Designed for Recycling
Service design in the world of product development
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SUMMARY

The flow of waste electronics is increasing, while at the same time valuable resources used in electronics are growing increasingly scarce as demand increases. Part of the problem is that products are not built to be recycled, which in some cases lead to degradation of materials and valuables such as gold ending up in low concentrations in scrap metal. Stena Recycling wants to mitigate these effects by initiating communication with designers of products, as they are key stakeholders in how recyclable a product will be.

Through an integrated process involving both designers and recyclers a service has been created in order to bridge the knowledge and cultural gaps between the recycling industry and product developers of electronic equipment. The service is centered around a product analysis and a feedback report where recycling and end of life aspects of the product are discussed. Advice on how to improve the product's recyclability from a current perspective is provided in the service, as well as an outlook on the future of recycling. The service has been tested on two major cases and two reference cases to verify requirements and make the service broadly applicable and relevant.

Keywords: recycling, WEEE, Design for recycling, disassembly, design for disassembly

Foreword

Environmental issues have been a current topic for a while. Making a difference through one good design is of course good but trying to approach the issue more widely and trying to change behaviours, thus affecting several designs would be better. We chose this project based on a mutual understanding between ourselves and Stena Recycling that the way we design, use and throw away products today is largely unsustainable. Stena wanted the designer's perspective which we could provide, and so we decided to venture jointly into this Design for Recycling project.

We would like to take this opportunity to thank all involved especially our supervisors Mats Torring from Stena Recycling and Ralf Rosenberg from Chalmers for all the support and for the patience they have had with us.

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The teachers and researchers from Chalmers we would like to thank are: Örjan Söderberg, Oskar Rexfeldt, Lena Bendrioua, Lars-Ola Bligård, Maria Knutson-Wedel, Mattias Andersson, Erik Stenvall, Christer Ekberg, Petra Andersson

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Crem international, the washing machine company and the small electronics company for being kind enough to let us use their products.

List of abbreviations

General Abbreviations

CRT	Cathode Ray Tube
DFD	Design for disassembly
DFE	Design for environment
DFR	Design for recycling
EEE	Electrical and electronic equipment
EOL	End of life
LCA	Life cycle analysis
PCB	Printed Circuit Board or Polychlorinated biphenyl (a PVC additive banned in 1977)
PD	Product Development (and its department in a company)
WEEE	Waste electrical and electronic equipment
R&D	Research and development
RoHS	Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment
REACH	Registration, Evaluation, Authorization and Restriction of Chemical substances
C2C	Cradle-to-cradle

Material Abbreviations

ABS	Acrylonitrile butadiene styrene
ASA	Acrylonitrile Styrene Acrylate
EPDM	Ethylene propylene diene Monomer (M-class) rubber
FR	Flame retardant
GF30	30% glass fibre
G40	40% glass fibre reinforcement
MD40	(40% mineral reinforced)
PA	Poly amide
PC	Poly carbonate
PU	Poly urethane
POM	Polyoxymethylene
PP	Polypropylene
PPS	Polyphenylene sulphide
T20	20% talc

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Introduction

Background

Due to increasing raw material prices and decreasing material resources recycling is getting more important in order to enable us to use the materials we need in the future. At the same time consumption is increasing, thus consuming more resources. As the development of technology advances materials become more complex. On one hand materials become more durable and lighter, lasting longer and consuming less energy in transport. On the other hand the composition of materials makes it harder to separate and extract valuable and hazardous substances.

The link between manufacturers and recyclers need strengthening as the manufacturers must become better at designing products that are better from a recycling point of view. And who could be better in aiding with the recycling issues than the recycling companies?

Recyclers would benefit from educating their customers to construct products that are easier disassembled and more suitable for recycling. Better design for recycling means it would be possible to separate the different components and materials, resulting in cleaner recycled materials. This in turn would increase both the recycled material's properties and their potential usage performance, thus increasing the value of them. This value motivates the project, as manufacturers, recyclers and re-users as well as the environment would benefit from increased recycling.

Aim and research questions

The overarching goal of this project is to increase recycling in electronics industry. This will be done by bridging the information gap between recyclers and product developers. Specifically, these questions will be looked into:

How can the recyclability of electronic products be improved?

What do product developers of electronics need to know to be able to design their products for recycling?

In what form can recycling knowledge be transferred from recyclers to product developers?

Goal

The goal of this thesis work is to create a feedback mechanism, offered by Stena Recycling to the electronics manufacturers. The manufacturer provides a product to Stena Recycling which is then analysed with regards to recycling. Stena Recycling should then communicate back relevant information and enable the manufacturers to create products more suitable for recycling (Figure 1). The function should ideally affect construction and material choices, requirement and manufacturing processes and product development culture towards creating products better fit for recycling.

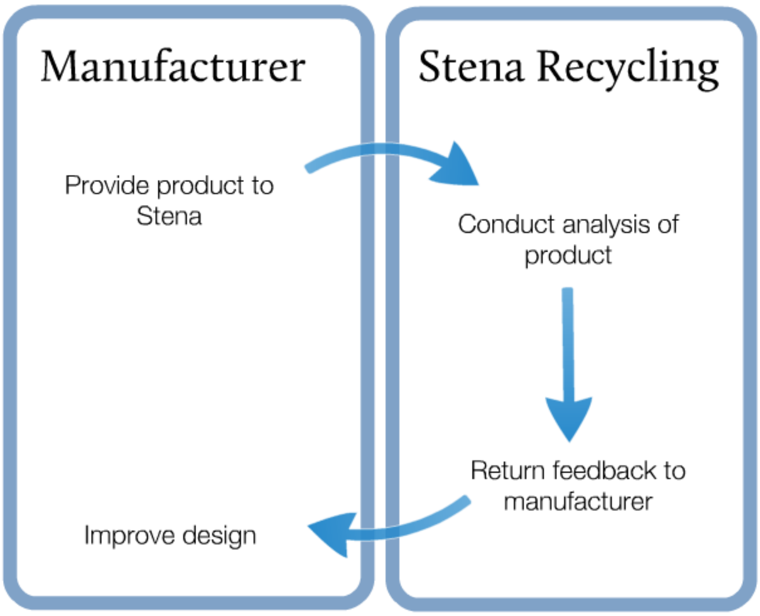


Figure 1. Basic schematics on how the service work

Delimitation

The target customer in this project will be consumer electronics manufacturers. This is to have a graspable scope and to be able to reach a relevant result. Similar projects would be beneficial to conduct in other areas such as automotive industry. In this project components on the circuit boards will not be analyzed as these components often are essential and not easily exchanged. This report do not consider the product life cycle outside the recycling phase, such as energy consumption during use etc. even if this is a very important aspect, neither does this thesis include the packaging of the product.

1 Methods, tools and process

1.1 Planning

The initial planning stages centered around stakeholder management - getting both Stena and Chalmers to reach a consensus on an feasible project and scope to delve into. As soon as the project was defined, a Gantt planning chart was set up to plan for the project and a SWOT created for early trouble shooting. A stakeholder objective chart was created as a Venn diagram to map out stakeholder interests.

1.1.1 Gantt chart

A Gantt chart is a planning tool, where the stages of the project are visualized as bars on a timeline. This is created jointly in the project group and gives the members a unified view on the project process. The chart becomes a reference later on in the project so that deadlines down the line are not compromised. It also works as a big picture ToDo-list, showing e.g. when it is time to start writing the report etc.

1.1.2 Calendars

A shared Google calendar was set up to book meetings, study trips and other information on the project group members. A big visual cardboard calendar was created for the same purpose, showing more detail than the gantt chart as a quick reference for deadlines and time progression.

1.1.3 SWOT

SWOT, short for strength, weakness, opportunity, threat is an aid in forecasting how a project will progress. The project group discusses around what strengths, weaknesses, opportunities and threats there are to take into account. These factors can then be further looked into, for instance if a threat is a potential for failure of the whole project then perhaps the project scope should be redefined. SWOT is also useful in the final evaluation of a project - was the SWOT forecast correct? Did the strengths come into play etc.

1.1.4 Venn diagram

Venn diagrams are overlapping circles where each circle represents a stakeholder or other entity. The intersecting areas visualize the mutual interests or factors of the entities.

1.2 Information gathering

The information gathering in this project has been centered around observations, interviews and literature. The information was collected through study visits to factories, recycling branches and disassembly plants, an exhibition on Cradle to cradle certified products, a seminar on EU's eco-design directive, a conference on future recycling, and also a recycling workshop with a design department of a garden equipment manufacturer.

1.2.1 Observations

In user studies, one can use structured or unstructured observation. Structured means that the observer is looking for a specific aspect, and knows before the observation what to look for. Unstructured is more for a general understanding of the observed phenomenon. Observations can also be naturalistic, meaning the observer tries to interfere as little as possible in the behaviour of the observed. Observations can also be participatory, which means the observer performs the action to study in order to gain first-hand observational experience.

Sometimes, the observed acts in a different way when he/she knows they are being observed, perhaps even trying (subconsciously or consciously) to comply to the observers perceived desired response. This could lead to distorted conclusions and is called observer-expectancy effect. Imagine for instance an ergonomist coming in to judge the office environment. Chances are the staff would sit up straight and try to work more ergonomically than they normally would, simply because there is an ergonomist in the room.

1.2.2 Interviews

In the research phase, interviews are an essential tool to gather information. Interviews come in three modes: unstructured, semi-structured and structured. The structured interview is where the questions are set before the interview and no answers outside of those questions are taken into account. A semi-structured approach is where the questions are set before the interview, but the interviewer can ask follow-up questions to relevant answers and pursue interesting leads. The unstructured interview is even looser, letting the conversation lead to where it is going within the defined discourse.

1.2.3 Survey

A survey is similar to a structured interview, where defined questions are asked and sent out to relevant respondents. There can be room for open questions in a survey, but more defined answer alternatives can yield more "hard" and reliable data. The benefit of surveys compared to interviews is that a big number of participants is possible without a big cost. The downside is the lack of depth and motivations behind an answer that an interview could provide.

1.3 Idea generation

1.3.1 Sketching

Sketching is a way to visualize ideas fast, used in the creative parts of a project process. Sketching is important for communication between project group members to get everyone on the same page to avoid misunderstanding.

1.3.2 Brainstorming

This method is for idea generation. There are many ways to do brainstorming, but the main idea is

- present a problem and its boundaries
- the group then brainstorms ideas on how to solve the problem - either individually written or straight away in a group discussion
- no feedback is allowed during the brainstorming session

The “crazy” ideas that come up during a brainstorming might open up for realistic ideas in the same vein of thought. After the brainstorming session, the ideas need to be refined and evaluated against the initial problem.

1.4 Analysis & Evaluation

1.4.1 Mental Model

A mental model is a representation of what is going on inside someone’s head, how they relate to the real world. It is used to communicate within a workgroup and to set goals for a desired mental model. It can be visual or text based. The easiest representation is to make something that takes up a lot of thought processes bigger, but mental models can be complex. An example of a mental model is the angel and devil on the shoulder known from cartoons, a gimmick used to represent different aspects of a personality.

1.4.2 Weighted Matrix

A weighted matrix is a way to compare different concepts or products semi-objectively. Aspects are weighted according to relevance, for instance prize could have a weight of 5 but quality a weight of 3 on a scale 1-5. The different products are then rated on each aspect, and the rating is multiplied with the weight before summarizing the total score. The total score is then used to measure the different concepts against each other.

1.4.3 After action review - AAR

The AAR is a really simple but effective tool that is useful when discussing the outcomes of a project. It was developed for the U.S. military where bureaucratic review processes are often not possible out in the field. The after action review asks three questions:

1. What happened?
2. What did you think would happen?
3. How do you explain the difference?

1.4.4 Role playing workshop

This way of meeting is a way to engage meeting participants in theoretical discussions. By taking on the role of a certain stakeholder (such as designer, recycler and manager), discussions around a problem or challenge come alive and conflicts of interest are brought to the surface in a way that would not happen during a simple group discussion.

2 Pre-study

To be able to improve a product, from a disassembly and recycling point of view, manufacturers need to know the demands from the recyclers and how they can design in a more sustainable way. In order to find some answers to these issues a wide market research was conducted. In this research we wanted to obtain a deeper knowledge of the recycling process as well as the problems and possibilities related to it. We also aimed at understanding the mechanisms of the recycling business and the incentives for recycling. This research also aimed at discovering future prospects in materials, techniques and systems for recycling**.**

This theory chapter is a description of the most relevant findings from the conducted literature study, interviews and study visits.

2.1 Sustainability and environmental models

Sustainability is a wide and complex topic. There are many stakeholders to consider. Different organizations and organs have tried to define what sustainability is for them and how to run a sustainable planet. This has resulted in many definitions, but the common denominator is the aim at making the definitions easy to understand and implement. Below, we will define the most commonly spread definition.

> "We have infinite responsibility, but limited capacity"
> -*Brian Palmer* (2011)

2.1.1 Brundtland – Our common Future

The expression s*ustainable development* was expressed for the first time in 'Our Common Future', a report written by World Commission for Environment and Development (WCED) in 1987. It describes sustainable development as: "*the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission On Environment and Development, 1987). This is now known as the Brundtland definition, named after the Norwegian politician Gro Harlem Brundtland who was heading the commission. At its core, the definition is a compromise between economics and ecology, between increase in global wellbeing now and maintaining systems for the future (Ekman, 2011). It is normally illustrated with a three-part Venn diagram as seen in Figure 2, where sustainable development is a system that is sustainable socially, ecologically and economically (people, planet, profit).

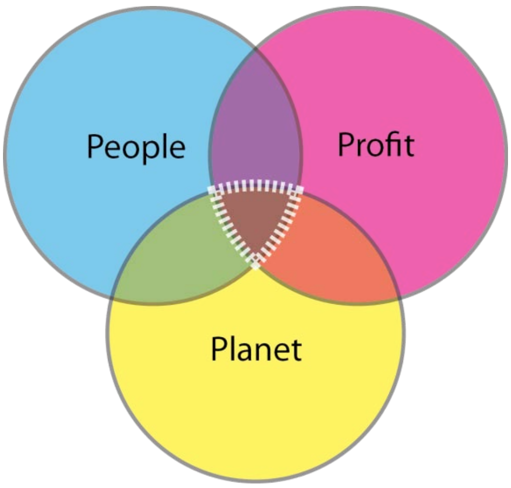


Figure 2. The triple bottom line model of sustainability.

Sustainable development is then defined as the middle of the diagram where these three aspects overlap. For a forestry company, this would mean that they earn enough to stay in business (economic), while workers are safe and live a good life (social) while only cutting down as many trees that the forest can regenerate and caring for the ecosystems: water use, respect for animals, not polluting (ecological). This approach aims for the triple bottom line, as opposed to the single bottom line of purely capitalistic companies that seek the goal of profitability exclusively.

The increasing population, demand for higher quality of life and technological eco-efficiency all have impact on the environment. With these three factors in mind the future sustainable society is a challenging goal, one that can only be reached if the eco-efficiency is increased ten times over. In other words, material input per service must be reduced with 90% in the production-consumption system to become sustainable. Anything less than 90% only slow down the current depletion of environmental resources (Vezzoli & Manzini, 2008).

Human development is tightly connected to resource and energy consumption. While this is not sustainable, lowering resource consumption while still having a growing global economy (*decoupling*) have proven to be problematic, as our energy and resource consumption keeps increasing with economic development in countries such as China, India and Brazil. Put another way, it has been shown that a 10% increase in income will lead to a 9% increase in energy use(Holmberg, 2010). The decoupling question is then: how can we make a 10% salary increase lead to a decline in energy use?

2.1.2 The Natural Step

The Natural Step (The Natural Step, 2011) has developed a model for integrating sustainability in the strategic planning of organizations. The model is based on a comprehensive research and scientific studies and is constantly evolving as it is used.

The natural step has a funnel metaphor which describes how resources are decreasing (the top wall) while the demand for resources are increasing (the bottom wall) due to population growth and a global increase in the standard of living. The metaphor describes how the walls are closing in on earth (Figure 3) unless we change the relation between resource use and economic growth.

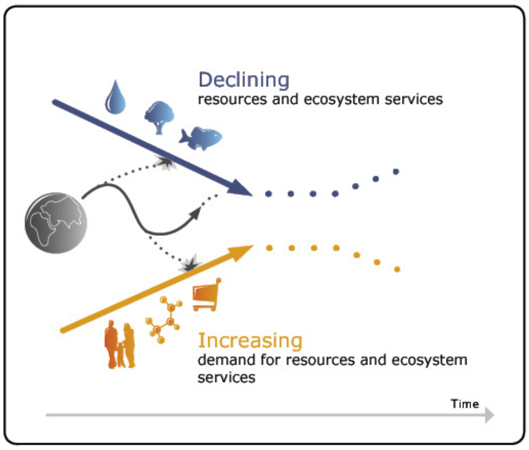


Figure 3. The funnel which earth will have to travel through.

> "In a sustainable society, nature is not subject to systematically increasing:
>
> - Concentrations of substances extracted from the earth's crust
> - Concentrations of substances produced by society
> - Degradation by physical means
> - and people are not subject to conditions that systematically undermine their capacity to meet their needs "

The natural step provides these four practices that we need to move away from in order to reach sustainability. These conditions set the boundary for what we, humans must not expose our nature to and violating these boundaries would result in an overexposed nature and an un-sustainable society. (The Natural Step, 2011)

2.1.3 Planetary Boundaries

Developed at Stockholm Resilience Centre, this model illustrates 8 macro scale natural systems that human activities impact and affect (see Figure 4 below). These systems all have tipping points where the human activity is upsetting the systems' long term balances. The purpose of the model is to map out and describe the ecological challenges of today, and assess where we are at concerning the tipping points. A tipping point could be described as a system being resilient and

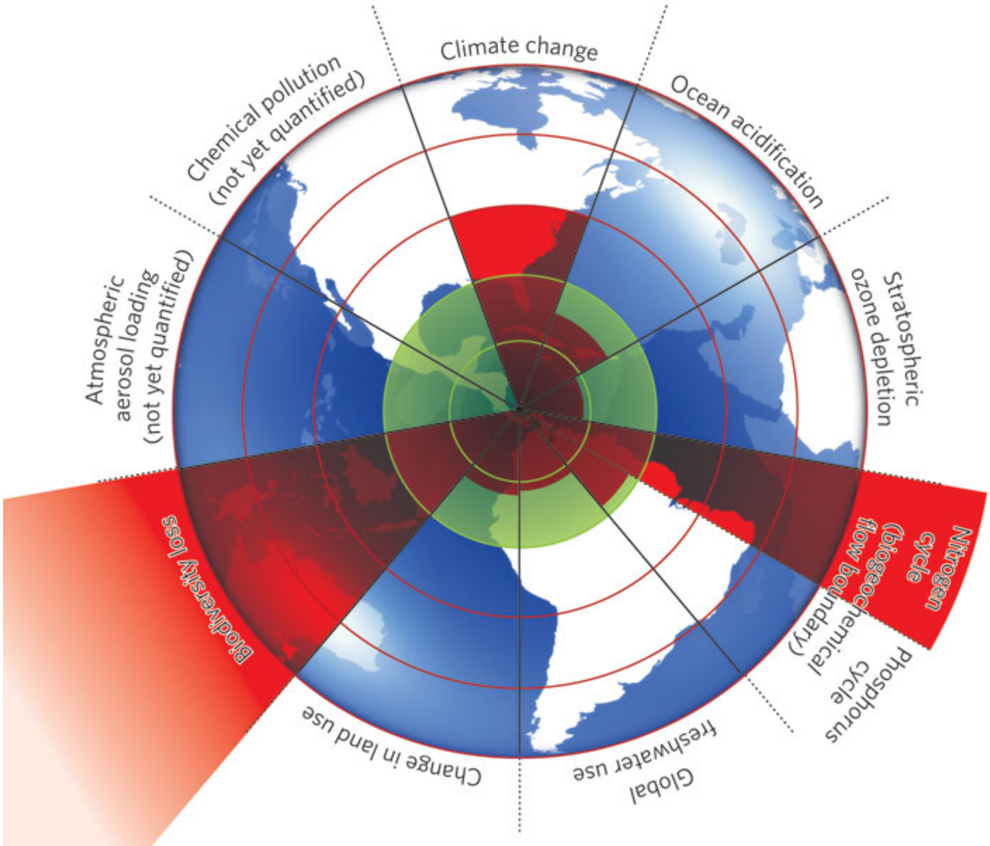


Figure 4. The planetary boundaries are breached. Staying within the green field is sustainable.

then rapidly deteriorating when a certain threshold, or tipping point, is reached (like a stretched out rubber band suddenly breaking). The tipping points of different eco-systemic factors are often interlinked and hard to quantify and measure accurately, which adds to the complexity. Another tricky part is that the feedback loops are really slow, so that when the problem becomes notable the system might already have shifted beyond repair.

