**The product may**
- Be in contact with skin
Appendix K - Screening

Concept screening 3 Type of product

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<th>Photo/video</th>
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<th>Tablets, Ipad etc</th>
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<th>Switches/outlets</th>
<th>Instalation material</th>
<th>Cables/multiple sockets</th>
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Result

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**Products**
## Appendix K - Screening

**Concept screening 3 Type of product**

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<td>+</td>
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<td>-</td>
<td>-</td>
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<td>+</td>
<td>-2</td>
<td>0</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

*It is difficult to say if the complexity of a product is positive or negative.

### Positive properties (+):
- The product **is** categorized as EEE
- The product **is not** in contact with food
- The product **does not** require high heat resistance
- The colour of the product **does not** have a great value
- The product **does not** require high resistance against vibrations
- The product **does not** require high pressure/tensile resistance
- The product **is** manufactured in a suitable quantity
- The product **is not** regularly exposed for UV-light

### Negative properties (-):
- The product **is not** categorized as EEE
- The product **is** in contact with food
- The product **does** require high heat resistance
- The colour of the product **does** have a great value
- The product **does** require high resistance against vibrations
- The product **does** require high pressure/tensile resistance
- The product **is not** manufactured in a suitable quantity
- The product **is** regularly exposed for UV-light
Appendix K - Screening

Concept screening 3 Type of product. Results

Total results
Photo/video
Computer devices
Mobile phones
Installation material
Switches/outlets/plugs
Cables/multiple sockets
Timers
Measurement equipment
Batteries/chargers
Torches
Alarm/safety
Thermometers/weather stations
Watches
Painting*
Cleaning equipment
Office*
Automatical dispensers

Complex products
Photo/video
Computer devices
Mobile phones
Automatical dispensers
Cleaning equipment

Non complex products
Installation material
Switches/outlets/plugs
Cables/multiple sockets
Timers
Measurement equipment
Batteries/chargers
Torches
Alarm/safety
Thermometers/weather stations
Watches
Painting*
Office*
Appendix K - Screening

Concept screening 3 Type of product

<table>
<thead>
<tr>
<th>Screening 2</th>
<th>PRODUCTS</th>
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<tbody>
<tr>
<td>Included in LVD (low voltage directive)</td>
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<tr>
<td>There is a growing market for &quot;green&quot; products</td>
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</tr>
<tr>
<td>Products where price is very important</td>
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<tr>
<td>Result Ranking</td>
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<table>
<thead>
<tr>
<th>Cleaning equipment</th>
<th>Watches</th>
<th>Thermometers/weather stations</th>
<th>Torches</th>
<th>Measurement equipment</th>
<th>Timers</th>
<th>Installation material</th>
<th>Cables/multiple sockets</th>
<th>Mobile phones</th>
<th>Computer devices</th>
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<td>Automatical dispensers</td>
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</tbody>
</table>

120
Appendix L - Replacing ABS with WEEEBR

The technical properties of WEEEBR have been compared to the ones for ABS using a MSDS. This comparison was done in order to give an objective analysis of how a plastic company would react if they were to use WEEEBR instead of ABS. Properties of the two materials are summoned in following appendix D. As can be seen in the MSDS the WEEEBR is, as other recycled materials, not as resistant as virgin materials. The properties have degraded because of the recycling process and is not as technically good as the virgin materials. WEEEBR is more sensitive to mechanical fatigue and impacts, UV-light and chemicals. A plastic company would probably prefer to buy another material, for example ABS or even metal, than buying WEEEBR if high resistance is required. If a plastic company however wants to use WEEEBR it is recommended to avoid products which are exposed for fatigue and mechanical impacts nor to chemicals or UV-light.

Same thing applies for plastic companies requiring high temperature resistance. WEEEBR has a service temperature on around 60 to 80°C that compared to other plastics is very normal. The plastics HIPS, ABS and PP are normally not used in temperatures higher than this and neither should the WEEEBR be. A plastic company demanding materials with high resistance to temperatures are recommended to buy another material. In temperatures around 60 to 80°C the plastic company might prefer to go for the WEEEBR. Only, the big variance of temperature (20°C) could cause a problem when designing a product since the developer does not know how the material will react. The more specific the forecast of the material’s reaction is the better.