Related to resource consumption and the recycling industry the boundary of climate change is of course central, caused mostly by our fossil fuel energy sources and the transports of products and material. The planetary boundaries model also shows that there are still a lot of known unknowns and probably even some unknown unknowns about how the system responds to human activity and our industrialized society (Rockström, 2009).

2.1.4 Cradle to Cradle and Sustainable Material Flows

Whereas a lot of effort in sustainability is put into describing the complexities and shortfalls of today's system, Cradle to Cradle (C2C) is a back-casting approach that poses the question how a sustainable industrial society would work. It is also the name of the toughest certification that a product can achieve in terms of being eco-friendly. The main answer is waste=food, that is, a future sustainable society cannot have any waste. Used products must have a second life in some form.

To achieve this, society needs to have closed and separated loops of material and substance flows: technical “nutrients” and biological nutrients (Figure 5). The technical nutrients are completely pure synthetic or refined materials (such as metals) that can be recycled forever in an industrial process. Even ppm-level additives will dilute the technical nutrients over time. The biological nutrients are materials from nature that can be decomposed and regenerate in nature (such as wood). Both nutrient types have to be completely safe for humans and ecosystems. This all implies products have to be completely material separable down to the smallest component, removing glues, composites, paints and lacquers, even rare alloys from the equation. In a way, it promotes a more orderly and disciplined approach to the entropy which now constitutes our materials universe.

C2C sets the bar really high and has thus been a driver for inventions in sustainable design - by not accepting any halfway solutions. It differs from other approaches is that it strives towards doing good, instead of being less bad. This is something that really attracts product developers, as the prospect of adding to the consumerist society is not a problem anymore. If a product is inherently eco-effective and creates a positive impact, consuming more would actually be beneficial! This is of course an interesting angle for companies that work within our capitalist system.

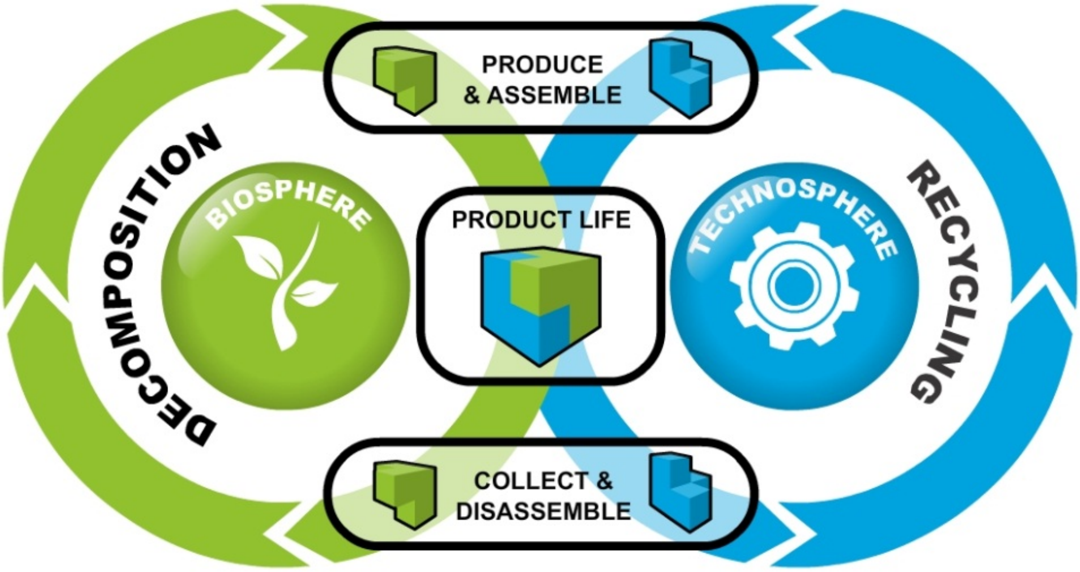


Figure 5. The two loops of Cradle-to-Cradle approach.

The hegemony of C2C has gotten some criticism; mainly around the locked-in nature of certification and approval (only companies associated with the creators know what materials are considered ok). The nutrient aspect is also debatable, as nutrients are not always good - an example of that are the fertilizers from agriculture that pollute the oceans by also fertilizing algae (Bjørn, 2011). C2C does not work with grey zones, at least not in its purest demagogical form (Potting & Kroezey, 2010). This will be discussed more when with regards to e.g. flame retardants in electronics where a compromise is needed, at least for the time being.

2.2 Recycling

2.2.1 The Re-Ladder

When talking about recycling, it is important to be distinct with the terminology. Can incineration of a computer screen be called recycling? Hardly. What about a plastic cup thrown into a municipal heat plant?

Recycling of electronics has historically mostly meant recovery of circuit boards, steel and copper. From an ecological sustainability perspective, we want the recycling to preserve the properties of the product or its components as much as possible. The “upstream” work and energy put into the function and material should only be undone as a last resort. Thus, there is a clearly defined hierarchy of recycling practices, one being preferred over the other. The hierarchy may vary for different product types, but the general preferred order of approach is as follows:

- Repair (maintain product)
- Recover and re-use functional modules or components
- Recycle materials
- Recover energy

(Kellner, 2009)

Notice that the last resort in this recycling hierarchy is energy recovery. In other models landfill is sometimes shown the last resort. Here it is not included since it is not a means of recycling. Were we to show the end-of-life processes currently employed, one could add landfill at the bottom.

Most materials and components start crude and gain complexity through refinement and shaping as the product is created. When the product reaches end-of-life (EOL), the value drops for the first time. This is the game-theoretical lopsidedness the society needs to adjust in order to raise reuse and recycling levels. In many cases, recycling is technically possible but not economically feasible due to cheap virgin materials and new products lowering the demand for recycled. Consider for example this toaster in Figure 7, which is sold new for 129 SEK (Rusta, 2011). It is so cheap that creating a business model where collection, repair and resale of old toasters would be very hard to get going, even though it would make sense from a material flow perspective.

Figure 7. On a second hand market nearly worthless toaster.

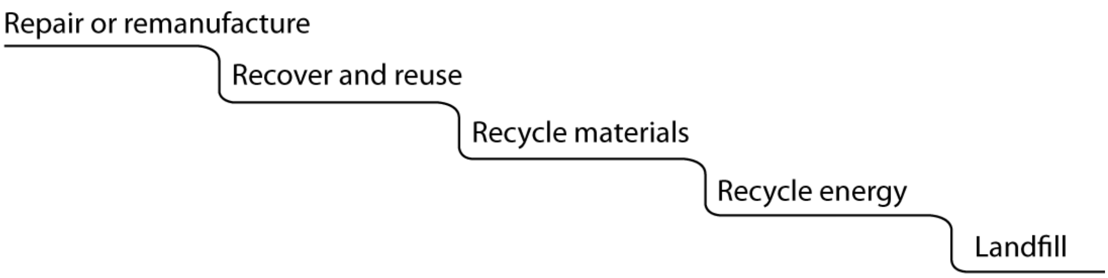


Figure 6. The hierarchical re-ladder with landfill as a last resort.

2.2.2 Material flows

Simplified, virgin materials are mined then produced into products, which are then used by users and eventually disposed of. New materials are either mined from the earth crust or recycled from waste products. Today most of the material comes from mines, while some is recycled material. Iron is a material that is easily found and extracted from the earth crust. Other materials are found in low amounts scattered around in the earth crust making them harder and more expensive to mine for. Due to the low concentrations, these materials would be very expensive to mine if the aim was to extract only these materials. Luckily these materials lie in areas with higher densities of materials that are more valuable to extract. As of this coincidence the rare materials are extracted together with the mined material. An example of this is the mining of zinc, which result in materials like cadmium, indium, germanium and silver being extracted in addition (Lehner, 2011). This implies that the supply of some metals is dependent on other, making the material flows more complex. A question one could ask is what happens with the flow of germanium if a zinc-mine is closed down?

After extracting materials from the earth crust, the materials are refined and manufactured into products. To get the right properties materials are often mixed with each other, creating composites that are hard to separate. Bromine is for instance added to a plastic in order to get a plastic with better thermal properties (more on this in the Flame retardants chapter in 2.2.5). This causes problems when recycling as the bromine is very expensive to separate from the plastic, which lead to an unwanted mix of plastic and the value of is consequently decreased (Sjölin, 2011).

When recycling metals one must keep in mind what materials are melted together and in what amounts e.g. if a small amount of copper end up together with the iron scrap fraction the quality of the resulting iron is diminished, while the properties of the resulting copper is marginally changed even if there would have been small amounts of iron together with the copper when it was melted (Lehner, 2011). Full listing of combinations can be seen in Appendix 2.

The recycling techniques of today enables products to be recycled to a high percentage, but if the products doesn’t get to the recyclers the effectiveness of the recycling process can’t be utilized to the maximum. The diagram in Figure 9 from (European Union, 2011) shows the amount of produced electrical and electronic equipment (EEE) and the amount of collected waste electrical and electronic equipment (WEEE).

It illustrates the problems with the waste not getting to the recycler. This is not a problem specifically for the electronics industry. According to research (Pardos Marketing, 2005) over 196 million tonnes of plastics were consumed 2005 and the forecast predicts a consumption exceeding 360 million tonnes in year 2015 only.

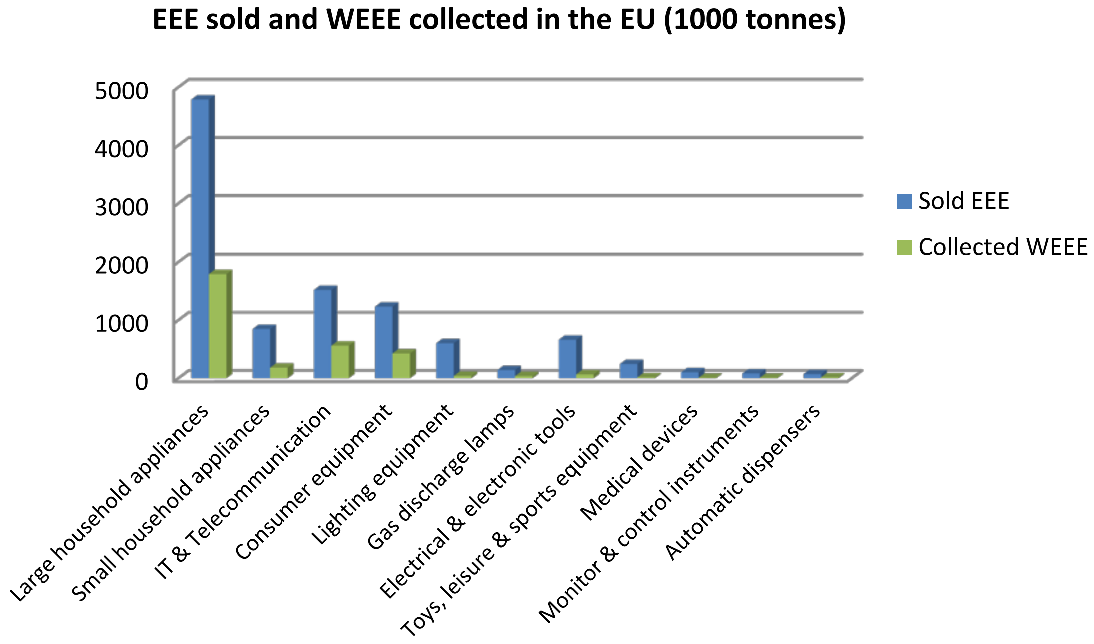


Figure 9. A comparison of sold EEE and collected WEEE divided into product categories

Little of this is recycled, incinerated or even put on landfill, instead a lot of plastics end up in the nature and in the oceans. Oblivious to most people there are floating trash islands in the middle of the oceans that have become called the pacific garbage patches (Figure 8) and they constantly pollute the oceans as the plastics degrade. The garbage also ends up as food for fish, whales and birds disturbing their digestion (Figure 10).

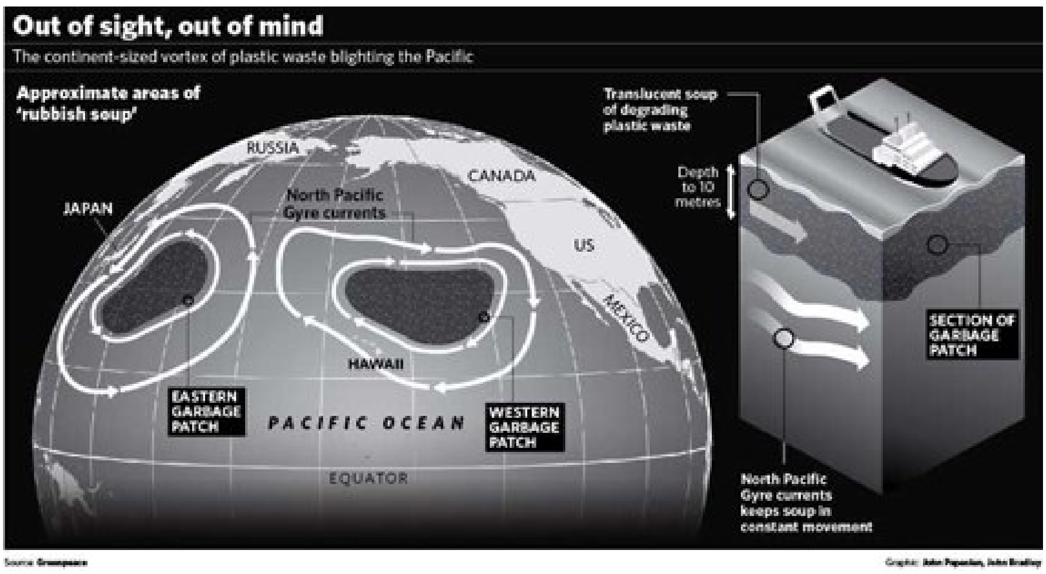


Figure 8. The rubbish soup known as the eastern and western garbage patch.

Figure 10. Plastics found in an albatross chick on Midway Atoll in the middle of the pacific ocean (Jordan, 2009)

Not only is it harmful for the environment and animals that products are thrown away into the nature there are also economical profits lost. Aluminum, for example, demands a high amount of energy to be processed from ore to usable material, compared to the energy needed to recycle aluminium to new aluminium. The former method consumes 20 times more energy as the latter (European Aluminium Association, 2011).

2.2.3 Valuable materials

The last few years, the industrial expansion and growth of the economy in Asia have seen an increase in demand for materials used in the production of electronics. Examples include gold which has great conductive properties, palladium which is used in computer processors and indium, a rare earth metal which is used in transparent conductive layers of LCD-displays. Palladium and gold have recycling practices in place, and account for most of the values on computer circuit boards. For indium, there is no recycling in place today although research is ongoing. With today's pricing of indium, we will run out the next 15 years. Running out will not happen though, as the demand for indium will likely drive prices to new heights, and extracting from previously unprofitable deposits will become profitable (Sjölin, 2011).

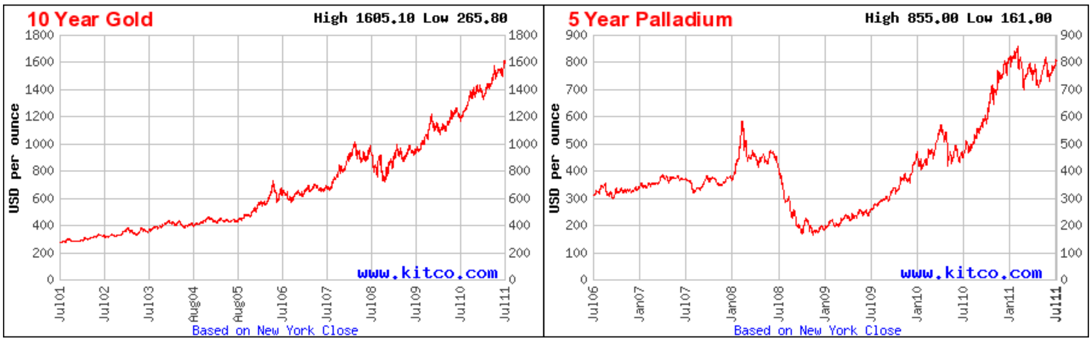


Figure 11. The development of gold and palladium prices (Kitco, 2011).

2.2.4 The business case for recycling

Who earns money from increased recycling practices? The monetary loss for a product's lifecycle is naturally highest for the customer, who pays to access the function the product provides and not to make money off of it. The customer might also have to pay for the waste management of the product (e.g. a municipal fee).

Recyclers earn money through a simple business model: buy waste, sort it into fractions and sell the "refined" waste for profit (often to specialized “sub-recyclers” all over the world). The model also works with “negative pricing”, that recyclers get paid to accept hazardous or difficult waste and then pay subcontractors to take care of the waste. Since different waste types call for different processes, many recyclers are more into separation, logistics and trade than actual material extraction and reproduction. The processes of extracting gold from mixed metals, for instance, is often handled by mining companies down the chain who hold great expertise in metallurgic processes (Lehner, 2011).

For recycler's the materials and their flows are the commodity. Recycling, when not dictated by law, is a function of profit more than it is a function of technological limitations. If there is profit to be made, it can be recycled or taken care of. The stepping stone are mostly the volumes and the logistics of it. If the materials come from factory scraps, they are often pure and predictable which is good and make for valuable waste. Most recyclers sell complete solutions where they take care of all waste for a factory or business, not because they make money from all fractions but because the client is happier to just have one contact point to waste management.

Since recycling historically has not been seen as a must-do, the market played out so that many virgin materials are cheaper than recycled. A perfect example of this is styrofoam (foam made from polystyrene). The foam is made from pure PS and very easy to recycle, yet these foams have been the source of environmental controversy. The reason is that the density of the foam is so low, while the transportation costs are too high for any business incentive to recycle it. So the secondary emissions from transporting styrofoam waste is the culprit(Torring, 2011).

For recyclers, mixed waste from households is not as valuable since it takes more processing to recycle well. If the recycling process is costly, it can create a situation where district heating plants pay more for the burnable waste (plastics) than the recyclers, and materials end up incinerated. Designing products that are faster and easier to disassemble would increase the recycler’s margin and competitiveness as well as decrease the producers cost for EOL treatment. From the producers point of view a design for recycling and disassembly could make maintenance easier as well as strengthen their brand. The objectives of recycling from both the recycler and the producers point of view is seen in Figure 12. In Japan, many of the electronics companies have a vertical ownership with product development, production and WEEE management. Since waste management is not an externalized cost, the companies have an easier time reusing old components (Goosey, 2009)

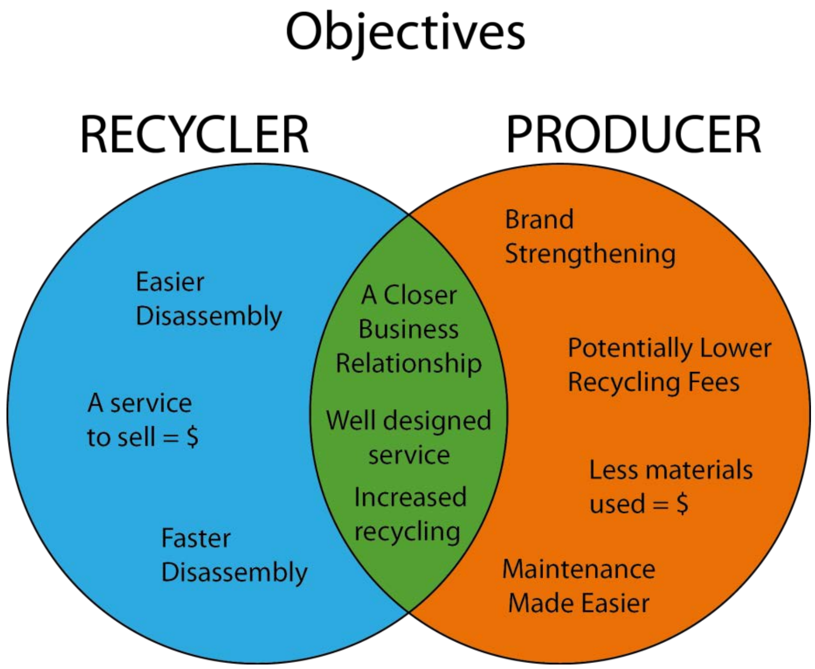


Figure 12. A visualization of the overlapping of the recyclers and producers objectives.

The volatility and increase in prices make the manufacturers want to use as little valuables as possible to make their products cheaper. This means that new products have less and less gold in them. For the recyclers the trend is similar albeit backwards. The price make e.g. the gold worth to recycle in smaller quantities, but the decline in prevalence in the product might make the gold end up in scrap fractions since it will not be extracted. This game theoretical paradox is one of the reasons traces of gold is found in reinforcement bars, as scrap iron might be exported to other countries where e.g. concrete steel is made and the gold is tied to the material and then tied into a wall of a building. This means valuable (in more than an economic sense) resources are locked into buildings for as long as those constructions will stand (Torring, 2011).

2.2.5 Hazardous materials

Many materials and substances have over time been found out to be dangerous or plainly lethal to the human or nature. Some toxins do not surface for a long time and might be carcinogenic or mutagenic and these effects can sometimes be hereditable (Vezzoli & Manzini, 2008). Historically substances like radium, mercury, arsenic and chlorinated pesticides have been used in different areas with the belief that they would be harmless to humans, only to later be proven quite the opposite. These are not the only substances and there are constantly new discoveries. When those occur they are sooner or later banned completely or limited to a few areas of use, however strictly regulated.

An example of this right now would be the use of antibiotics, and the resistant bacteria growth in the sewage system. In the future, measures to limit this development might be deployed to safeguard society and keep antibiotics effective (Nilsson, 2011).

Batteries

Batteries come in many different shapes and sizes and also different material compositions. Batteries contain many heavy metals and toxic substances that need to be taken care of properly. When recycling electronics it is important to separate all batteries from the devices before further processing. Mercury oxide batteries are hazardous and contaminate surrounding materials if the batteries are shredded together with the rest of the electronics. Cadmium is a heavy metal that is toxic and sometimes used in batteries. Usage of these types of batteries should be minimized. But if they have to be used the product should be marked and the batteries should be easy to remove. Today batteries are removed manually, which is time and resource consuming. Designing for an easy extraction of batteries simplifies the disassembly process and is a legal requirement through the WEEE directive (Sjölin, 2011; Kell, 2009).

Radium

In the early 20th century radium was used to paint watch hands in order to make them glow in the dark. The radium was substituted for other substances in the 1960's as it was found to be the cause of the death of the painters. Radium was also used in toothpaste and drinking water (Figure 13) as it was believed to have positive effects on health (Oak Ridge Associated Universities, 1998)

Figure 13. Radium water anno ca 1928

Flame retardants

Flame retardants prevent the materials to burn with a flame and resist spreading of fire. Besides from being used in EEE they can be used in furniture, textiles, vehicles etc. where the risk of fire is considered to be higher and the consumer safety is at risk. There are several different types of flame retardants working with different principles (EFRA, 2010). Many of the flame retardants are toxic in themselves while others have health related issues. An early flame retardant was PCB which was banned 1977 as it was found to be toxic and had effects on i.e. the liver and the nervous system. Today the most widely used category of flame retardants are the brominated flame retardants. This group consists of TBBPA, HBCD, PBDEs, DBDE, OBDE and pentaBDE. All but TBBPA and DBDE are considered bad due to the toxicity and the higher risk of health issues in children. TBBPA is used in 70% of printed circuit boards and is considered to be safe when reacted into the PCB according to the EU Risk Assessment. As an additive in plastics TBBPA is classed as a toxic substance. The European risk assessment found the DBDE to be safe to use. Even though both TBBPA and DBDE are considered safe there is still too little research done and the information on the toxicity is limited(Stevens & Goosey, 2009).

2.2.6 Legislation

WEEE

According to the 2008 review of the Waste electrical and electronic equipment directive (WEEE) directive the amount of e-waste in the EU will reach about 12,3 million tonnes per year by 2020 from today's 10,3 million tonnes per year (United Nations University, 2008). This increase is concerning both from a waste quantity point of view but also that a part of the WEEE contains hazardous substances and ought to be handled correctly. A part of the work in handling theses issues is the WEEE directive, which imposes the responsibility of disposal of EEE to the producers. Some of the things that need to be separated from the waste stream are batteries, CRTs, toner cartridges, components containing mercury etc. The full list of regulated materials see extract from the WEEE directive in Appendix 1 (European Parliament and the Council, 2003). The directive aim to increase the public awareness of their role in dealing with WEEE and also minimizing the amount of electronic waste going to landfill of incineration through improve the re-use and recycling of WEEE. WEEE products are to be marked with the crossed-out wheelie-bin mark, as seen in Figure 14 (Butler, 2009).

Figure 14. The Wheelie bin sign.

RoHS

The Restriction of Hazardous Substances Directive (RoHS), constituted by the European Union in 2003, prohibit or limit the use of certain hazardous substances. Theses being lead (Pb), mercury (Hg), cadmium (Cd), hexavalent chromium (Cr^{6+}), polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE). The legislation is applicable on EEE put on the market after of 1st July 2006. The maximum allowed amount of Hg, Pb, Cr^{6+}, PBB, PBDE in a single component is 1 ‰ while the limit is 0,1 ‰ for Cd.

There are some exceptions to the ban. Mercury is allowed in very small amounts in some fluorescent lamps. Lead is allowed as solders in some special cases (e.g. military applications) and as an alloy in Steel under certain prerequisites (European Parliament and the Council, 2003).

As this legislation is only valid within the European Union there are issues with these substances being present in components imported from overseas. There are similar legislations applied in other parts of the world e.g. the Management Methods for Controlling Pollution by Electronic Information Products that is the Chinese equivalent to the RoHS directive (Stevens & Goosey, 2009).

Currently RoHS compliant products are marked in many different ways, as there is no standardized mark or sign for it. Companies have so far made their own logos and marks.

Reach framework

The REACH (Registration, Evaluation, Authorisation and Restriction of CHemicals) framework aims at controlling and ensuring a safe use of dangerous chemicals both for humans and for the environment (European Commission Enterprise and Industry, 2011).

Registration - Every company that manufacture or import chemicals exceeding 1 tonne per year must register this at the European Chemicals Agency, both chemicals as they are and as parts in a mixture are bound by the legislation.

Evaluation – REACH is evaluated on three levels:

Documentation is evaluated by the European Chemicals Agency;

Substances are evaluated by a Member State to determine if a substance is a potential risk to human health or the environment;

Registered intermediates are evaluated by Member States

Authorisation – The 'Candidate list' register substances that are considered to be of high concern. Eventually these substances end up in the Annex XIV of the REACH regulation never to be released on the market again. Exemptions can be granted if it can be shown that risks are controlled if there is no suitable substitute (Atrion International, 2006).

Restriction – The Restriction procedure regulates the possibilities for a manufacturer to put products on the market that contain the restricted substances. This part covers substances that are considered to pose an unacceptable threat to either health or the environment that are not regulated by the other parts of the REACH procedure or other Community legislation.

Enforcement – Inspections and penalties are to be issued by the authorities of the Member states.

Eco-design directive

The eco design directive regulates the energy consumption of products in an attempt to increase the environmental performance of them. The directive includes both EUPs (energy using products) as well as ERP (energy related products). The latter category does not directly consume energy but still affects energy consumption e.g. windows, insulation etc. The European Commission has developed the Ecodesign methodology to be able to assess whether products are to be incorporated by the directive and what limit values or requirements is appropriate to be set. These limits in the directive are in many cases only valid for some few years where after the limits are tightened and a lower consumption is required.

Except for the consumption of an active product the directive also regulates the energy consumption in standby/off-mode. For products like washers, TVs, computers etc the standby/off consumption limit have been set to 1W, as of 2010. In 2013 this limit is lowered to 0,5W (European Commission Enterprise and Industry, 2010).

2.2.7 Consumers and recycling

The WEEE directive states that the producer has to accept the returned product at end-of-life. This goes for the retailers as well - returning a computer or stereo at the point of sales means they have to accept it and dispose of it correctly. But this is not a practice that is done throughout Europe, most retailers would frown upon getting handed an old laptop. In fact, in Philips efforts to understand consumer behavior in recycling terms, they had a whole R&D department working on their eco-line of products go and try to return a WEEE product. The staff of the retailers did not know or agree they had to accept the waste, and no system was in place to do so. Overall, customers are largely unaware what happens with their waste, what can be recycled, what fractions are compatible. Some don't care either. Brake plates have been found in the municipal compost collection in Falun when they analysed how well citizens sorted their trash.

“There will always be some who don't comply, and wasting energy on convincing them is unnecessary. Most people want to help, and eventually when everyone is doing it these people will come along”, says Jan-Olof Åström (2011) of UMEVA, Umeå municipal waste management.

Some can be blamed on the laziness of the consumer but a huge responsibility is on the producers and retailers as well landlords etc. as they need to provide the consumer with the right conditions for them to act correctly. If the consumers do not have any trash bin for e.g. batteries, the batteries will, in many cases, be thrown with the municipal waste (Vezzoli & Manzini, 2008).

2.2.8 Disassembly

To be able to recycle materials properly waste must be sorted into separate fractions. Different kinds of plastics must be sorted as they can’t be separated once they are melted together. Plastics are all theoretically recyclable even if mixed if they are broken down to molecular level before rebuilding the polymer chains. However, this is very costly and is not really an option today. Metals on the other hand are easier to separate if they are melted together, while the ultimate would be to separate them according to their composition before they are melted. The cleaner fractions are the less energy is needed at later stages to get new pure materials, or materials of the same composition as the original. In a perfect world where energy was free, all materials would be separated after exact composition and directly melted to the same material.

Manual disassembly

There are many reasons why products are disassembled manually. Usually this is done to remove hazardous materials in order to prevent these substances contaminating the rest of the materials. Products that contain things like batteries, mercury etc are separated from the rest of the product flow and handled separately. Manual disassembly is also conducted when the product contain valuable materials, which are worth extracting manually. CRT-televisions contain lead which is toxic and need to be taken care of but they also contain a substantial amount of high grade copper in the copper winding at the back of the CRT, which is removed for its value (Sjölin, 2011).

Repairs and maintenance of a product often require a manual removal of worn out, consumed or broken parts. A good example is the exchange of ink and toner cartridges in printers and photocopiers, which needs to be done from time to time and can be done with a few if any tools. Manual disassembly can be categorized into non destructive and destructive. The choice of manual disassembly method is based on the intended use of the disassembled components. If the intention to reuse the components the disassembly must be done more carefully than if the components/materials are to be recycled. The gain of a careful disassembly is that valuable components/materials can be extracted and reused, thus naturally being more time consuming and more expensive (Vezzoli & Manzini, 2008; Mital, Desai, Subramanian, & Mital, 2008).

In many countries there are separate collection systems for e.g. fridges and CRTs as there is a steady flow of these products and it has been possible to optimize the treatment. The rest of the WEEE ends up at the mixed at the recycling facilities. At the manual disassembly stations at these recycling facilities the staff receive a wide variety of WEEE and continuously sort the products to different categories depending on their content. Some continue to shredding while some are further processed manually. The latter category is then opened to extract the hazardous components/substances and materials that are worth the time to be extracted manually e.g. batteries CRTs, backlights containing mercury (Sjölin, 2011; Kell, 2009).

Automatic disassembly

Products can also be disassembled automatically, but due to uneven product flows and the great variety of products processed in most recycling facilities the automated machinery would need to be highly flexible. An “Automated and Flexible Disassembly Unit” would have to consist of many different features such as cutting machinery, dynamic automated screwdrivers, pick-and-place systems, tactile sensors etc. (Vezzoli & Manzini, 2008). With a takeback system, discussed earlier, a designated automatic disassembly line could be put up by the manufacturer at an economically defendable cost.

2.2.9 Shredding

As manual disassembly is time consuming and automatic disassembly demands advanced custom made equipment shredding is a usable method for separating materials. In practice this means that the waste is crushed and shredded into cornflake sized pieces and then sorted into different material fractions through various processes such as magnetic sorting, sorting by density and optical sorting. The result is ferrous metals, non-ferrous metals, different plastics etc. There are nearly always some materials that can't be sorted properly and ends up as a mixed fraction. A major part of the materials are successfully sorted and the mixed fraction is relatively small. Clean fractions are then manufactured to new raw materials, while the mixed fractions have to be further processed or put on landfill. Today very little waste goes to landfill compared to just ten years ago. Only substances that are not fit for either recycling or incineration end up in landfills (Sjölin, 2011; Vezzoli & Manzini, 2008)

The advantage of fragmenting the waste is that large waste flows can be handled and the process can handle a large variety of products (Sjölin, 2011).

2.3 Design for X

In product development jargon, there are now a number of Design for X, where X could be Manufacturing, Environment, Repair, Recycling, Remanufacture and Disassembly amongst others. DFX are approaches for designers to improve area X of their products, and supports the following functions:

- Gather and present facts about products and processes.
- Clarify and analyze relationships between products and processes.
- Measure performance.
- Highlight strengths and weaknesses and compare alternatives.
- Diagnose why an area is strong or weak.
- Provide redesign advice on how a design can be improved.
- Predict what-if effects.
- Carry out improvements.
- Allow iteration to take place.

(Sundin, 2004)

Design for environment is closely related to the LCA approach and is a synonym for Ecodesign. It is defined as:

"An approach to design where all the environmental impacts of a product are considered over the product's life" (Dewberry & Goggin, 1996).

Design for environment could be said to contain Design for Recycling and Design for Disassembly as sub-discourses. This thesis deals mainly with Design for Recycling and Design for Disassembly. They are often supplementary or identical, although in some cases they can be conflicting.

Having a product that is easily disassembled often enables the product to be repaired and maintained, increasing the lifespan. Another reason for disassembling a product is the need for removing dangerous substances or valuable materials, as mentioned earlier. The largest issue with manual disassembly is that manual labour is expensive and if extracting valuable materials from a product is too time consuming it would be more profitable just to shred it, which is normally done today. Not all products need to be designed for disassembly though, as they will go through a mechanical recycling process and be fragmented. Designing for recycling is then the approach to take.

There are many aspects that are important to consider when designing for both disassembly and recycling. In general one must consider:

- The materials a product consists of
- How materials and components are joined together
- If there is a need to disassemble the product.

(Mital, Desai, Subramanian, & Mital, 2008; Vezzoli & Manzini, 2008)

There are of course more aspects to have in mind and there are guidebooks and checklists to follow for a better design. Mital et. al(2008) have compiled a checklist for designer to use which covers many aspects from design for recyclability but also some that are valid from an design for disassembly point of view (Appendix 3).

Materials

The choices of materials play a more important role in design for recycling as products are often shredded without any treatment than in the design for disassembly even if the same principles are good to adopt. For the best result one need to consider following points:

- Choosing as few materials as possible increases the efficiency of the recycling process.
- Using materials that are recyclable in the shredding process today increases the level of recycling as well as minimizes the waste put on landfill or incinerated.
- Using compatible materials if multiple materials are to be used to be able to separate the materials properly.
- Using e.g. metal screws in plastic is thus bad from a DFR perspective. The screw would sometimes stay with the plastic through the recycling process and would result in the plastic burning in the smelting process and not be recycled.

- The use of additives should also be limited to areas where it is absolutely necessary. The problem with plastics with additives is that they cause problems in the recycling process due to their properties.

Let's say a plastic A contains an additive giving the plastic high strength but also a modified density. As it happens, plastic B also has the density of the plastic A. In the recycling process these two plastics cannot be separated and they end up as a mixed material fraction which is less valuable if not worthless compared to if these two materials could have been separated into clean fractions(Sjölin, 2011; Vezzoli & Manzini, 2008).

Joining methods

There are many ways to joining part together. The choice of method is often based on what seems to be the best from an economical and manufacturing point of view. This approach is often bad from a disassembly and recycling point of view. Doing it properly is not very hard but it might take some effort as many aspects have to be considered. Should the product be possible to repair? Are there any components that are dangerous or specifically valuable? Should it be easy to disassemble or should it fall apart easily in a shredding process. If a product is to be disassembled manually making the parts accessible without the need of using tools is a clear advantage. Many believe that snap-fits are good solution for joining two parts. This is in many cases true. When assembling a product they are fast and do not need additional tools or screws. When shredding the product these two parts are separated without any problems. But when it comes to manual disassembly they are often troublesome and time consuming to open unless the snap-fits are designed to be opened. A good example of a joining that is easy to disassemble manually and separates easily in the shredding process is the bayonet, which is basically a wing-nut that is twisted to release two parts. Whatever method for joining parts together is used one must remember their implications in each end every situation (Vezzoli & Manzini, 2008).

2.3.1 Example: The BLOOM laptop

In a project initiated by Autodesk, students at Stanford University and Aalto University were to design a fully recyclable electronic product. The challenge in the project was to develop a product that was easily disassembled and sorted, minimizing the need of primary recycling processes used today. A modular design with good possibilities for repairs and removal of components for reuse was an important goal to strive for.

The project resulted in the Bloom concept, a concept that, without any tools, can be disassembled to a part level where the parts are easily separated into plastics, metals and circuitry (Figure 15). These materials can then be fully re-used or recycled. The disassembly instructions are integrated in the product and describe the 10 step process, which takes under 2 minutes compared to a 45 minute disassembly of a MacBook conducted by three engineers.

Figure 16. The bloom concept. The purple parts are removable without any tools, mainly due to the bayonet lock under the keyboard module.

It is not only the practical disassembly and recycling that has been in focus, but also the users and their experiences have also been considered. As the computer is easily disassembled and can be done easily by the user his/her relationship to and ownership of the computer is strengthened.

An additional feature is the wireless modular keyboard, which can be separated from the computer and used wirelessly. This makes the use of the computer more flexible and more comfortable, as one would wish for from a portable computer (Figure 16).

In their work the students found that the users were the weakest link in a products life, thus focusing on their behavior and involving them in the recycling would lead to an increased recycling. Users were in general considered lazy and to enable them to recycle more effectively the disassembly and disposal have to be easy enough.

The computer case is made out of ABS plastic and only some fasteners and the electronics are made from other materials. Due to the fact that the components

Figure 15. An example on the flexibility of the wireless keyboard.

are fitted into their positions and held there by the design of the casing they are easily removed for repairs or upgrades. The bayonet mechanisms under the keyboard are twisted to reveal the innards of the computer. (Bhobe, et al., 2010).

2.3.2 Active Disassembly

Active disassembly, is that the same thing as automatic disassembly? No, not quite. Active disassembly refers to emerging technologies that will allow products to disassembly passively (yes, passively) by the application of heat, electricity or even visible light. This can be done through advanced shape shifting materials or debondable adhesives.

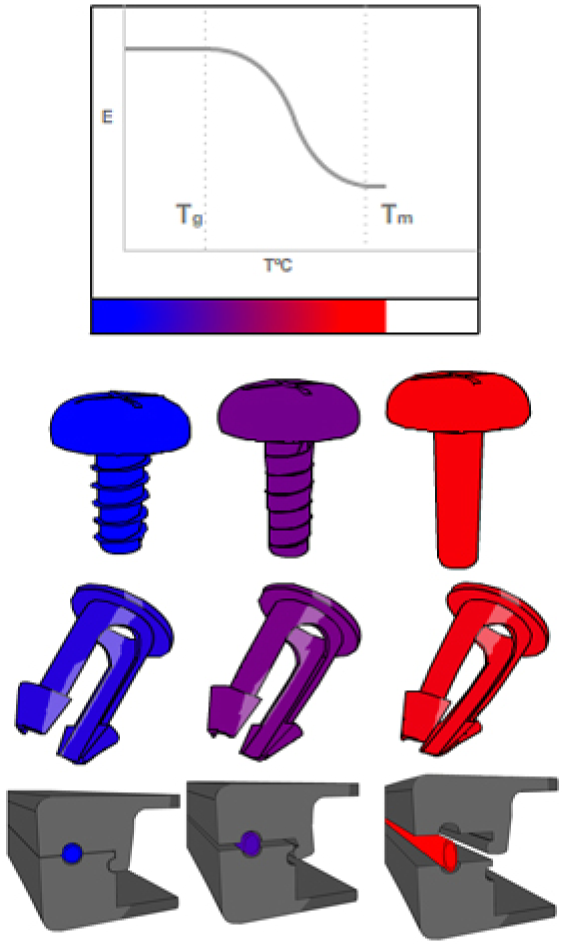


Figure 17. Examples of the use of shape memory materials that transform when heat is added. The top image shows how rising temperature changes the state of the material which changes the shape of the component. The three pictures show possible applications of the SMM. Screws where the thread flattens, snapfits that shift shape and unsnap, pipes that expand and open a snap fit.

Shape shifters

Smart materials such as Shape Memory Alloys (SMA) and Shape Memory Polymers (SMP) can be utilized in a construction as a "self destruct mechanism" activated when it is time to separate materials. When arriving at the recycler, the electronics with SMM (Shape Memory Materials) would be put in a big "tumble dryer" where they would spun under heating for a few minutes. The components would then separate and sorting would follow. Figure 17 show a few examples of design for disassembly through SMM (Active Disassembly, n.d.).

Adhesives and releases

Adhesives and glues are generally considered bad construction practice. This is because it gets stuck on the material it adheres to, be it plastic or metal, thus compromising the purity of that material. Adhesives are getting more common in light weight applications, since rivets and screws do not go well with composite materials.

It comes as no surprise then, that debondable adhesives has been called the holy grail of adhesives (Adhesives Magazine, 2008). Why is that? A debondable adhesive could compete with other means of fastening, such as screws and rivets.

A specific application that is interesting is in assembly lines, where clamping parts are bad for tolerances. Adhering the parts for assembly and then releasing without any residue would benefit end product quality for e.g. the car industry. The development of debondables is not quite there yet.