Engineering Materials (2013) writes about a material, Hycolene, that has the advantage of being 10 - 12 % lighter than other virgin materials. The same could be said about WEEEBR, even if the difference in density between WEEEBR and ABS is small. In a product with demand of low weight the WEEE-BR could have an advantage. The bad mechanical resistance of WEEEBR could, however, lead to the need of a thicker structure resulting in the same weight for ABS and WEEEBR.

One of the advantages of ABS and the reason for why it is used in the LEGO bricks is the many colours it exists in. (Brunder. 2012). WEEEER on the contrary is only available in various dark grey, see picture A.

![Picture A. Show some samples of the WEEE-BR after it has been manufactured.](image)
Uncertainty of the input material also causes a slight uncertainty and variation of the colour of WEEEBR. The colour might be possible to modify but this would need further investigation, which was not done during this project. A plastic company would normally prefer to buy the ABS, a material with more choices and variation in colours and with a higher material certainty. An interesting aspect is if the product is designed to be that specific colour of WEEEBR already from the beginning. For example, if the black colour of the product is a requirement. Imagine a product absorbing solar light, the colour will here play a big role as different colours absorbs light differently and the black colour could be an advantage. However, WEEEBR will degrade in UV-light so this specific use is no good for the material. But it is interesting to see if the plastic company can adapt the product to the colour of the material instead of adapting the material to the product.

Coatings and colourings would of course be possible to use to change the colour of WEEEBR. But this will not be further investigated in this thesis since it require more knowledge on additives and on how the are affecting the WEEEBR.

Since the WEEEBR is a new material never used before it need some evaluation before being released on the market. A new material has to pass through the existing legislation, if not it will be hardly impossible to sell the WEEEBR to a company.

The RoHS directive is one of the most well-known directives that every new material has to pass. Fortunately, none of the prohibited materials in RoHS are found in WEEEBR. WEEEBR and ABS could therefore be stated equal in this point of view. Companies are doing many decisions on habit and they rarely want to change something working well. Because of this further comparison were made using the critical raw materials proposed by EU and the banned list of C2C. Here were some low amounts of antimony (Sb), mentioned on the critical raw material list, observed in the fraction. Which might decrease the will of replacing ABS with WEEEBR. Important to mention is that the list of critical raw material principally was created in order to limit the extraction of these materials. Since the materials in WEEEBR are not extracted but recycled one could argue for the relevance of the use of the list. Same argument may be used discussing the fact that WEEEBR contains about 1000 ppm PVC. PVC is stated as one of C2C’s banned materials. The use of PVC can be discussed but since the WEEEBR is produced by recycled material it is difficult to limit the PVC. Additionally, if the PVC is decreasing in new produced products then the PVC will eventually disappear from the WEEEBR as well (i.e. there will be no input of PVC in the recycling process). But as mentioned before, companies are not
willing to break their habits and if WEEEBR has some low values of PVC and ABS not it is difficult to persuade the company to the change. A total list of the materials can be found in appendix A.

Even if the WEEEBR is possible to classify as a legal material some product areas were defined as impossible for the material. A plastic company producing products requiring high cleanliness and certainty of the included substances will never replace ABS to WEEEBR. By safety reasons this will be avoided, especially when a recycled material always vary with a few percent depending on the input material.

A generally used manufacturing process when producing plastic details of ABS is injection moulding. It is one of the most popular plastic manufacturing processes and can be used for WEEEBR as well. Though, the WEEEBR might cause some troubles when switching from a virgin plastic to recycled plastic, leading to a higher cost. Injection moulding is normally used for products that are quite small, not have any sharp edges nor thin edges and surfaces. For every detail a new mold have to be produced and that are quite expensive. Changing from ABS to WEEEBR will therefore require a large initiation fee for the company.