Most debondable adhesives on the market today are epoxy based resins that when affected by the debonding agent (light, heat etc) create a cross bond in the epoxy which lowers the adhering forces drastically. The company Lumina Adhesives use this fact to easily attach and remove colostomy bags. An opaque cover plastic is removed when it is time to peel off the plaster, and after a minute of ambient light in the room, or a few seconds with a strong LED flashlight the plaster is removed easily without pain for the patient. The adhesive can be manufactured stronger or weaker depending on the application, and can be made “very strong” according to Anders Jacobsson (2011) of Lumina Adhesives.

Other examples are a glue string that loosens in boiling water and floats to the surface leaving the previously bonded surfaces clean. Exonera, a company from Karlstad has a glue that debonds when a small electrical current is applied. A cruder type of debondable is a powder of microspheres which expand when heated. They can simply be sprinkled on to the normal adhesive, and when the joint is heated to 120 degrees Celsius, the spheres expand and break the bond. This does not create any smooth surfaces though, since the glue is still stuck onto the pieces.

These techniques are only debondable once, so any construction utilizing the technique must have this in mind. If the construction is to be re-sealable the e.g. repairman has to glue it together again. So the focus should be on single use adhering where tolerances or surface finish is of the essence.

2.3.3 Example: Philips work on debondable adhesives

Tom Devoldere, Mechanical designer, PHILIPS Innovative Applications, is the man behind Philips Econova (Figure 18), a TV recently awarded with the EISA Best Product award in the Green TV category (EISA, 2011). The TV has a 40 W energy use, made mostly in aluminum and with an unorthodox flame retardant. Now his team are researching the use of debondable adhesives in Philips home electronics products.

Figure 18. Philips Econova Television

Philips is a big company with many designers, so we asked Tom what he knows in his specialist role that his co-workers would benefit from knowing.

“The main point is awareness”, Tom (2011) states. “Many of my colleagues don't even know what happens at the recycler's. So they don't really understand the importance, or what is important and how to work towards a good recycling of the product. The second point is management, convincing them is key. If there is a structure and requirements, it will happen. For designers, rules of thumb are better than specifics since all products are unique with a different set of challenges."

We heard you are researching debondable adhesives for up and coming products?

"Yes, we are looking into that. I can't say too much, but it is definitely interesting for us."

What about if the debondable glue parts end up in a normal recycling process?

"Gluing two metals is fine, gluing plastics and metal means the plastic will burn with the metal. Gluing two plastics is something we haven't done any research on yet. The plastics could get contaminated by the glue."

2.3.4 Life Cycle Design

The impact a product has on the environment is not only the materials used in the product or the emission from fossil fuels. Life Cycle Design implicate a wider approach than is conventional and assesses the whole life cycle of the product from the toxins emitted (output) when extracting materials (input) from the earth crust to the energy used in recycling. Vezzoli & Manzini (2008) distinguish a product's life cycle into five stages.

Pre-production

This first stage is where resources are mined from the earth crust and refined into raw materials to be used in the production stage. In this stage one have to remember to include the usage of resources and the "output" i.e. emissions created in the process.

Production

In short, raw materials from the pre-production are further processed into components which are then assembled and might be treated in a way or another to a finalized product, ready for distribution. Resources used to complete a product can be split into direct materials and indirect materials, direct materials being the incorporated material in the final product while equipment and resources used for the production of the product are the indirect materials.

Distribution

The final product is then packaged and transported to the end user via e.g. storage retailers. Here the energy consumed and the emitted gases by the transport are obvious to include in an analysis of the products life cycle. Less obvious is the resources used for building the truck, the storage facility etc. Even the rubber worn of the wheels of the truck are considered as an "output".

Use

Products are used in different ways and often consume resources in a way or another during the use-stage. The product might be designed for a long life time but it might still use energy or, on the other hand, the product could be designed for a shorter life time where it is consumed by usage i.e. ink cartridges or motor oil.

Disposal

At some point the user decides to dispose of the product. A part of the products are recycled while other end up in the municipal waste. Recycling products is of course a good thing but one has to remember that recycling processes also consume resources. Municipal waste is often incinerated at thermal power plants that produce heat, exhaust gases and residue where the heat is used for heating or converted to electricity while the exhausts and the residue have to be taken care accordingly.

2.3.5 LCA

Related to life cycle design is the tool of Life Cycle Assessment (LCA). This is where all stages in the product lifecycle are measured and quantified, often in terms of energy used (carbon footprint) but sometimes in compounded scores that weigh in water use, toxin release, energy and material use etc. The point of an LCA is to compare environmental impact either at what stage in the lifecycle the environmental impact is largest or between products, which has the biggest impact. It is thus always a relative method. The unit of measure is of course a topic for debate. What is more important, energy use or pollution from production - and can they actually be factored into the same LCA variable?

Another factor is where the end of the LCA system is. For the footprint of a product, should we include the fuel spent on the factory worker to get to work? And then for all subcontractors? A thorough LCA is a lot of work, and the line has to be drawn somewhere. But while a sometimes blunt instrument, even a simplified LCA is a good way to get an overview of a product's impact profile (Vezzoli & Manzini, 2008).

2.3.6 Whole Systems Design

While life cycle design and the LCA are quite comprehensive there are angles that they don't fully cover. Products are always puzzle pieces in larger systems and focusing only on the life cycle of the product leaves might miss the big picture. Take a combustion engine as an example. It consumes, amongst other things, oil for lubrication when used. A life cycle assessment could propose a reduction of oil, which could have disastrous consequences for the engine as it might overheat and break. Instead the solution could be using different bearings and the oil consumption might be lowered as well as the fuel consumption.

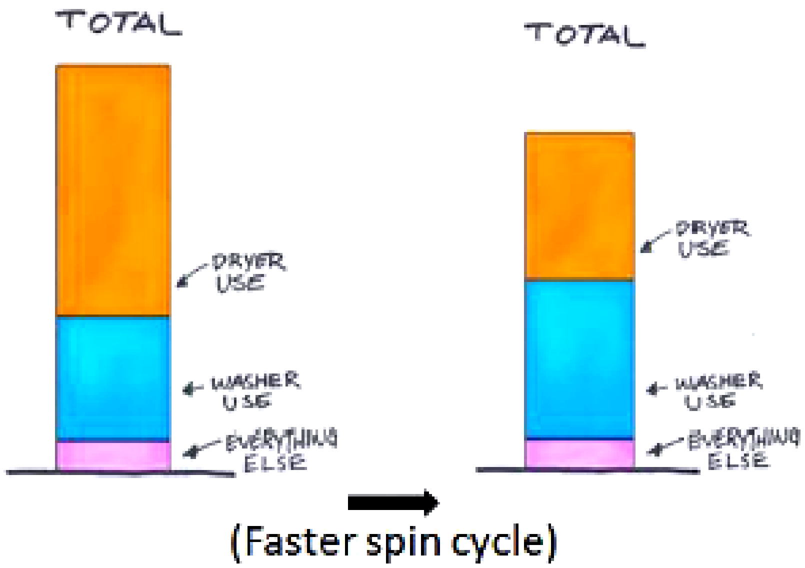


Figure 19. Comparison of the total energy used to wash clothes in two different cases. To the left the energy use is highest in the dryer (orange). In the example to the right the spin cycle at the end was increased, thus more energy consumed in the washer (blue). Resulting in dryer clothes and less need to tumble dry.

Assessing the greater system is essential as only focusing on the components could pessimize the whole system (Hawken, Lovins, & Lovins, 1999), suggesting that other products or components could influence the use or function of the product in focus. An example of whole system thinking is the system of washing clothes described in an educational video by Autodesk. The system is then not only the washing of clothes. The storage, wearing and drying might also influence the total energy consumption (Autodesk Inc., 2011).

At the outset looking only at the dryer, the LCA concluded that the energy consumption was the biggest issue. Looking only at the dryer, the solutions to lower the energy consumption could be to come up with innovative drying solutions, insulate it more etc. But looking at the whole system, we notice that energy use in the dryer is related to the wetness of the clothes. Increasing energy use in the washing machine by adding a spin cycle would lower the total energy used (Figure 19).

These solutions need to be properly evaluated as increasing the speed of the washing machine would raise new issues where stronger materials would be needed resulting in new environmental effects. Whole systems design, a "systems LCA" of sorts, is important to consider (Autodesk Inc., 2011).

2.4 Takeback and recycling logistics

How do we reach 100% recycling for electronics? The recycling practices vary throughout Europe, although the whole of the EU is subject to the WEEE directives. But even if a producer has responsibility over its product if returned, far from all electronics come back. The EU wants to increase the take back of electronics to at least 4 kg/person, and later to 65% (based on the sold EEE the preceding 2 years). The map in Figure 20 shows how much electronics is collected per capita throughout Europe. Sweden with 14.8 kg/person is on top, but many countries have a long way to go to reach that level, which means the electronics is not recycled properly (European Union, 2011)

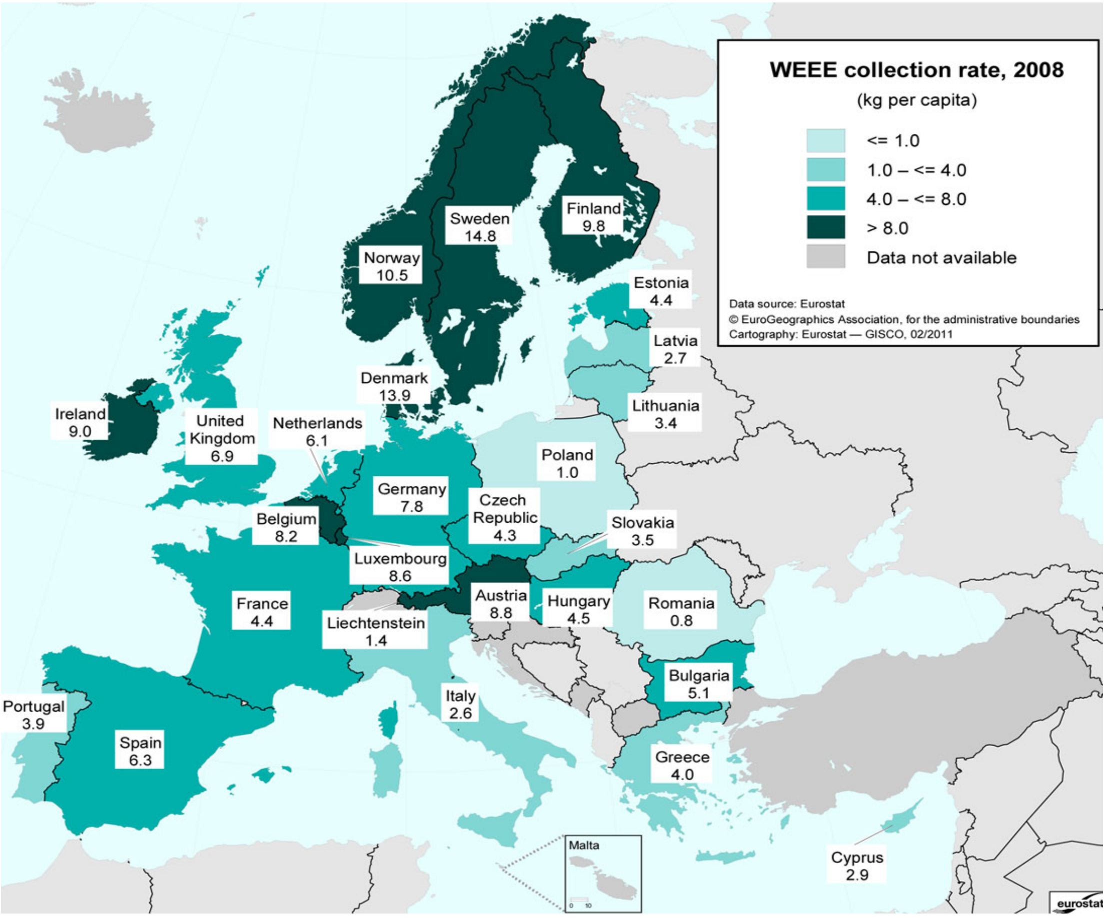


Figure 20. European map showing the waste collected per capita.

Take back is a term that can hold different meanings. In its most basic form, it is just how (and if) the product is collected in the system, a synonym to collection. More specifically, "takeback" and "reverse logistics" refer to how producers can make sure products, sub-assemblies, components or material can be retrieved from the customer for reuse, refurbishment or controlled material looping (Figure 21). This more specific term is the one this report will use throughout. Takeback is sought after since the quality of materials is known and component complexity is preserved - saving energy and cost in a recycling context and a prerequisite for remanufacture and reuse. However, often the logistics of take back is much more complicated than the initial production due to the inconsistency and unpredictability of the flows, especially if the product is out on the consumer market.

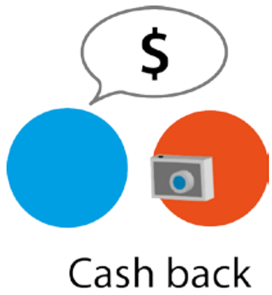
There are four levels of takeback: **external, inform, refund** and **lease** (Stenkjær Paulsen & Hellhammer Johannesen, 2011).

Figure 21. The producer, the customer and the product exchanged between them.

External is when a company simply sells a product and externalizes the waste management, i.e. the producer leaves the EOL-handling to the consumer without any guidelines. This would be true for low complexity products such as a fruit. For WEEE, however, this is not acceptable.

Inform means that there is no contact after the point of sale, but that the producer or another actor encourages the consumer to return the product after use. This can of course be done to different extents, ranging from a little recycling symbol in the manual to a more coherent branding strategy.

Refund ("Pant" in Swedish). The product is sold with a deposit added to the price. This deposit is refunded upon returning the product at EOL. This is a way to create customer incentives for takeback, and is utilized with success in Sweden for aluminum cans and PET bottles.



Leasing. The product ownership remains with the producer throughout the product life-cycle. The customer holds a subscription on using the product, perhaps not even for the product but for the function it provides, e.g. personal transport. Implies a strong producer/ customer relationship.

To make return logistics work, companies need to see the products coming in not as returns, but as feed stock for future products through e.g. remanufacture. Through this mind shift, managers are more likely to endorse and support the logistical efforts since recycling in itself is not held high in all camps. It is also important that a second hand market of components or whole assemblies compete in another market, lest the company will compete with itself. B2B takeback is more developed today, as the product flows are bigger and more accessible than for consumer products (Brusell Winblad & Öhman, 2009).

2.4.1 Example: The Kodak Single Use Camera

One of the best examples of a well-functioning takeback system is the Kodak single use cameras that roamed the market before the dawn of digital cameras (Figure 22). Marketed as a "disposable camera", the camera actually was reloaded, repackaged and reused multiple times before being disposed of. The main reason for the success is of course the strong incentive to hand in the camera - to process the roll of film inside and receive the photographs. This was, of course, the purpose of buying the camera in the first place.

Figure 22. A reused single use camera from Kodak.

2.4.2 Example: Ahrend furniture

Ahrend is an office furniture company, working towards Cradle2Cradle principles. One such initiative is the Green Lease, which focuses on selling office environments rather than furniture (Ahrend, 2009). This is a product-as-a-service approach, where the customer pays for seating and desks, and Ahrend makes sure the chairs are up-to-date, clean and of good quality. Ahrend claims this means a lower total cost of ownership compared to buying furniture. The upside for Ahrend is that they can take their old furniture back when replacing it and reuse components that are not primary surfaces, e.g. the steel base of a table can get a new top when the old laminate is worn or the color out of fashion. For their powder coated lockers (Figure 23), they actually have a washing machine so they can remove the paint and apply a fresh coating of color.

Figure 23. The Hinged door cabinet from Ahrend

2.4.3 Precycling

An incentive for companies to work harder on DFR is precycling, a market mechanism designed to improve the recycling efforts. It works like this: products that have a high risk of becoming waste pay a tax, whereas fully recyclable products are tax exempt. The money from the taxation is then put into recycling research and efforts to improve the taxed products. The precycling mechanism could be used internally within a company as a combined whip and carrot, punishment and reward. A product with a high waste generation would need to show a better profitability since some of the profit from selling the product is reduced through the internal "tax".

Management could then support increased recyclability without interfering in construction and design details.

2.5 Information Visualization

The amount of data that our society handles has grown enormously the last 20 years due to the developments in information technologies. Large quantities of data have become increasingly accessible for everyone. An example is Google's n-gram viewer where most books released since 1500 A.D. have been scanned and fed into a database word for word (Labs, 2010). They are public for anyone to download and analyze. The huge data sets have seen the rise of a new discipline, info graphics. Visualizing data is not something new, but the tools available now connect data (which previously was the exclusive territory of scientists) with graphic design software. The challenge for designer's then is to both create aesthetic visuals while conveying the data in a true manner. This bestows the designer an almost journalistic responsibility in getting the facts straight and not lie through how the information is conveyed. It is not only about looks either, the aesthetic qualities of a visualization are correlated with how well the data is understood (Klanten, 2010).

Figure 24. Infographics: Crayolas crayon color assortment as a function of time (Worley, 2010).

> "The purpose of visualization is insight, not pictures"
> - Schneidermann (1999)

2.6 Product vs. Service

In Sweden today, 80% of newly started businesses are service based i.e. they provide a service as opposed to sell a product. Half of the Gross Domestic Product (GDP) and a quarter of export revenue come from services. The format of a service is different from a product. Whereas the purchase decision of a product is based on function and price, the purchase of a service is more about the total experience, and the effect it has on the overall process (Almega, 2011). Let's look at the differences between a product, and selling the function that product provides as a service (Table 1):

Table 1. Comparison of differences between owning a car versus renting it.

	Own car	**Renting a car**
Form	Physical (product)	Abstract (service)
Ownership	User	Rental Agency
Cost	Purchase, gasoline, insurance, repairs, mot, long term parking	Rent, gasoline, (insurance)
Usage right	Whole product life time, free	Time-bound, geographically bound
Contractual obligations	Path of Sale, then forget about it	Collect/Return at specific time & place
Quality aspects	Durability, function, mileage	Comfort, ease, service, no unforeseen expenses
Drawbacks	Vulnerable to unforeseen expenses	Less care for the product
Description	Technical, facts, price, story	A lively story, limited offers

Time is an interesting factor in this comparison. When buying a product, it is yours forever unless you decide to sell it. When leasing a product, you can return it whenever you feel like it. Still the feeling of being “locked in” is greater in the leasing, since you are still involved with the seller and committed to paying monthly etc. So the time you are bound to a company is shorter when purchasing the product, but the time you are stuck with the investment is longer.

Consider the example of personal transport for medium distances. The product involved to transport you would likely be a car. The comparable service would be vehicle rent, taxi or public transport such as bus or train. Let’s choose renting a car as it is the same object (a car). Now, the function is the same for both the service and the product: a way for people to transport themselves from point A to point B, but the selling points differs. In Table 2 the differences are displayed.

From a resource perspective, having a society built on car rental rather than car purchase would mean that less cars would be needed which free up resources for other things. The cars that do exist are used more frequently and don’t sit in the garage wasting space and time, and ultimately money. One drawback of renting cars and not owning them is that drivers care less for the vehicles, with an increase in wear and tear as a result.

Table 2. Comparison of owning a product and using a service for the same function.

	Product	**Service**
Form	Physical (product)	Abstract (service)
Ownership	User	Seller
Cost	Purchase	Lease/Pay-per-use /Support/Consulting
Usage right	Whole product life time	Time-bound
Contractual obligations	Path of Sale, then forget about it	Continuous
Quality aspects	Durability, function	Perceived benefit
Description	Technical, facts, price	A lively story

2.7 Discussion

For this part of the project, the facts surrounding recycling were in focus. What does this mean? It means that the focus was on conducting a wide research including a wide variety of aspects covering everything from sustainability, actual recycling methods to innovative designs that could be interesting from a recycling point of view. This recycling focus also implies that there were other things that were not so heavily focused on, such as the process of designing a service. The process we applied in our planning and indeed our execution was that of a product design process with a user focus. This is what we have learned through the industrial design engineering master programme. It appeared as though the service process would be a product process without the product - eliciting demands and requirements from users only to later assess the finished service against those requirements. Oskar Rexfelt (2011), researcher and assistant professor at Chalmers, claims that the service design process is fuzzier and less tangible than a product design process. A product is often physical object while a service is more abstract and harder to relate to, which mean that the design processes also differ. This difference was something that held true for our process as well.

This, initial research part was a huge part of our project as there are a great amount of subjects to be covered that are closely related to recycling. In center is the recycling itself, but then there is also the recycling logistics and incentives, which lead to the topic of energy consumption. This then lead to LCA and other areas which are not directly recycling but still intertwined. The research could have been even greater than the one conducted in this project. Somewhere a limit of what to include had to be set. That limit came quite automatically as we felt that we had answered and dealt with the issues raised in the beginning and during the project. One could wonder what all this research has to do with the creation of the service. Should the research have been as extensive as it was? There are of course things to add or remove, depending on who you ask. We believe that we have covered most topics that should have been included, but adding topics that are extra, as important non the less. Many topics covered in this report are directly essential to fully understand the world of recycling and in creating a service that is comprehensive and relevant. Some topics are included as they complement and resolve questions that naturally are raised.