Yet another difference between ABS and WEEEBR is the fact that WEEEBR is based on recycled material. The existence of WEEEBR depends on the input material and it is therefore of great importance that new input material continuous is provided to Stena. To not be totally dependent on other products and their materials it is preferred that the product is going back to Stena in some way. Preferably back to the WEEE fraction. Otherwise this will cause another uncertainty for the plastic company buying the WEEEBR, an uncertainty of quantity on the market.

As stated by Plastics Europe (2012) a lot of the plastic companies are located in Asia. Here it is important to differ between the plastic production and the product manufacturing. A plastic company may produce both the plastic and the products made of plastic but it can also do only one of these processes. The WEEEBR can either be shipped as the non-processed problematic fraction to a plastic production in Asia or be shipped as already processes WEEEBR. A disadvantage is however that the material, in contrary to ABS, has to be shipped the whole way from Sweden to Asia. The products manufactured in Asia are, ironically, then sent back to Sweden and other European countries. A possibility could be to use these empty product containers to ship the WEEEEEBR to Asia. The production in Asia is known to be cheap and closely linked to the development of new products which is why it might be hard for the WEEEBR to compete with Asia produced plastic. An advantage of using ABS is that the raw
material is produced closer to the product manufacturing. Starting up a business in Sweden, producing both the material and manufacturing the products could be a way of raising the value of using WEEE BR. The WEEE BR could be claimed as locally produced and transportation will also decrease.

The price is also one of the factors influencing when the company is choosing material. As can be seen in the MSDS the difference in price between ABS and WEEE BR is big. A company that is willing to buy a plastic with lower quality are probably interested in making a replacement. Said that the replacing costs, like transportation and modifying processes, are smaller than the possible profit.

A company interested in providing a green image and making environmentally friendly decisions might also be interested in WEEE BR. As is highlighted in the earlier calculations the WEEE BR has lower energy consumption and CO2 emissions than virgin ABS. This is not affecting the material's properties itself and might be hard to use as an argument for why a plastic company should replace the ABS with WEEE BR. But it is still very relevant to keep in mind. Especially when new legislations about the level of recycled material is taking into account. One example is the new legislation from TCO Development requiring that 85% of the plastic used in computer screens are recycled. With a higher pressure from the government it can be a good decision for a company to change their ABS to a more ecofriendly material such as WEEE BR.

If you also add the increasing customer interest and their increased will of buying green and eco-labelled products it might be a very good decision to distinguish a product by being green. But it is hard to claim that by just using WEEE BR the product is green, to do that a much wider and thoroughly investigation of the manufacturing process has to be done.

A part of this investigation has actually been done by Yu (2014). In his studies he has been examining the recyclability of the WEEE BR and also how it is affected by age. This was of importance because if the material shall be claimed to be green it needs to have a long lifetime and good recyclability.

Finally, most of the properties of WEEE BR have been claimed to be worse than the ones of ABS. It is observed that it might be difficult to persuade a plastic company to use WEEE BR in their products instead of ABS only by looking at technical properties. One might argue that the technical degradation of properties are a result of the treatment in the recycling process and that by changing the recycling process a better (technically) material can be provided.

But as was mentioned before, the recycling process is the one that is most feasible at the moment. The WEEE BR do has some advantages in comparison to ABS and by avoiding products that require material with high resistance,
many colours and cleanliness a cheap and environmentally friendly product can be developed.
Enkät om "grön" elektronik

Q1 Rangordna vilken av dessa produkter du helst skulle köpa som en "grön" produkt (med en positiv miljöpåverkan)