2.8 Conclusions

- As the world's population grows and general quality of life increases, the need for recycling and for communicating recycling will become increasingly important.
- The challenges to achieve a society with 100% recycling are very layered and complex. Costs, behavior and laws all influence what is recycled, what can be recycled and how. Cycling refined materials instead of wasting or incinerating them costs both energy and money.
- Hazardous materials have historically been identified after they are widespread, so a product that is harmless today might not be so tomorrow. This means that design for disassembly is important even for the products that we think will just be shredded at their end of life, as they might contain toxins that we will discover in the future.
- The service creation process is fuzzier than for a normal product development cycle.
- A product fit for recycling needs to consist of pure materials which separate easily. On top of that, the recycling or remanufacturing must be financially competitive with their virgin material counterparts.
- Recyclers and product developers share the goal of increased recycling, as both parties would benefit financially. The recycler gets better "raw material" and the product developer lower their cost for producer responsibility.
- Innovative design technologies for recycling exist. Recyclers and product developers would need to develop and implement these solutions together. This is a new constellation, and the systems are very large. A small scale product implementing an innovative technology would mean recyclers would not have value in investing in the solution that is coupled with it. The product would be a too small part of the material flow, so the logistics would not work.

3 Problem definition

How is this going to work? In short: As both the product developers and recyclers benefit from an increased recycling there is a need of an increased communication between these two parties on matters concerning recycling. In practice Stena Recycling analyses a product and provides the developer with a feedback service.

After disassembling a product in this project (chapter 3.4), the broad research presented in previous chapters need to be condensed and presented in a way relevant to the product's unique context.

The service idea is simple but the functionality and content of the service is much more complicated. What information does Stena want to emphasize? What does the product developer want/need to know? How is this information communicated in the best way? How can the service be general enough to be fast to perform, but specific enough so to be of value?

To set the boundaries of the service, a preliminary service flow was created, and a generic mental model of the designer constructed. This aimed to map out the priorities and requirements put on a designer to understand the incentives and motivations on the mental obstacles and opportunities when it comes to design for recycling. The requisition of the case products, study visits and interviews with company representatives gave insights as to how they perceive their role in product development, and where they are at now when it comes to knowledge on their product's end of life.

What should be included in a service? This is of course different depending on the product and company analysed, but a survey sent out to the case companies gave general insights that harmonized and complemented with the mental model that was created "blindly".

After analyzing the case of a washing machine specifically, through a manual disassembly and later consulting interviews with Stena's expertise, the actual design of the feedback ensued.

While reading this, please bear in mind that there are two processes described, sometimes in parallel. There is the ***process of creating the service***, which is the process of the thesis project itself, and then there is the ***the service***, which is the result, or product, of the thesis project.

3.1 Service flow

To get a better overview of what the service would consist of and how it would work a service flow was created (Figure 25). This show shortly describes who would do what. The service is of course more complex than the illustration. After initial contact the parties would discuss the product to be analyzed. Before conducting the analysis the needs and wishes of the manufacturer must be defined, as the feedback will be customized for each customer. The analysis is then conducted with the support of experts within Stena Recycling and Stena Technoworld to ensure the highest quality and accuracy of the results. The analysis can be done with a focus either on a specific part e.g. on the recyclability of certain materials or on the construction, or the whole product. The results are then presented in a way decided upon in unity with all parts. There are many methods for presenting the results, report, poster, workshops, web tools, presentations etc.

After presentation there will be follow-ups and evaluation of the result for further improvement. As a part of the service there should be a possibility to get some support for some time forward. This whole process can then be repeated on the next product for further improvement.

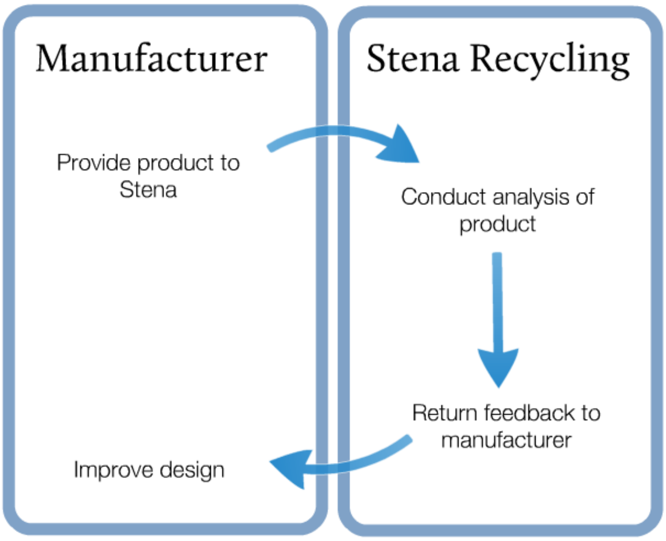


Figure 25. A basic illustration of the intended functionality of the service

The goal of the service is not just to specifically address the analysed product. Rather, the product is a case that can be used to show the product developers where their thinking and acting is not congruent with good design for recycling. Often, the constructions through different product generations stay roughly the same. The learnings from a current machine will benefit future product designs, and initiate the recyclability discussion at the product development department.

3.2 Stakeholder Mapping

In the design process there are many stakeholders involved. There is the product developer, which we have put in focus, while e.g. politicians, suppliers, investors, executives, economists, materials buyers might have their agendas, thus effect the final product. They all have their inputs on what a product should be, what it should do, how it should look, what it should be made of, how many there should be made etc. The product developer must consider all these stakeholders and come up with a product that is satisfactory to all. The mental model of a product developer has been mapped as shown in Figure 26. Product developer is broadly defined in this context, and could be interchanged with designer or even the whole product development department at a company. The size and colour of the coloured fields represent the importance each area has from a designer’s point of view. This picture seems to be valid after interviews with several designers during a workshop where a gardening machinery manufacturer and representatives from Stena were present. Apart from the appearance of the product efforts are often put into maximizing profit from the product. Often this result in a focus in areas such as: assembly time, material costs, labour costs. The focus seldom is on the recyclability or the disassembly of the product as they are considered to be time consuming and costly, while not giving any clear advantages towards competitors. It is also felt that these things are hard to communicate to the customer. Even if designers would like to put more energy on these issues they are not able to do so as their superiors, who often make the decisions, consider other areas to be more important and the recyclability and disassembly is often left behind.

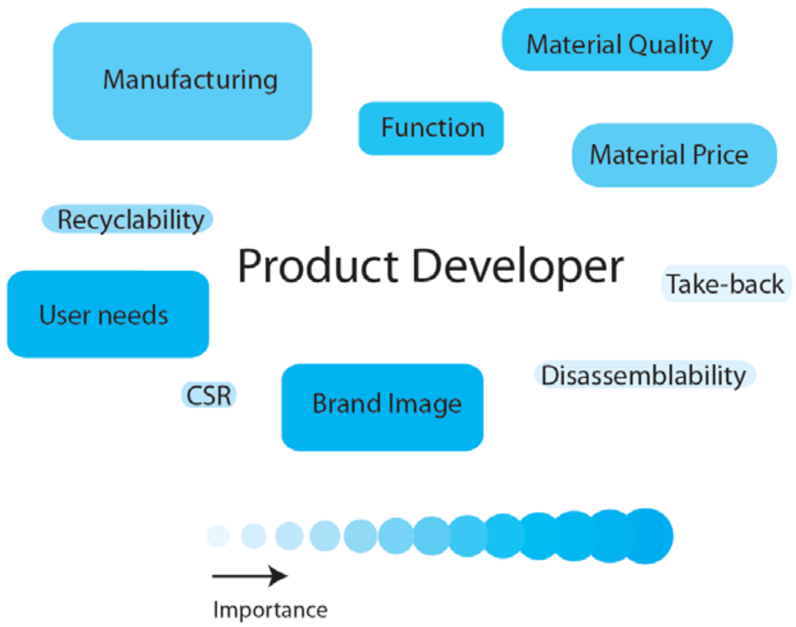


Figure 26. A mental model of the priorities of the product developer.

3.3 Understanding the product developer

To reach the needs of our user, who ironically is a product developer, two methods were used. First, a workshop with industrial design engineering students was conducted to learn what knowledge designers currently have. Later, a survey was sent out to product developers to learn what they want from a design for recycling service.

3.3.1 The role playing workshop

The objective here was to explore the current state of affairs in product development. 4 students of industrial design engineering were taken in and each given a role in a product development group– one budget responsible, one designer, one material buyer and one manufacturing expert. A scenario was then presented as follows:

You are the [assigned role] at product development department of Elecotronics AB. It is a Friday morning and your boss comes in with a laptop made by the company and says that it is not good enough. The corporate division are bitching about the "eco-friendliness" of it. Apparently this product your team just finalized is hard to recycle. "Make it better. I want a proposition on my desk by 4 p.m.", your boss states in a dry voice before exiting the room.
Clearly you need help to get this thing right. In your company you have mechanical and industrial designers, materials buyers and other people to consult but you don't have any direct contact with sub-contractors. Together with your colleagues with other competences, you need to improve the design to the best of your knowledge.

A laptop was provided as reference and then the discussion ensued. Gradually, we posed questions to lead the discussion towards our service. Notes from the discussion were taken, and together provided an overview of the needs of product development. Here are some points, in no specific order:

- Stickers are bad
- What are the materials worth for the recyclers?
- Burning of plastics means the material is gone
- What is the latest in disassembly technology?
- Stena are not the innovators, the PD are!
- Modular or design for long lifetime – are they complementary or conflicting?
- Timeless design lasts longer
- A support hotline would be nice!
- If there's a consultant helping with the design, maybe the knowledge spreads to competitors.
- Is there a certification?
- Get a video of the disassembly together with a report would be nice.
- Get a second hand product if the first one fails.
- The boss might be the one needing the knowledge

The discussion clearly showed the need for facts, as a lot was speculation and things they "had heard". Making the product developers certain they are doing the right thing should be a priority of the service.

3.3.2 Survey

Designers might have different opinions on recycling than their superiors or other co-workers. They might feel obstructed or pressured by management and would, if given the right premises, design differently. In other cases they simply do not have the knowledge that things can be improved or how they can be changed for the better. Managers could have their own reasons for recycling not being prioritized.

To get a deeper understanding of the manufacturers view on this subject and what kind of help they would need a survey was conducted. The survey consisted of a mix of close ended questions with the possibilities to comment and open questions where the respondent could discuss and reflect freely (see Appendix 6).

3.3.3 Results of survey

When asked who is the most influential in increasing the recyclability in their product, something interesting happens. The managers consider the design engineers most influential, and the design engineers consider the power to be in the hands of management. This is a problem, if no one owns the problem, then no one will deal with it either. This is a topic for discussion which should be brought to the companies.

The respondents to the survey all desired relevant and specific design tips on how they can improve the recyclability of their products, and that they should come in the form of a report. The initial service flow with different modes of feedback was thus limited to a report format.

The main downside with focusing on recycling was the development costs with an unclear benefit. The service or the recycling industry must show the benefits clearly, preferably in profitability terms.

The benefits of recyclability are perceived to be reparability, brand strengthening, environmental benefits. Most respondents only chose one of the multiple choices (it was possible to tick several). This also shows the diffuseness of one perceives recycling. What is it good for, and for whom?

One respondent, when asked to elaborate, states that one hindrance of increased recycling is lack of knowledge all through the supply chain, through supplier-purchaser-designer-marketer-salesmen-retailer-customer. He also thinks that virgin materials are too cheap when compared to recycled stock. The survey with responses can be seen in Appendix 4 and 5.

3.4 Content design, analysis and validation of cases

To evaluate viability and start looking into how a service would work, four case products were analyzed and the resulting data collected. The case products were consciously chosen from different areas in order to get a wider perspective as the products differ in size, use, function and also in their disposal process. Each case product provided information that would later be used to create feedback to the manufacturers. In these tests the products were disassembled and every step was documented for future use. Both good and bad examples in the design of the products were included in the result and also basic design for recycling (DFR) recommendations were compiled.

Figure 27. The case products: a washing machine, a coffee machine, a backpack and an electronic shelf label.

3.4.1 The household appliances company

The first case company is a household appliances manufacturer who produces washing machines, dryers and dish washers. They aim at delivering high quality and durable products with a Scandinavian design.

The case

For this project, the manufacturer sent a washing machine already in production. Since the washing machine is a consumer product with quite a long life-span, the company's focus is on choosing durable materials as the maintenance will be limited. Their other main focus is energy-efficiency during use, meaning that recyclability of materials is not a priority as of today. Design for disassembly is not something they working on at the moment.

Results of analysis

The disassembly was conducted to separate all the parts from each other and to separate the machine into material level. Parts were removed in the most logical order and way implied and enabled by the machine. Most of the parts and components were fastened to the chassis with Torx head screws (T8), with a few exceptions.

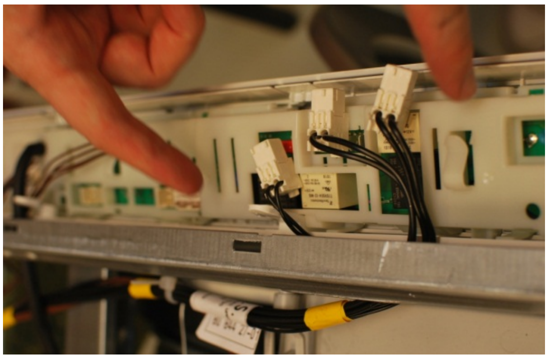


Figure 28. Three of the seven connectors that need to be removed to access circuit boards.

The screws were mainly accessible from the back, also with some exceptions. For example the front was fastened with two Torx head screws diagonally from below, two from the back and two plastic snap-fits.

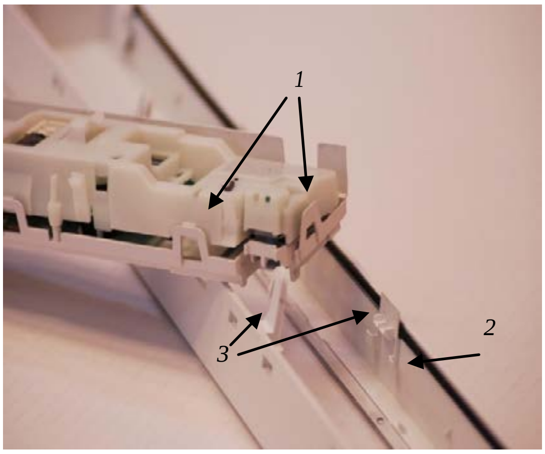


Figure 29. Two of ten snap-fits holding the inner pieces together [1], one of eleven snap fits securing front panel to inner assembly[2], two of eight snaps fits securing the whole assembly to the main

The front instrument panel assembly was snap-fitted onto the chassis and to extract the circuit boards 52 snap fits had to be released and the seven electrical connectors had to be disconnected (Figure 28). These electrical connectors were secured with snap-fits and were time consuming to open by hand mainly because there was little space for fingers to reach all the releasing mechanisms (Figure 29). Humans have only 2 hands and 10 fingers, and releasing the snap fits is much harder than it could have been if design for disassembly was considered.

The machine contained many different materials. Several types of plastics were found along with steel, aluminum, iron, rubber etc. The front instrument panel consisted of a circuit board with components and was surrounded with several different plastics:

- The front cover - ABS
- The two inner covers PC+ABS-FR
- The transparent window - PC
- A number of unmarked plastic parts on the circuit board

With a few exceptions, all materials were marked with material type, including materials with a weight lower than the 25g as legislated in the WEEE directive. But the full specification of the contents of the flame retardants in the two inner covers and power supply cover could not be found. The rear cast iron weight was fastened with eight torx screws and also tightly fitted to the drum and its removal demanded use of a crowbar and excessive force. A crowbar was also needed to remove the arm/shaft part from the inner drum. This might not be considered to be a high priority problem since the materials are compatible in the melting process.

The larger EPDM tubes were fastened with clamps that couldn't be removed without destroying them. In our analysis several methods were used and the best method for removing the clamps was to cut them open with wire cutters, even though this method was quite troublesome.

Other problem areas found was:

- The isolation is glued to the metal.
- Detergent front is covered with a metal plate that is not removable unless deformed.
- Outlet tube has to be cut in half be removed from the metal back piece.

Design for Recycling recommendations

This design is quite acceptable from a shredding point of view while the design is very flawed if this assembly was to be manually disassembled. Choice of material is under criticism where a more consistent choice of materials would be desirable. Also the flame retardant used in the plastic should be specified.

3.4.2 Crem International

Crem International is a merger of the Swedish company Coffee Queen and Spanish Crem. They aim at fulfilling people's beverage needs through serving a wide variety of beverages e.g. instant coffee, espresso, water and juice. They manufacture these machines from the best parts available for the highest quality possible.

The case

Crem's products have previously been analyzed with a focus on the life cycle of the products using the method of LCA, which indicated areas with room for improvement from an energy consumption point of view. This analysis did, however, not view the machines from a recycler's perspective, which is to be assessed in this project. The Coffee Queen machine *CQube M Carbon black* is to be disassembled and studied.

Disassembly analysis

The coffee machine is a complex machine with many components and functions: it heats water, grinds coffee beans and mixes hot chocolate etc. The back and side covers as well as the door are disassembled from the main body with a number of screws and are removed fairly easily, revealing the central frame which everything is built around, making the components easily accessible. This benefits, besides from the assembly personnel also maintenance and repairmen. The coffee brewer module is a good example of an easily accessible module as it is easily lifted off. In other cases the disassembly is more troublesome. An example of this is the circuit-boards located on the backside of the machine, which are obstructed by the engine turning the coffee mixer. Another example is the circuit board in the front panel, which is tiresome to access and remove as there are many panels and covers in the way that need to be removed first.

One issue there is with the central frame structure is that it would need rotating and moving around a lot if it would be manually disassembled at a recycling facility. This is a minor issue as the machine is shredded as it is today. But it is still a issue to think about for the future as the machine has good possibilities to be easily disassembled. Locating the components and fasteners on one side would decrease time consumption when disassembling the machine.

The usage of different joining methods is quite limited which is very good as the dissemblers save time as they do not have to switch tools that often. On the negative side many of the components are fastened with many screws, which seem a little unnecessary and time consuming both from an assembly and disassembly point of view. This is, again an issue for manual disassembly. In today's shredding process this only is a problem if plastics are fastened to metals as there will be some loss when materials end up in wrong material flows in the shredding process. This problem is also linked to parts glued together, which will not separate properly.

In general the machine consists of few materials, which is appreciated and desirable as the sorting of the shredded machine will be more efficient, result in a higher degree of recycling and larger quantities of the materials. Metals are the mainly used materials in this machine, but also plastics and rubber. In general the metals are easily separable from the other materials and would separate nicely when shredded. The water valve and the connecting tubes are thoroughly fastened and will most probably end up as in the mixed fraction that will be incinerated. These are not huge problems but still affect the recyclability of the machine and could be taken into account or future development. There is also quite a lot of cabling used. Designing in a way where components are closer to each other and the cables do not need to be as long is preferable.

Markings and information

The materials used in the machine are poorly labeled. The metal casing is not marked at all, the same goes for the plastics, with a few exceptions. As plastic parts over 25 g must be marked according to law, solving this problem should be a high priority. A bill of materials should also be readily available. The documentation received for this project was a inadequate. The desired BoM would contain all the components, what they are made of and their weight.

Takeback and recycling

Since Crem International produces rebranded machines for resellers but also is its own brand, the question of who the customer is, is a little bit fuzzy. Is it the reseller or the gas station owner? Who is in charge of the recycling of old machines - the companies with service organizations such as Jede with a direct contact with users, or Crem International? Crem should have better control of the whole lifetime. Just knowing how it works is a step in the right direction. Somehow retrieving the machines could be interesting as reusing parts that do not wear significantly could be an good idea as the life time of the components could increase and the material and shape complexity could be preserved, not to mention the energy to reach that complexity - compared to the destructiveness of shredding and recycling.

Design for Recycling recommendations

- Create more slots and tabs in the sheet metal for easy assembly and disassembly.
- Consider, with the help of your resellers, if there are any components that could be reused, and then make them accessible in the design.
- The access is good half-way, but for instance the circuit board is laborious to unmount. It is one of the valuables the recycler wants easy manual access to.
- Fewer types of screws would shorten disassembly times, and thus the recycling fee.
- The use of few base materials is great!
- Recycled material use is limited and could be increased.
- Even though there are no components that must be removed as it is today making valuable components more easily accessible could be worthwhile in the future.
- Guiding the recycler to the components that need to be removed or are valuable can be crucial as a too time consuming search for the valuable or hazardous components result in that the product is shredded together with the valuables, which is suboptimal from a recycling perspective. This could be as simple as having these parts clearly visible and reachable which definitely is the case with the coffee machines, great!

3.4.3 Klättermusen

Klättermusen (KM) is a small outdoor wear and equipment company from northern Sweden. Their products have a profile of high quality and environmental friendliness, and are priced in the premium range. Aiming to be a leader of environmental product development in their field, Klättermusen is looking to close their material loops in order to claim a high degree of recycling without downcycling. For a couple of years they have been using a takeback system (*pant* in Swedish) for their backpacks. When returning an old product, a customer can get a voucher of up to €20.

Klättermusen also has created their own grading system, ECO-index, for their products, where they have a number of requirements which are either fulfilled or not. The fraction fulfilled/unfulfilled then becomes the grade, e.g. 5 out of 6 requirements fulfilled, 5/6 = 83% (Klättermusen, 2011). This is hardly scientific but shows the commitment to transparency and the ever important "we're not there yet".

The case

For this project, the 30 litre backpack Allsvinn was chosen to be analyzed. It can be considered to be one of their simpler bags ("simple but sturdy"), it has an internal ECO-index grading of 57% or 4 out of 7 (*Made from recycled material, more than 70% • Recyclable in confirmed recycling system • Long life cycle as opposed to lightweight products • 1% to the environment projects*).

Analysis

The takeback system is a way for Klättermusen to control their materials. For many of their applications, they use polyamide (PA or more commonly known as nylon). It is a durable plastic good for recycling. Klättermusen uses a recycled nylon called PA-6 as fabric and PA-6/6 for buckles and stiff details. Aluminum is also used for some details. These go in two different material loops for optimal recycled material quality.

One of the design issues for a small company like Klättermusen is leverage when negotiating with manufacturers. KM wants to recycle their stuff in the same process where they got the materials, but since they're such small players it is hard to catch the ear of the big companies. When it comes to their PA-6 backpack with a poly urethane (PU) coating (for water resistance), they got the word that it was fine in the recycling process, and later on in the product development the manufacturer/recycler (same entity) said it didn't work. With a better knowledge what is possible and not, KM has a better position to negotiate. Stena has a greater material flow, and have more experience of these sorts of negotiations. They could then help KM to get the facts right from the start. The PA-6 Stena retrieves is incinerated at the moment, but an extreme option could be to hold up that flow until they reach sufficient quantities to send to recycling. KM's material would then be included. This is important for KM from a branding perspective so they can say that a backpack is made (partly) from an old backpack which a customer brought in at end-of-life, thus validating their takeback system.

PA with PU – is it recyclable?

The issue of whether or not the PA with PU coating is recyclable or not is not as clear cut as it seems to be. After discussions with four different experts, the problem was untangled successfully. The experts were:

- Martin Leander, Plastics Recycling Expert, Stena Recycling
- Christian Cronvall, site manager of Stena Recycling in Borås
- Mikael Skrifvars, polymer scientist , Högskolan Borås
- Christer Forsgren, Head of environment and technology at Stena Metall

The volumes and logistics of it all does not make business sense. Stena normally count plastics in tons and trucks, and the backpacks plastic stream would simply not yield enough material. An LCA approach would thus hardly favor the extra miles needed for proper recycling of all parts (the metal being the exception)(Leander, 2011).

Textiles are a bit like metals: the tougher and stronger the material, the harder it is to recycle (Cronwall, 2011).

For KM, Cronvall recommends finding a second use of the material first and foremost, selling them second hand or using parts in new backpacks but not going for the material recycling as of now due to energy usage. For the future they should try and use compatible materials (Cronwall, 2011).

The mix of PU and PA cannot be recycled in the normal recycling process. To recycle the fabric, one would have to break down the polymers to oil again, and start the process all over (Skrifvars, 2011).

A new technology is being developed, where the mixed fines from shredding are microwaved in an oxygen free chamber. This pyrolytic process make the plastic evaporate as a syngas, some of it becomes oil. The metals remain and can then be recycled. For Klättermusen, the syngas is the interesting part. From this, new polymers can be created. The road to a new backpack is long from just a gas rich in short polymer chains, but it's a first step towards completely closed loop recycling. The degree of recycling from this pyrolytic process is a theoretical 100%. Right now the process is not scaled up enough, since no polymer producer would accept so small quantities of syngas – but if Klättermusen wants to make a statement, they could create a story out of this bottle of syngas that a backpack would produce - which can be made into a backpack once again (Forsgren, 2011).

Design for Recycling recommendations

In summary, the recommendations for KM are that while recycling is theoretically probably possible, it would not be economically feasible. The pyrolytic processes currently available are very expensive and the material flows of KMs are very small increasing the costs further. As KM positions their brand quite high there could possibly still be an interest to use this method. Closer contact with experts and marketing at Stena would be advisory it this was something that would be an option.

To really do innovative recycling and be a pioneer in their field, the pyrolytic method is an option that would surely be in the frontline.

A more economical and probably more realistic option is to create a strong second hand market for the backpacks, thus elongating their lifespan. Another option is to use fabric or parts from used products and manufacture new products or components for other products.

3.4.4 Small electronics company (Reference Case)

The company is a provider of complete and integrated IT systems. Customers include many of the foremost retail chains all over the world. The system consists of small electronic units which are wirelessly connected to a computer via transceivers. The “consumable” in these systems is the small electronic unit. These units consist of e.g. a PCB, display and batteries integrated into a plastic shell. After a preset time before the batteries die, typically around 5 years, all the units are exchanged and replaced.

The case

The company wants to know “what happens” with their products. For the project, one of their standard products will be analyzed.

Analysis

Used units are to be disposed as electronic waste, but in theory they could have their batteries replaced and work for another 5 years. No customers have asked for that option yet.

For Stena Technoworld, the Stena branch responsible for the EOL treatment, the products come in tons at a time. They then manually break them open to extract the batteries.

The legal requirement on battery hatch construction is that they need to open without the use of tools. Today this is included in the design. However, this is merely cosmetic since the shop keepers normally don't exchange batteries and according to Rickard Knutson (2011) at Stena Technoworld, the battery hatch is unlikely to be used by the disassembly personnel as it would be too time consuming and costly to open each battery hatch just for the battery. Instead the product is manually bent and broken into pieces until the battery is possible to remove. The rest of the product is then thrown into the shredder.

Design for Recycling recommendations

- Easier battery and component access is wanted. The WEEE directive actually states that batteries should be "easily removable". Today, its not.
- Since the products are made in large series, an automated disassembly process could be taken into account when designing new products.
- Some metal connectors are hotriveted onto the plastic. This means the metal will likely not be recycled. These should instead be held in place in a way so that meatl and plastic are separate after a shredding.

3.5 Requirements

From the literature study, the initial project brief, the contact with the case companies and the pre work a requirement list for the feedback was created.

The feedback report should:

..clearly visualize the conclusions and points made in the report
..include positive as well as negative feedback on the construction
..teach best practices and future technologies
..help the client understand what happens to the product at end-of-life today
..support internal communication within the client's company, i.e. show key metrics in economy and material savings etc.
..provide rules of thumb for design for recycling, while still being specific enough to be worth the price of the service
..be easy to read for a layman while covering in-depth concepts

3.6 Discussion

3.6.1 Survey

The major impediment to the survey was the lack of participation. Only a fraction of the designers approached took the time to fill it in and mail it back. The answers given, even if few, were qualitative in nature which was beneficial in the project (though that initially was not the reason for doing the survey). In the question dealing with feedback medium (report, poster etc), there were no limitation in how many choices could be made. This was intentionally a question with multiple selectable options as the participants could indeed wish for many different forms of feedback. Adding cost or in other way making the subjects consider their answers could have increased the realism of the answers. Then again the participants would have been facing even more issues than just wishing for feedback medium. To some extent the answers left us a little shorthanded due to the low amount of comments and explanations. Receiving more comments on the chosen options would have been desirable as there would have been less assumptions and interpretations when analysing the answers. In terms of contribution to the project, the ongoing dialogue with the case stakeholders was more rewarding as more open dialogue with more qualitative answers could be obtained.

3.6.2 Case analysis

The choice of products for these analyses was, as mentioned earlier, quite varied. Choosing a backpack for a thesis on electronics recycling might seem odd but it gave us the opportunity to dig deeper into recycling and gave us a wider understanding of the different processes. In addition to the coffee machine, the washing machine and the price tag products from categories other than electronics could have been used as well but in order to keep the project within graspable boundaries the backpack was the only allowed exception in the project.

Starting off by analyzing the washing machine we got a broad base of ideas and thoughts. During this analysis more questions surfaced than were resolved. We gained a respect for the complicated process of designing a product - making a super-recyclable washing machine is not done overnight! The expertise from Stena came in handy resolving the factual questions on materials and recycling, while we were still needed more process information from the manufacturer's side and the designer side of things.

The analysis itself was conducted quite thoroughly breaking the product into its smallest components. In retrospect this might not been necessary for the future service. This kind of disassembly is rarely done as it would cost too much and in a disassembly project, as the one this project is designing the service for, there is no real need to disassemble everything to its tiniest part. Data could be estimated just by opening the product and analyzing what could be seen and possibly extracting some parts that would need more attention. For the first try though, it was a learning experience on product complexity and composition.

The disassembling of these products increased our understanding for work of the disassemblers, and also forced us to reflect more on the role of the designer and what issues he/she can face. We have also realized that products are often constructed in ways that undermine the recyclability of the product and even though there are solutions that would make the recyclability better there are many other systemic factors to include.

3.6.3 Process timing

When in the process should the feedback come? When talking to the head of R&D of the washing machine company, he said he best thing would be to build it into the minds of the product developer. In practice, he'd like for the service to be more pro-active and enter earlier in the design phase instead of being an analysis of an already existing machine. Analyzing an existing product is too late as the “damage” is already done. If a designer knows in advance what he/she should do the result will be better already the first time. He would like to have guidelines available before the design of a new product starts. Having a check lists to fill in collaboratively would engage and teach the designers of the ins and outs of recyclability related to their product.

3.7 Conclusions

- Disassembling the case products manually, we realized how hard design for recycling is. Is it possible to create a copper spool magnet and still have it water proof, food grade and easy to separate the materials in a shredder? It's hard.
- The case products, especially the washing machine and the coffee machine, both had some interesting and useful construction examples that could be used to cross-fertilize designs. What do we mean by that? Some ideas can be taken from the washing machine and then be implemented almost directly in the coffee machine design and vice versa.
- Optimising material for every function in a product means choosing different plastic types throughout the machine. At the same time, it leads to suboptimizing the recycling, since there will be a lot of different plastics in small material flows. The perfect plastic for a function, such as the PP with 20% talc used in the laundry detergent tray, is one example of this.
- The companies studied are all very different in their product development processes. For the service, this means we can't go into specifics on implementation of design choices, as this will vary between the companies. Some will have specific gates in their project structure and will want to have checklists, other companies may just need the knowledge as the product development is very small. The service needs to be quite flexible and be relevant for different types of companies.
- Both management and product developers need to be thought of when constructing the service, as the design concerns are influenced by economic decisions. Where is the value for the company to do this? The service needs to communicate this.
- The product developers want their feedback in the form a report with specific tips on their product.

4 Concept design

The concept design phase is where learning's from the pre work are embodied into a tangible service and the best practices for communicating design for recycling and design for disassembly is explored. The aim is to create a service that is functional for different types of electronics manufacturers, while still being customized to each company. The feedback should be communicative, simple to understand and enjoyable to read. To reach this, the visualisation and composition of a feedback report was developed through an iterative process with idea generations, graphic design and evaluations of ideas. The ideas resulted in a service concept centred around a feedback report. Stena and the washing machine manufacturer were consulted for constructive criticism before the same improved feedback report was created for the most similar case, that of a coffee machine from Crem International.

4.1 Service framing

The service flow previously described is not new and Stena has conducted analyses of products before. As a part of this thesis project the results and feedback reports made in these previous analyses were examined in order to get a deeper understanding of what was done and what kind of information was delivered to the manufacturer. This examination revealed different areas that could be improved in order to make the relevant information easily available and were set in focus for the rest of the thesis project. The previous feedback reports were considered tedious to read as there was only plain text. Reporting in this way though, has its advantages as much information and data can be printed. On the other hand long reports are tiresome to read and getting an overview of the analysis is hard unless one read the whole report. Another issue identified was that, in some cases, one would have to read the whole document to find what one was looking for, if that information was there at all.

The focus in this work became the feedback report but additional feedback in form of posters, showcase models etc. were considered to be an effective way to increase the interest and engagement with in the manufacturers organisation to the issues given in the feedback.

As a part of the service there should be follow-ups and evaluation of the result for further improvement. There should also be a possibility to get some support for some time forward. The service do not end here, continued contact and new analyses can then conducted on other products or even next generation products for further improvement.

4.2 Graphic design

A considerable part of this task was to create a communication tool that would be pleasing to use. What to include in this service and most importantly the feedback report had been determined in the pre work phase. This content needed a face that is both informative and matches the visual profile of Stena.

4.2.1 Stena's visual brand identity

The graphical material of Stena is simple, light and the use of colors is limited to the primary and secondary colors: blue, green, orange, purple and gray. The imagery used is linked to their business and often consist of employees or details from the recycling process, bringing the reader closer to the company (Figure 30).

Figure 30. Homepage of Stena Recycling, typical with images of employees and limited amount of color.

The use of rounded and straight corners give a straight forward but not too harsh feeling, thus depicting Stena as sturdy but humane. Even more lightness is added through the use of gray lines instead of traditional black lines. Through basic, understandable illustrations the reader can relate to the information given. The use of every day examples that are close to the reader also makes the information more interesting and easier to understand (Figure 31). The overall feeling is the business-like seriousness and professionalism. This visual profile, together with animated examples, depicts recycling as easy and friendly.

The visual brand identity of Stena correlated well with the ideas and the requirements set for the feedback report that was to be developed in this project. The aim was to create a light report that would be pleasing for the eye, enjoyable to read and the information would be easy to understand and find. The colours were directly taken from Stena's graphical profile and the style of the homepages was imitated to connect the feedback report to their brand identity.

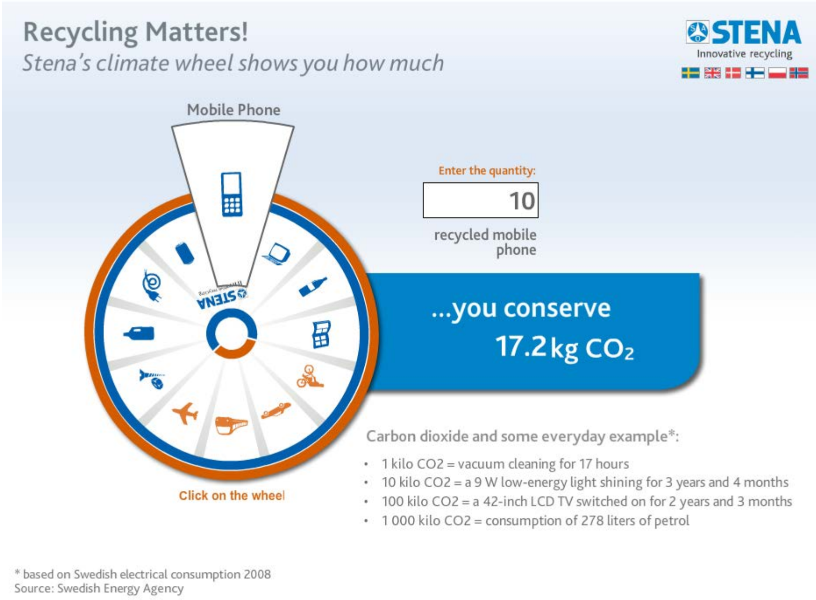


Figure 31. A tool found on the homepage of Stena Recycling. Light and simple but still communicative.

4.2.2 Features of the feedback report

The structure of the feedback report was aimed at being as simple as possible while covering all the necessary aspects for a company to improve their product. To achieve a perspicuous feedback report the information going to be put in it needed to be split up and categorized. The categories were based upon different things that had been learnt during the earlier research phase. Here are the different categories/features and what thinking went into their creation. The feedback report can be found in Appendix for reference.

Initial words

This included a brief presentation of the report and how to read it, and a little text on the recycling ladder, and finally a disclaimer on the grading system. Since the readers will have different depth of knowledge on recycling, this first page is an attempt to get everyone up to speed using one of the most widespread models, the re-ladder or recycling stairs. Since it is only covering recycling and not product development, the reader is put in a frame where recycling is central compared to other requirements of a product. This tone is used throughout in order to internalize recycling awareness in the reader, while still recognizing and balancing with the fact that there are other conflicting requirements.

The grading, which we will get back to, is not scientific but more in the style of guidelines. Later we noticed that even though we had this disclaimer to preempt any questions on the scales, the questions still arose.

While being the first page, the feeling striven for similar to that of a dedication page in a novel (e.g. "To Sandra, without your support..."), a page that sets the mood but is still not the actual content.

Face page

The next page, the face page, was to be a visual eye-catcher that would sum up the report's content without the need for critical thought on behalf of the reader, a short introduction with graphics. The object of this was to create interest and invite the reader to flip through some more pages. By creating an airy and visual approach close to a coffee table book format, the report would be able to live longer and the knowledge would be transferred to more people in the product development departments, by being picked up and even discussed around the office. Learning is mediated best in a non-stressing situation such as a coffee break.

The idea of grades was part of the discussion when the project was initiated. A compounded total grade for the product would be nice. What unit should this grade be in? Percent, a pass or no pass (like a certification), or a point on a 1 to 5 scale? To not oversimplify, this idea was discarded. The ins and outs are too complex to reduce to one numeral. Instead, visualizing all sub-grades side by side created an instant visual impression of the product's recyclability, and is easily comparable to other products.

Figure 32. A sign from the Tokyo metro alerts passengers to not injure their hands. Even though it is a warning sign, the mood is kept light hearted and positive through the use of cute animals.

For the first sketches, the face page included some additional icons. A battery icon if there is a battery in the product, icons for hazardous materials and flame retardants (Figure *33*). As the work progressed this box was removed from the initial draft, since they were discussed within the other categories.

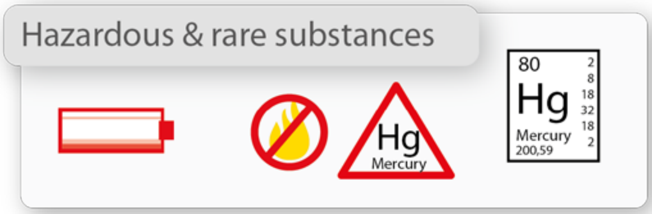


Figure 33*. An idea how hazardous and rare substances could be visualized in the feedback report.*

Some ideas for the face page included cartoon creatures, e.g. Mike the Moose. He would be equipped with a speech balloon and comment on a specific aspect such as ecology, with regard to the product analysed. Mike would have the appropriate facial expression that show whether he is happy, sad or angry about the subject he is commenting on (Figure 34). Cartoons are quite powerful conveyers of information since no one expects the concepts explained by a cartoon to be complex Figure 32. There is thus no resistance to learning which could be the case with a dense body of text. Also, it is a backdoor for conveying a feeling, which is frowned upon in a business-to-business report. The drawback is of course the report could be taken less seriously. Except for the moose there was Recycling Rick, Designer Dan etc. In the end we decided to swap this cartoon for an expert at Stena (Sverker Sjölin in the first design) commenting on a detail. This shows the depth of knowledge within Stena, as well as showing that the organization is built up from nice people - both of these factors of course strengthening the brand of Stena Recycling.

The Recommendations field is a short summary of identified possible future improvements in bullet form for the lazy, stressed or peripheral reader.

Figure 34. Different expressions of Mike the moose.

Category chapters

Following the face page the report was divided into the five chapters identified: *Documentation*, *Recycling incentives*, *Disassembly*, *Product composition* and *Joinings*. In these chapters the results from the product analysis are presented more thoroughly. For every chapter, a grading system was created. At this stage, the object of the grading was for the product developers to see where they are at, what a natural next step in their recycling development would be, and also to show what an ultimate goal would be, a vision for every category. The *Joinings* chapter was visualized in a unique way, as we will see later. These grading systems were changed later for the final concept due to functional reasons, which will be discussed later. The grades were separate milestones, some very descriptive and "objective" in their nature, others more subjective and up to the report writer to judge.

Documentation

Documentation (Figure 35) deals with the aspects of carrying information over time. When it is time for recycling of the product, often many years have gone by. The manufacturer needs to make sure that the recycler has access to valid information. For the recycler, this information affects the price to charge/pay for handling the products at EOL. Thorough documentation is also important for all product parts, since there is no way of knowing what might be considered hazardous materials in the future. Historically, toxic materials have been used first, only to be regulated later (e.g. mercury compounds, brominated flame retardants).

Figure 35. Documentation scale

There are a couple of ways to convey the information over time, the most obvious being to include a list in the product and mark all the parts. For plastics, parts over 25 g are regulated to be clearly marked. Most often this is done with the triangular recycling symbol, but for more advanced plastics it is written out. This is not always to be trusted though, since manufacturers and subcontractors might change the type of plastic but still use the same mould, which is worse than not marking the component.