Svarade: 219  Hoppade över: 2

<table>
<thead>
<tr>
<th>Produkt</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Totalt</th>
<th>Genomsnittlig rankning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stationär dator</td>
<td>38,36%</td>
<td>43,84%</td>
<td>17,81%</td>
<td>219</td>
<td>2,21</td>
</tr>
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<td></td>
<td>84</td>
<td>96</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td>54,79%</td>
<td>41,55%</td>
<td>3,65%</td>
<td>219</td>
<td>2,51</td>
</tr>
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<td></td>
<td>120</td>
<td>91</td>
<td>8</td>
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</tr>
<tr>
<td>Digitalbox</td>
<td>6,85%</td>
<td>14,61%</td>
<td>78,54%</td>
<td>219</td>
<td>1,28</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>32</td>
<td>172</td>
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</tr>
</tbody>
</table>

Appendix M - Survey at LiU
Enkät om "grön" elektronik

Q2 Vilken av dessa produkter tror du har störst negativ påverkan på miljön?

Svarade: 210  Hoppade över: 11

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<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Totalt</th>
<th>Genomsnittlig rankning</th>
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</thead>
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<td>39,05%</td>
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<td>TV</td>
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<td>56,94%</td>
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<td>4,29%</td>
<td>92,38%</td>
<td>210</td>
<td>1,11</td>
</tr>
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</table>
Enkät om "grön" elektronik

Q3: Har du lämnat in/lagat eller på annat sätt fått service av någon av dessa produkter?

Svarade: 211  Hoppade över: 10

<table>
<thead>
<tr>
<th>Svarsval</th>
<th>Svar</th>
</tr>
</thead>
<tbody>
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<td>7,58%</td>
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<td>Digitalbox</td>
<td>2,84%</td>
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<tr>
<td>Ingen</td>
<td>69,67%</td>
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Totalt antal svarande: 211
Q4 Lagade du denna/dessa själv eller lämnade du in den/dem på service?

Svarade: 201  Hoppade över: 20

<table>
<thead>
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<th>Svarsval</th>
<th>Svar</th>
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<tbody>
<tr>
<td>Själv</td>
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</tr>
<tr>
<td>Lämnade på service</td>
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<tr>
<td>Båda</td>
<td>16</td>
</tr>
<tr>
<td>Inget av dem</td>
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<tr>
<td>Totalt</td>
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</table>
**Enkät om "grön" elektronik**

**Q5 Vilken av dessa produkter tror du är lättast att laga själv?**

Svarade: 210  Hoppade över: 11

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<td>6,19% 13</td>
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<td>Digitalbox</td>
<td>12,38% 26</td>
</tr>
<tr>
<td><strong>Totalt</strong></td>
<td><strong>210</strong></td>
</tr>
</tbody>
</table>
Q6 Rangordna vilken av dessa produkter du helst skulle vilja laga själv?

Svarade: 208  Hoppade över: 13

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<td>Digitalbox</td>
<td>12,50%</td>
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<tr>
<td>Totalt</td>
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</tr>
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</table>
Enkät om "grön" elektronik

Q7 Vilken av dessa produkter skulle du helst hyra (stället för att köpa själv)?

Svarade: 205  Hoppade över: 16

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<td>Digitalbox</td>
<td>62,44%</td>
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<tr>
<td>Totalt</td>
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</table>
Appendix N - Summary EPEAT in existing computers

<table>
<thead>
<tr>
<th>Product/Criteria</th>
<th>HP ProDesk 600 G1 Tower Business PC</th>
<th>DELL OptiPlex 9020 MT</th>
<th>DELL Studio Hybrid</th>
<th>Apple Mac mini (MD387)</th>
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</thead>
<tbody>
<tr>
<td>Reduction/elimination of environmentally sensitive materials</td>
<td>5 of 5</td>
<td>5 of 5</td>
<td>5 of 5</td>
<td>5 of 5</td>
</tr>
<tr>
<td>Materials selection</td>
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<td>0 of 3</td>
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<tr>
<td>Design for end of life</td>
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<td>2 of 2</td>
<td>2 of 2</td>
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<tr>
<td>Energy conservation</td>
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<td>1 of 2</td>
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<tr>
<td>End of life management</td>
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<tr>
<td>Corporate performance</td>
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<td>2 of 2</td>
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<tr>
<td>Packaging</td>
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<td>3 of 4</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>19 of 24</td>
<td>18 of 24</td>
<td>18 of 24</td>
<td>19 of 24</td>
</tr>
</tbody>
</table>