Another way to convey the bill of materials is to have a database available on the internet for reference. Many of the bigger manufacturers do this and according to Sverker Sjölin (2011) at Stena Technoworld it is a functioning system. The risk is that if a company disappears, the information will too.

RFID is a radio chip technique that is getting cheaper. Having an RFID on a product that is then scanned by disassembly personnel could tell them all the necessary things, such as if there is any hazardous materials and a link to the internet database. There would be a need for a new infrastructure (having RFID scanners in the WEEE pre treatment), but in the scale we wanted to show ideas that could be used in the future, or ideas that could be part of a pilot programme for WEEE handling.

The plastic parts of the washing machine were clearly marked. One marking was unclear, many parts had the material and then "+FR", for instance "PC+FR". FR means flame retardant. After consulting Sjölin (2011), it became clear that only marking the plastics as flame retarded is not enough to follow legislation, the name of the specific of the specific flame retardant is needed.

The documentation category is close to the recycling incentives category but has been separated as the documentation category grades the communication producers give to recyclers while the recycling incentive is the information given to the end user by the producer.

Recycling incentives

This chapter had many names during development: Takeback, Reverse Logistics, Recycling incentives. How can the product end up in recycling in a good way, and how is it communicated throughout the life cycle?

“Takeback” and “reverse logistics” refer to how producers can make sure products, sub-assemblies, components or material can be retrieved for reuse, refurbishment or controlled material looping (Figure 36). Most companies today do not deal with these questions, mostly because it very challenging to create viable business models and logistics around it. However, it is important to raise these questions so all parts of industry are aware and look for solutions to create healthy material flows. The grading used is taken directly from a Danish master thesis around Reverse logistics (see Takeback and Reverse Logistics in Part I).

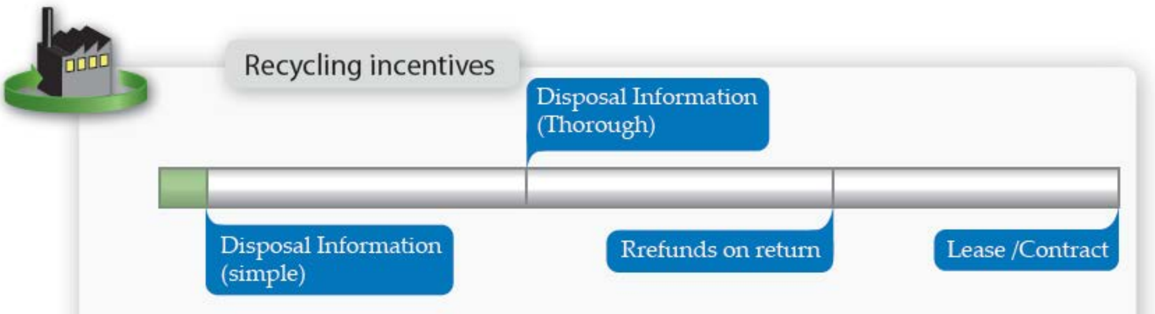


Figure 36. Recycling incentives scale.

Disassembly

The disassembly section (Figure 37) aim at making the designer aware of how the disassembly is practically done and to emphasize the implications their design has for the disassembly process. The initial idea was to only cover manual disassembly in this category as it was believed that 'an easy manual disassembly leads to a easy separation in a shredding process'. This is still true but the subject is deeper than that and there could be processes between manual disassembly and shredding that could be good. The idea behind the scale is that a hard disassembly results in a low score and the easier the disassembly is the higher

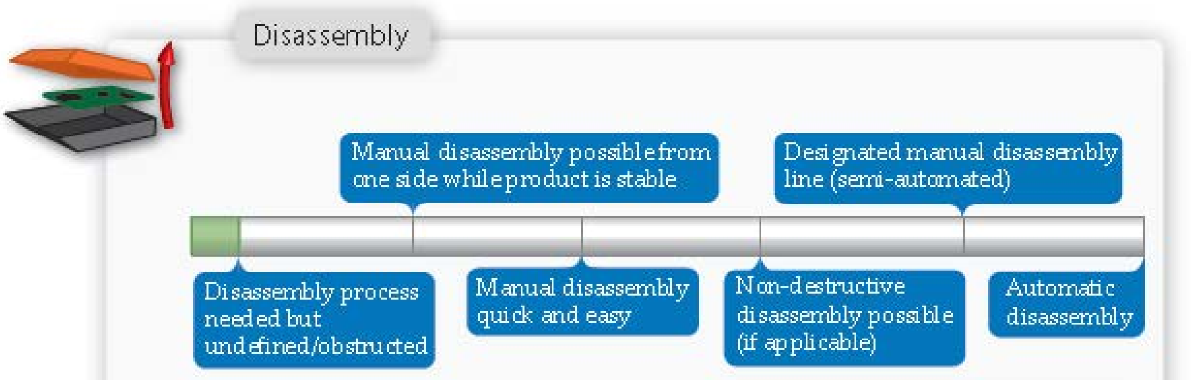


Figure 37. Disassembly scale.

grade the product get. In this case the worst grade is given when a product must be disassembled to extract a component or to separate a hazardous material etc. This is often also legislated by e.g. RoHS or WEEE.

The easier a product is disassembled the better it is from a recycling point of view. One might think that unscrewing a couple of screws would be a simple procedure. This would be true if, let's say, one was to change the battery of a robotic dog. But considering the huge product flows at the recycling facilities unscrewing a couple of screws every time a battery need to be removed would be very time consuming and the risk of not be done naturally is higher. What if there was no need for any manual disassembly at all even though there are components that need to be extracted? That could be achieved through some kind of shape memory material and a disassembly process for it, which implies that the 'automatic disassembly' bubble belongs to the joining category. This is a known fact, but trying to describe how easy a product is to disassemble and why, is almost impossible without mentioning something about joinings. This overlapping or intrusion is considered to be a must, simply because the categories are so connected and since the two categories focus on different aspects.

Product composition

The category of product composition is a summary of how materials are used and mixed in the product (Figure 38). The focus is mainly on plastics and metals, and since wood is scarcely used in electronics it is not part of the grading. Also, the circuit boards are definitely a problem when it comes to the material mix and separation, but this is outside the scope of this project.

For a product developer, choosing the right material for a component is a jungle. There are requirements ranging from tolerances, yield strength, scratch and corrosion resistance, manufacturing and assembly constraints, sub-contractor relations and of course cost. Added to that, this project aims to put recyclability as a priority to the list.

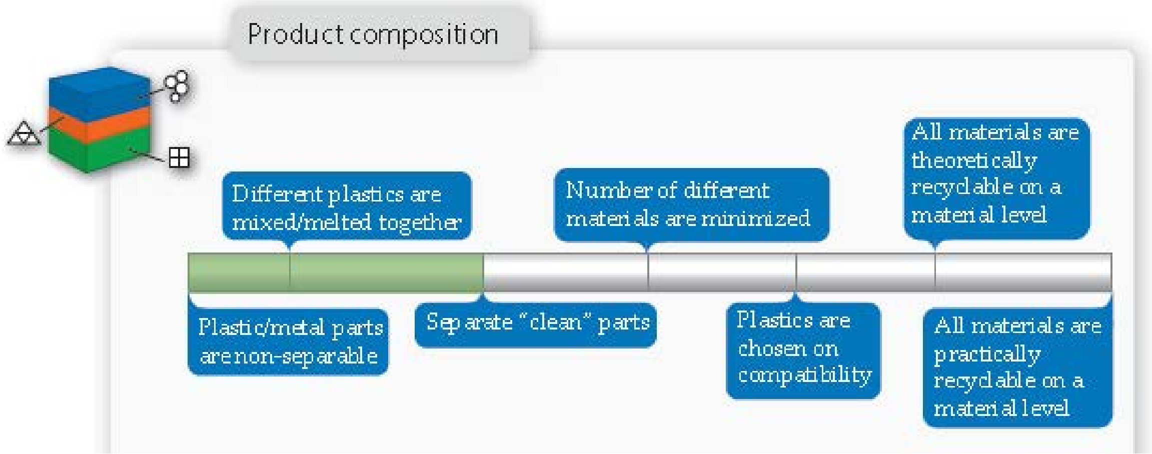


Figure 38. Product composition scale.

The most important point conveyed in this chapter is the need for parts to be able to separate nicely. It ties in with the next chapter of joinings, but focus more on the materials. It also includes how many components there are. Could we skip features and have fewer components? Could we use the same plastics on multiple components on a systems and product line level instead of optimizing parts individually which ruin the economics of the return flows?

For recycling purposes, exotic plastics are a nuisance that could corrupt the recycling of the main types of plastics: PP, PS and ABS. This is what is meant by compatibility.

The process for metals is well established and functioning. They have a working sorting process and the value is generally high compared to logistics costs which make them worth the effort of recycling. A problem is metal screws in plastics, which don't separate well in the shredding and subsequent automatic sorting. A little bit of plastics does not destroy the metal fractions, but losing the metal into the final waste fraction is far from optimal. That is why metals screws in plastics are not recommended.

Joinings

The joining chapter deal with the method parts and components are joined together (Figure 39). Different methods are better than others. The methods used today are usually chosen based on the properties and what is most suitable for the assembly of the product. What is suitable for disassembly and recycling is seldom considered.

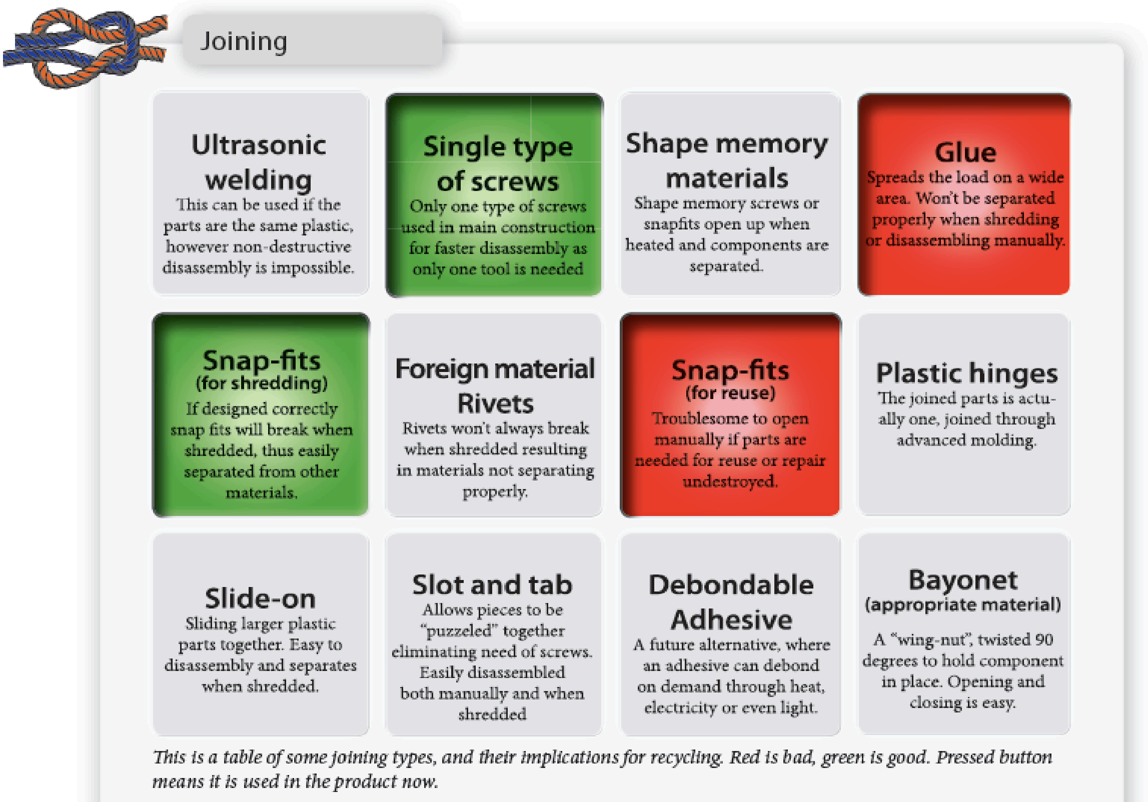


Figure 39. Push buttons showing the used joining types.

This chapter originates from the disassembly chapter. It became an own chapter as disassembly became too wide and complicated in order to be graspable. At first the joining section was a linear scale as all the other, but after some deeper analysis it was found out that it was hard, or even impossible to arrange the methods relative to each other, as the circumstances would change for each product. Therefore a set of buttons where designed. These would be arranged in a matrix pattern, but without any specific order. Instead they would either be turned 'on' or 'off' by the Stena personnel conducting the analysis. The 'on' or 'off' status demonstrate if the joinings. methods were used in the product and the color would show whether the methods were good or bad from a disassembly and recycling point of view.

This method of visualizing the reader would get an overview of their product but also see that there are other methods that could be used. The unused methods were left gray as coloring them could lead to misunderstandings and getting a clear overview would be harder. In the first version the buttons were only labeled with the type but it was soon realized that the reader would not understand what each button meant and a short description was added. The new 'button' design also resulted in a need to change the scale on the face page. On the face page the same amount of each red, green and gray button would be represented with a smaller button with no text as there was no space for text.

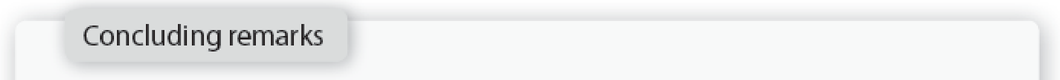


Figure 40. Headline for the concluding remarks section.

For the conclusion part (Figure 40), ending on a strong note was a priority to push the designers into action. That is why a bold VISION: type was placed in the bottom with a call to create a washing machine in a single material (Figure 41). Doing so would be possible, but it would go against most other requirements (the paragraph below is mostly a disclaimer as to the challenges it would create).

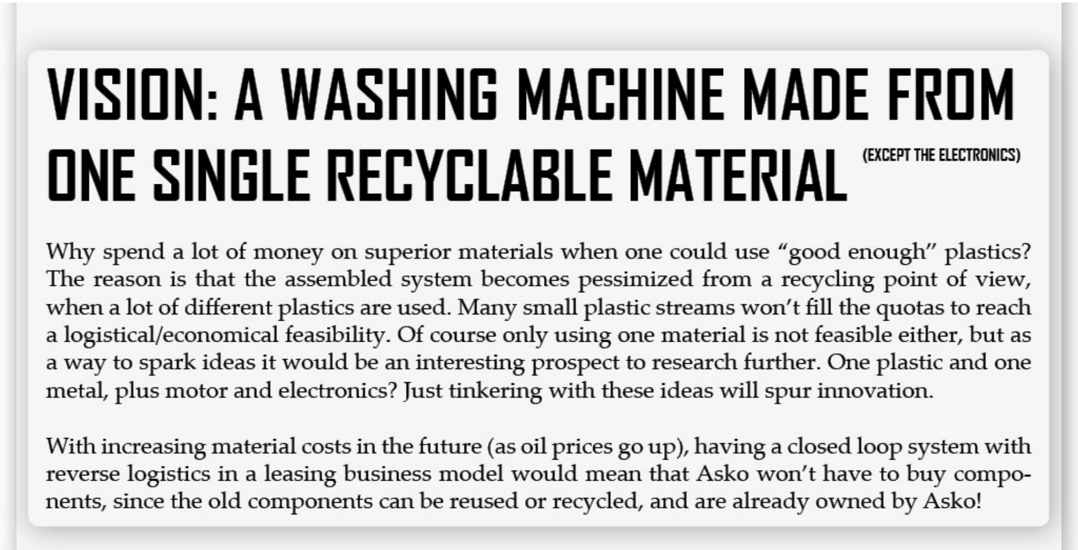


Figure 41. The vision box. A wake up call and food for thought.

While possible, it would be a positively stupid thing to do. Bear in mind that the main purpose is not to be feasible, but to make the product developers start thinking high and wide for new ideas and approaches.

Having a vision like this would mean the vision would need to be reformatted for every new case, since having one material is not the most visionary thing for all EEE products.

4.3 Critique and evaluation of the feedback report

After the initial feedback report on the washing machine was finalized, Mats Torring of Stena Recycling, Sverker Sjölin of Stena Technoworld, Ralf Rosenberg of Chalmers department of Design and Human Factors and last but not least the R&D manager at the washing machine manufacturer's had their say.

Overall, the external comments ended up in "interesting, but needs more specifics". **Mr. Torring**'s more general points included:

- An attractive front page.
- A presentation of the service at the outset.
- Adding more into the report to make it thicker.
- Index for faster overview of content.
- Dismantling and shredding should be two different "tracks" pursued in the report. Design for shredding is most likely what happens now, but design for disassembly is vital to push for.
- A part on hazardous material (it was previously included in the running text)
- In Product composition, the text would benefit from being in paragraphs according to material type.
- Transport logistics when recycling. Too much air in transport is inefficient. Can it be easily put in cages or containers?
- A ”Board room” page with hard facts (explained below).
- A part on the potential use of recycled material.

Mr. Rosenberg, the Chalmers supervisor, discussed the scales in the feedback report, which were deliberately not linear in any way at the outset, but still conveyed linearity. This was considered a cause of confusion. If there was a way to convey the information as simple as the "progress bar" without removing so much information it would be preferable. One other point he raised was how certifications work, and that employees are asked to go through a check list together. This is a nice way to get engineers involved and reflect on their product, and perhaps something to be combined with the visuals and the scales. In a way, the big square joinings' buttons are a check list, but they need more descriptions to be clear so having them in a column will increase that feeling.

The **head of R&D** at the washing machine company had a few comments. Overall, he really liked the layout and the visual approach of the report. In terms of the usefulness of the report, he was a bit confused as to if the analysis was for the specific model, or if it was for the company's washing machine line, or for white goods in general.

To keep the interest of the reader the communication should be as short and concise as possible. Bullet points for fast recommendations are preferable. "Best practice" examples are important for the products to evolve continuously. The R&D manager thinks it is important to leave the details to the individual designer, and any influence on the development should rather be inspirational than authoritarian. Apart from the feedback report, the R&D manager would like to have a presentation of the result to discuss the feedback. Support while development is progressing would also be interesting.

4.3.1 Discussion on the critique

Board room

The “board room” page would be a page filled with facts, graphs and statistics to underline the win-win aspects of recycling, to be used for internal communication within the customer company's departments and management.

Headlines for speed

By putting the text together in smaller paragraphs with a clear headline for each, Mr. Torring felt that writing each new analysis form a template would be faster, as well as being easier to search through for a reader. Also, more material in general on each chapter was requested for the report. This was not a problem, as a lot of text previously was intentionally left out to keep the report light. By adding some theoretical material prepared for this thesis report, the revised feedback report gained weight as well as authority. Also a template had been intended to be created eventually.

Workshop with input from potential customers

Early July 2011, a workshop was held together with representatives from Stena and the design department of a major garden equipment manufacturer. The spawn of the meeting was tied in with the service – to present to the designers how recycling works and how Stena can help. The designers were quite eager to know more, and seemed interested in the service and the feedback report. However, some issues also became clear. We presented the report made on the washing machine, but we got stuck on issues where the designers thought they would get a report on washing machines. Somehow they had a hard time conceptualizing the report done on their product when this other example was in the way. This led to an understanding for the need of a neutral presentation of the service, devoid from any product that would lead a potential client astray.

Service, what is thy name

To tighten up the service, a catchy name was needed so that people involved could refer to it in an easy way. A small brainstorming session was held, where a name alluding to design, recycling, feedback and development was sought. REvolve, REvolver, CIRCLES, Loop were some ideas. REvolve came out as a favorite. Why?

REvolve alludes to Recycling and the RE-ladder (RE), continuous development and improvement (evolve) and the cyclic flow of materials sought for (Revolve). REvolver and REvolution could both be said to communicate the same thing, with some semantic differences. The word revolver is American and violent, and revolution has an upsetting connotation. Revolve is both neutral and imperatively powerful.

Joinings

The further the development of the service went the more complex the feedback report was becoming and as the intention of the feedback report was to make it easy to understand and to work with, simplifications were needed. The section on joining needed to be easier to evaluate as there can be many scenarios with different amounts or joining types etc. that would affect the grading more than just “on or off”. Also the design of the “buttons” on the was found to be visually functioning but it was hard to fully understand their meaning. These would have to be further developed to clarify their function and meaning.

Grades

During the preparations of the feedback report questions of the meaning of the scales and their boundaries surfaced as some scales overlapped each other at the first glance. For the simplicity and ease of getting an overview the texts the bubbles on the scales were kept short. This turned out to cause problems as there was a risk of misunderstanding what was the intention of the bubble. The complexity of Design for Recycling is simply not easily simplified.