Promoted as a green product                  No | No | Yes | No
Content of recycled plastic                15% | 40% | 0%  | 0%

<table>
<thead>
<tr>
<th>Product/Criteria</th>
<th>Lenovo ThinkCentre M92/M92p Tower</th>
<th>Apple Macbook Pro *optimal</th>
<th>WEEEP computer *likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction/elimination of environmentally sensitive materials</td>
<td>5 of 5</td>
<td>5 of 5</td>
<td>5 of 5</td>
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<tr>
<td>Materials selection</td>
<td>2 of 3</td>
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<td>3 of 3</td>
</tr>
<tr>
<td>Design for end of life</td>
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<td>5 of 5</td>
<td>5 of 5</td>
</tr>
<tr>
<td>Product longevity/life cycle extension</td>
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<td>2 of 2</td>
<td>2 of 2</td>
</tr>
<tr>
<td>Energy conservation</td>
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<td>1 of 2</td>
</tr>
<tr>
<td>End of life management</td>
<td>0 of 1</td>
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<td>1 of 1</td>
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<tr>
<td>Corporate performance</td>
<td>2 of 2</td>
<td>2 of 2</td>
<td>2 of 2</td>
</tr>
<tr>
<td>Packaging</td>
<td>3 of 4</td>
<td>3 of 4</td>
<td>2 of 4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>20 of 24</td>
<td>19 of 24</td>
<td>22 of 24</td>
</tr>
</tbody>
</table>

Promoted as a green product                  Yes | Yes | Yes | Yes
Content of recycled plastic                40% | 0%  | 95% | 65%
Appendix O - Inner components

**Motherboard:**
Size: 170 x 170 mm  
Price: 590 SEK  
Weight: 0,75 kg

**Power supply:**
Size: 100 x 125 x 64 mm  
Price: 349 SEK  
Weight: 1,4 kg

**Memory:**
Price: 398 SEK  
Price: 386 SEK

**Flash memory:**
Price: 556 SEK

**Total price:**
1893 SEK  
Total weight: 2,15 kg (exclusive memories and cables)

~Not needed~
Case (recommended)

https://www.inet.se/produkt/1902619/gigabyte-ga-j1800n-d2h-mitx  
https://www.inet.se/produkt/6900117/fsp-300w-sfx-bulk  
https://www.inet.se/produkt/5305525/corsair-4gb-2x2048mb-ddr3-so-dimm-1333mhz  
https://www.inet.se/produkt/5315032/corsair-4gb-2x2gb-cl9-1333mhz-value-select  
https://www.inet.se/produkt/4304401/a-data-ssd-sx900-series-64gb  
https://www.inet.se/produkt/6909323/silverstone-milo-ml05b-svart
Appendix P - Functional requirements

These are the functions that are required for the case. The requirements are divided by mandatory (M) and optional (O).

**Protect inner components**
The case of the thin client *shall*:
- Protect the inner parts against dust (M)
- Protect the inner parts against water (M)
- Protect the inner parts against shocks (M)
- Cover the inner components (M)
  - Microprocessor (170 x 170 mm)
  - Flash memory (64 Mbit flash memory)
  - Power supply (100 x 125 x 64 mm)
  - DRAM memory

**Facilitate reutilization and recycling of inner components**
The case of the thin client *shall*:
- Facilitate the reuse/recycling of the inner components (M)
- Easy reach the inner components
- Quick reach the inner components (less than 30 sec)
- Not destroy the inner components
- Be able to material recycle (M)
- Easily break down
- Fast break down
- Not break down in small pieces

**Keeping the thin client together**
The case of the thin client *shall*:
- Keep the inner components on their right place (M)
- Keep the inner cables on their right place (O)
- Be easy to disassemble (O)
- Hold the inner components together (M)
  - Hold the case together (M)

**Protect the user**
The case of the thin client *shall*:
- Protect the user from touching the inner parts (M)
- Protect the user from annoying sounds and absorb the sound from the inner parts (O)
- Protect the user from electrical shocks (M)
The case of the thin client shall not:
• Be in direct contact with food (M)
• Be in circumstances where the temperature is over 80°C (M)
• Be in contact with water (since it is EEE) (M)
• Be exposed to high pressure (M)

The case of the thin client may:
• Be in contact with skin

**Facilitate cooling of the inner parts**

The case of the thin client shall:
• Protect the inner parts from getting overheated (M)
• Facilitate passive ventilation of the inner parts (M)
  • Air in in the bottom and front
  • Air out in the top and sides/backside

(Thermal design power (TDP) from the CPU: 10W → passive cooling is sufficient)

**Connect to other clients**

The case of the thin client shall:
• Have space for inputs/outputs for (M)
  • 4 USB 2.0
  • 1 USB 3.0
  • 2 PS/2 (keyboard and mouse)
  • 1 display (HDMI)
  • 3 audio jacks (line in, line out, mic in)
  • 1 D-sub port
  • 1 RJ-45 port
  • Power supply
  • Gigabit ethernet

**Communicate with the user**

The case of the thin client shall:
• Show if its on/off (4)
• Be easy to understand for the user (M)
• Show how good the internet connection is (O)

**Ergonomically facilitate for the user**

The case of the thin client shall:
• Facilitate for the user to reach the ports (O)
• Facilitate serving of the inner parts (M)
• Be able to lift with one hand (M)
• Have a size so that it can be put in/on a shelf (<400*400*400 mm) (M)
• Can stand by itself (do not tip) (M)
• Hide the cables/sort the cables (M)

Guide the user to its functions
The case of the thin client shall:
• Encourage the user to switch it off when not in use (O)
• Encourage the user to give it away to a recycling facility in the end-of-life (O)
• Encourage the user to keep the thin client for a long time (O)

The case of the thin client may:
• Encourage the user to a greener overall lifestyle (O)
## Appendix Q - Relative matrix

| Encourage to | Encourage recycling | Encourage the user to switch it off when not in use | Keep the inner cables on the right place | Lower annoying sound | Show if it is on/off | Be ergonomic (easy to reach ports) | Show internet connection | Show that it is made of recycled material | Encourage the user to switch it off when not in use | Encourage to recycling | Encourage to long life time | Be easy to disassemble | Be assembled | Total Normalized WEIGHT |
|--------------|---------------------|--------------------------------------------------|------------------------------------------|---------------------|---------------------|-------------------------------|-------------------------|--------------------------------|---------------------|---------------------|------------------------|----------------------|----------------------|
| 1            | 1                   | 1                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 1                   | 1                   | 1                      | 1                    | 1                    |
| 1            | 1                   | 1                                                | 1                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 1                   | 1                      | 1                    | 1                    |
| 1            | 1                   | 1                                                | 1                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 1                   | 1                   | 1                      | 1                    | 1                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 1                   | 1                   | 1                      | 1                    | 1                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |
| 0            | 0                   | 0                                                | 0                                        | 0                   | 0                   | 0                            | 0                       | 0                              | 0                   | 0                   | 0                      | 0                    | 0                    |

| 7            | 7                   | 7                                                | 7                                        | 7                   | 7                   | 7                            | 7                       | 7                              | 7                   | 7                   | 7                      | 7                    | 7                    |

| 0,77         | 0,66                | 0,55                                             | 0,55                                     | 0,77                | 0,22                | 0,33                         | 0,11                     | 1                              | 0,55                | 5                   | 0,55                    | 0                    | 0                    |

| 0,75         | 6,5                 | 55                                               | 55                                       | 1                  | 10                  | 1                            | 1                       | 1                              | 1                  | 1                   | 1                      | 1                    | 1                    |
Appendix R - Sketches