4.4 Requirements – revised

After the critique on the feedback report the requirements list defined earlier was revised and updated. The additional requirements in bold:

The feedback report should:

..clearly visualize the conclusions and points made in the report
..include positive as well as negative feedback on the construction
..teach best practices and future technologies
..help the client understand what happens to the product at end-of-life today
..support internal communication within the client's company, i.e. show key metrics in economy and material savings etc.
..provide rules of thumb for design for recycling, while still being specific enough to be worth the price of the service
..be easy to read for a layman while covering in-depth concepts
..be dense and informative enough to merit a business-to-business value as a service product.
..have a transparency in why a certain grade was reached, and clearly show what would be needed for a higher grade.
..be readily editable by others in the Stena organization
..have a distinct name

4.5 Redesign

The redesign phase ensued, where the feedback and critique gathered guided the changes.

Grading and scales

The bubble project was scrapped, and different versions of grading were tested. A balance showing both good and bad aspects was sought for, ideally in one visual element. However, this proved to be hard. If a product features both really good material choices and really bad ones, what grade is that worthy of? If another product has not as good but also not as bad materials, is that a better product then? The experimentation led to the conclusion that both the negative and positive aspects needed their own "progress bar" (Figure 42). After discussions with Mr. Torring and Mr. Rosenberg how rigid the criteria would be, both concurred that a subjective scale would be the best option for reasons of flexibility since the service must fit a broad range of products (joinings is the exception, see below).

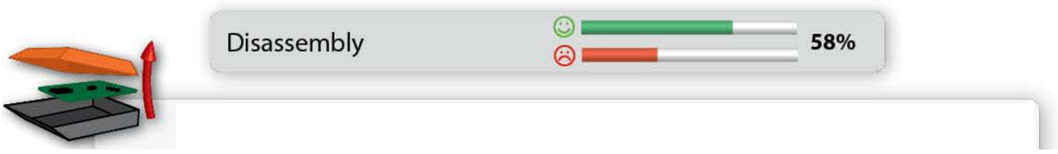


Figure 42. An example of the redesigned scales and grading.

After the grading of the different chapters (good and bad) on a scale of 0-100, a compounded score is calculated according to the following formula:

$$Compounded\ score = Positive\ Score * (\frac{\left(100 - \frac{Negative\ score}{2}\right)}{100})$$

The formula is designed so that a negative compounded score is not possible. The weight of the negative is also lower than that of positive things due to the promotional aspect of the feedback report. Keeping a positive tone and encourage the things companies are doing well is important to promote further recycling efforts.

Headlines

As one comment on the feedback report was the lack of headlines in each chapter these were added. This resulted in an lighter feeling of the feedback report and the reading experience became more enjoyable. The headlines also made it easier for the reader to get an over view of the content within each chapter.

Joinings

The joinings part of the feedback report created in the initial design phase was very visual, but at the expense of clarity in communication. Good/bad joinings were shown through color coding (red for bad, green for good). The push-button design clearly showed what joinings were used, and together with the color coding the designer could browse and ”shop around” the page for a green but unused joining technique to switch to. However, as the buttons were limited in size, the descriptions were lacking in detail and the reader's understanding became compromised. For the redesign, we changed the “tile checklist” design for a “button bullet list” with a paragraph of text for each joining.

Table 3. The joinings ordered from from best to worst in terms of design for disassembly and recycling. The complete matrix can be found in Appendix 6.

Joinings sorted by rank	
Tabs & Slots	10
Bayonet	9
Slide on/in	9
Snap-fits	8
Screws	6
Shape Memory	6
Debondable	4
Ultrasonic Welding	4
Rivets	3
Glue	2

Since just good/bad was not enough for a designer to learn anything substantial, a point grading system was developed. A matrix with important recycling and shredding aspects of different joining techniques were worked through for the small electronic and the washing machine case to span the width of the service. Weighing the importance of each aspect and calculating the score for each joining method, a special grading system was created (Table 3). Flow charts were developed for each technique (Figure 43), where optimal use of the method resulted in the maximum grade for that type of joining, the maximum score being the same as the score calculated from the matrix. These flow charts were intended for an appendix reference, so that the transparency requirement be fulfilled and designers could understand why a certain rating was given, and how to improve it. The button bullet list would then have a different max score for different joinings, so that the total joining score reflects the relative importance of techniques. In addition of a clearer information to the designer, using this method for evaluation of the joining types used would help the compilation of the feedback report.

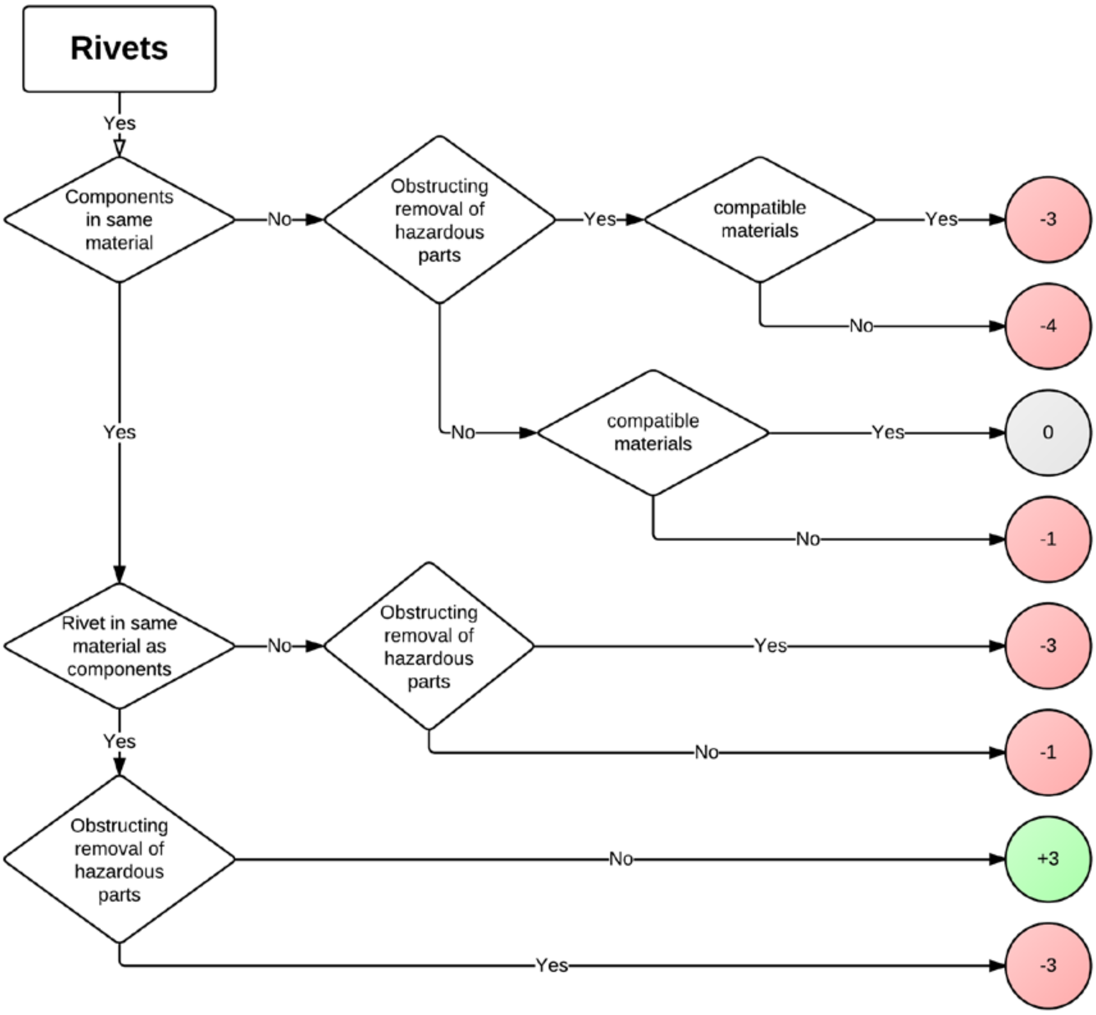


Figure 43. Example of a joinings flowchart, this one for rivets. The rest of the flowcharts can be seen in appendix 7.

InDesign vs. Word - compatibility rules

During the redesign work, Stena pointed out that all their staff does not have access to or knowledge in the software InDesign. Thus they would not have the possibility to insert texts from the analysis as easily as if a commonly used software was used. For this reason, the iterated report was migrated to Word with some loss in pizzazz. While some design elements were lost, the overall communication was only affected marginally.

Board room/Hard facts pages

In order to achieve a greater reliability and more KPI style (Key Performance Indicator) feedback that could be useful for management purposes a "board room" page, or "hard facts" page was added. The data for this page come from estimations and calculations based on the product analyzed. What type of data to include was based on a product analysis previously performed by Sverker Sjölin of Stena Technoworld. The numbers included in that analysis was:

- % (of weight) that can go to material recycling.
- % that can go to energy recovery (incineration).
- % that ends in landfill.
- If flame retardants are used or not.
- If the parts are marked or not.

This specific analysis performed by Sjölin was a check if the product met the legal requirements of WEEE, in which case 65 % needs to be recyclable (75% if incineration counts as recycling). The weights of parts were unaccounted for in our analysis until this part, but are easily gathered from a Bill of materials that

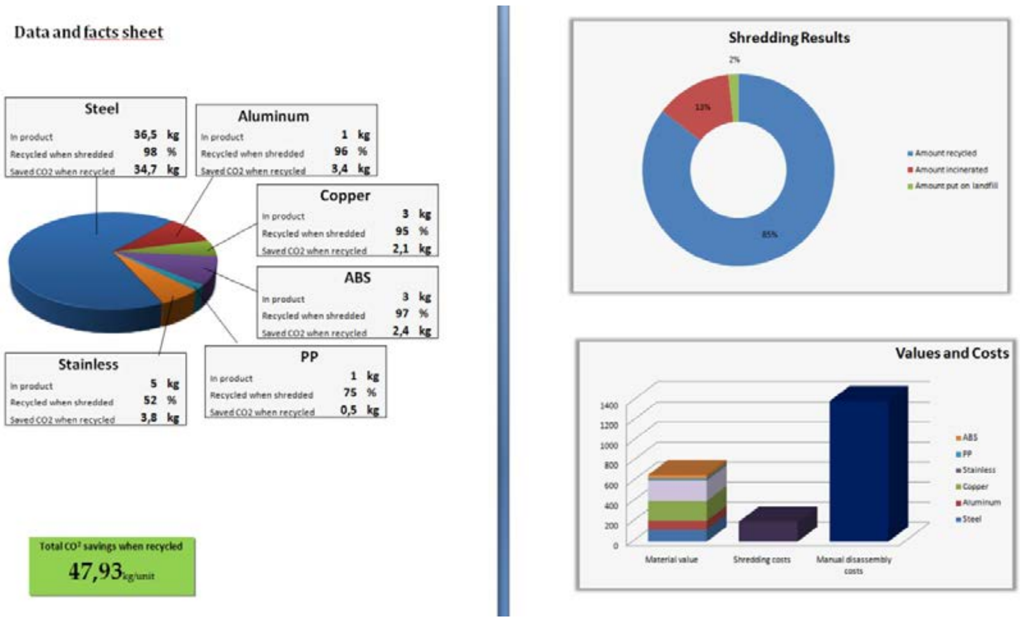


Figure 44. The hard facts pages after the redesign of the feedback report.

the manufacturer encloses when buying the service. Using generic numbers for CO_2 savings per recycled material type, the weight of different parts of the product can be used to gauge the total CO_2 savings of the product if it is recycled/uses recycled material (Grimes, Donaldson, & Cebrian Gomez, 2008). For example, 10 m of recycled cable saves 19,65 kg of carbon emissions.

In addition to the % data Sjölin had in his report data on the composition of the product with weights of each material, CO_2 emissions per material and in total, values of the materials for the recycler, cost to disassemble both manually and through shredding were included on this page (Figure 44).

4.6 Final Concept

Minor adjustments from the concept created in the Redesign phase were done for the final concept. For the final design, we also created a leaflet explaining what the service is about, to circulate to potential buyers and get the conversation going on recycling, while simultaneously putting Stena Recycling and REvolve first in line for the job of revamping a company's recycling efforts. After the final concept was completed, all specific comments from the analysis of the coffee machine were removed and the headlines kept to create a generic template for future analyses. Under each headline, some comments on what to look for or comment on were written down. Even to say "no comment" on some aspects is in itself a comment.

4.6.1 Leaflet

The leaflet is an introduction to the service that shortly describes what the service is and what the customer can expect from it. The leaflet describes the process of the product analysis and provides information on what is demanded from the customer and what will be returned upon the analysis (Figure 45). See Appendix 8 for the whole leaflet.

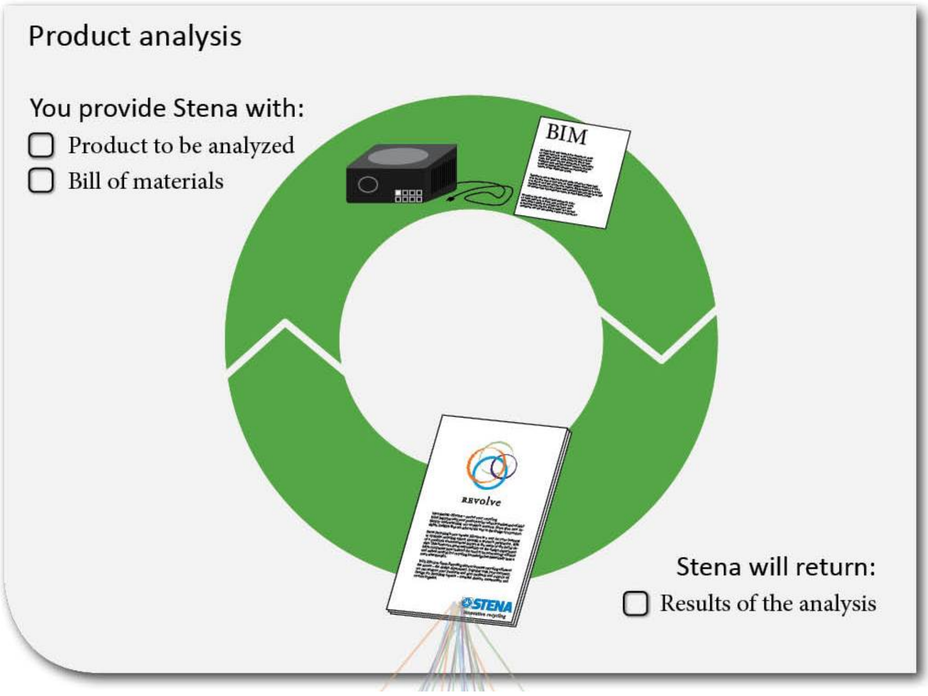


Figure 45. The exchange circle where product and BoM are provided and feedback report is returned

4.6.2 The feedback report template

As the final case product from Crem had been analyzed and feedback report had been fully developed it was time to reduce the feedback report to a feedback report template only consisting of the headlines and general components. As all the customized information was gone each chapter and headline was equipped with a little information and triggering questions on what to look for in future analyses. Below some of the features of the final concept are described.

Introductory pages

To get an, for the eye, more pleasing report in ones hand a front page was created. The next few pages were extended from before adding more information about the service and how recycling is done today (Figure 46).

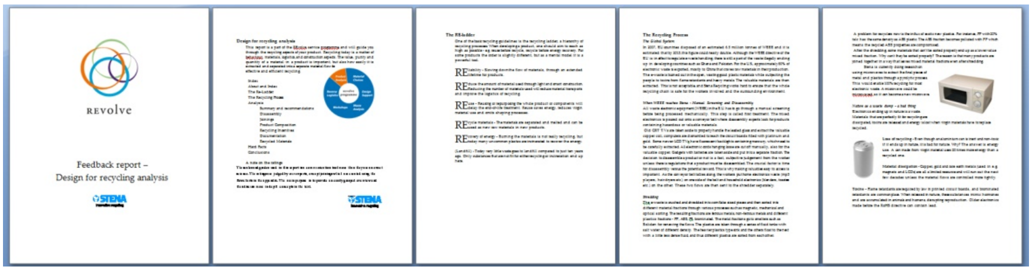


Figure 46. First five pages before the analysis results are presented.

Scales

As the function and design of the scales were not satisfactory they were modified for this final concept. Instead of loose boxes with only the scales the scales were combined with the headline for the chapter. The sad and happy faces that were left out in the word migration were returned (Figure 47).

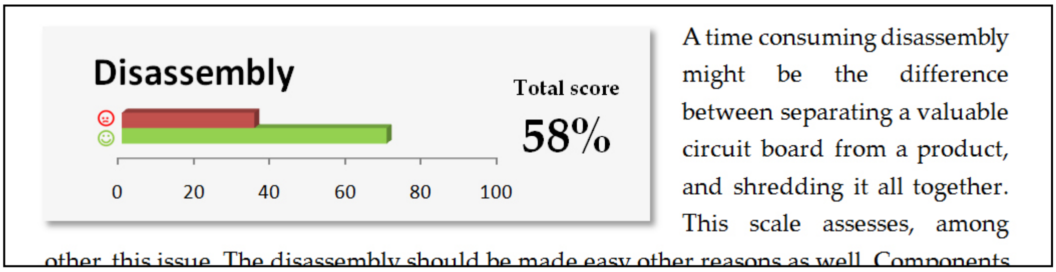


Figure 47. The design of the headline/scale box.

Recycled materials

A section where tips are given on how the use of recycled materials can be increased in the product

Board room/Hard facts page

On Stena Recycling's homepage, the energy equivalent of CO_2 are presented in terms of common activities to give perspective on the numbers. These figures communicate well and were also included in the hard facts page(Figure 48).

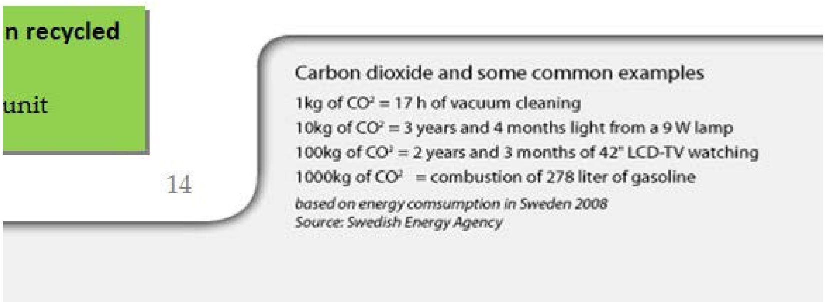


Figure 48. Examples of how much some activities emit CO^2

5 Part V – Discussion and conclusions

5.1 Discussion

The purpose of the feedback reports and the service is to give the manufacturing companies tools to improve the recyclability of their products. A wish that was expressed from the garden equipment company was that Stena would provide them with detailed design guidelines for their products. This would be almost impossible as there are many aspects to a product design beyond recycling that are outside the expertise of Stena and ours, thus the function of the feedback report is to enlighten the issues there would be from a recycling point of view instead of solving the issues. Solving the issues is a totally different matter and is to a great extent the responsibility of the manufacturer. The service should instead be seen as a tool to inform and activate not only the designer's thoughts but also the rest of the company.

The opposite of specific is general. And being too general is not a good way to go either. General guidelines tend to be quite wide and all general guidelines are not relevant all products in every situation making them tedious to take in. This has been a constant balancing in this project. Being both specific and general at the same time. We consider this service satisfying both sides.

5.1.1 The business case for Design for Disassembly?

Environment and sustainability is currently a hot topic and the branding promise of being best in the green class is alluring. The industry need to push the development of products since legislation will not be fast or flexible enough to push innovation (even though the eco-design directive is a step in the right direction). Among the "green" factors, recycling is not the top priority for many products – it is energy-efficiency and carbon dioxide. The reason for this is partly the eco-design directive's heavy focus on CO_2 (ultimately, a political decision from the EU) (Jönbrink, 2011), and LCA wise energy is often the culprit. Another, softer factor has to do with the customer and her relationship with the product - let's elaborate.

Designers work to establish relationships between customers and products, and most often it is a good thing because it means the products are taken care of and "live" longer. Imagine walking in to a car dealership with that car dealership smell, and a fine specimen of automobile catches your eye. It's all shiny and charming, you sit in it, and you feel the car to have almost like a personality. You "love it". Let's say they offer to custom make the chairs to fit you ergonomically, and they etch the lyrics of your favorite song in the dash board. Now, as the sales person talks to you, would it make you happy to know that the car can be taken into a million little pieces to be recycled? It is not really congruent with your perception of the car as a charming unit, **your** charming unit. So it could be that recyclability is a bad sales argument if handled bluntly.

With that theoretical discussion in mind, we should mention that most designers we were in contact with were interested in improving their product in all ways possible. They were eager to get more input on design for recycling. One garden machine designer said “So many people that are involved when planning for a product, I don't see why the recyclers shouldn't also be at the table.”

5.1.2 Planning and preparations of the thesis

Already from the beginning we knew that creating a service was a little different from creating a product, which we are more used to. This fact did not stop us from proceeding we hoped this would become a journey full of new learnings and experiences. Planning the project was the initial task.

SWOT

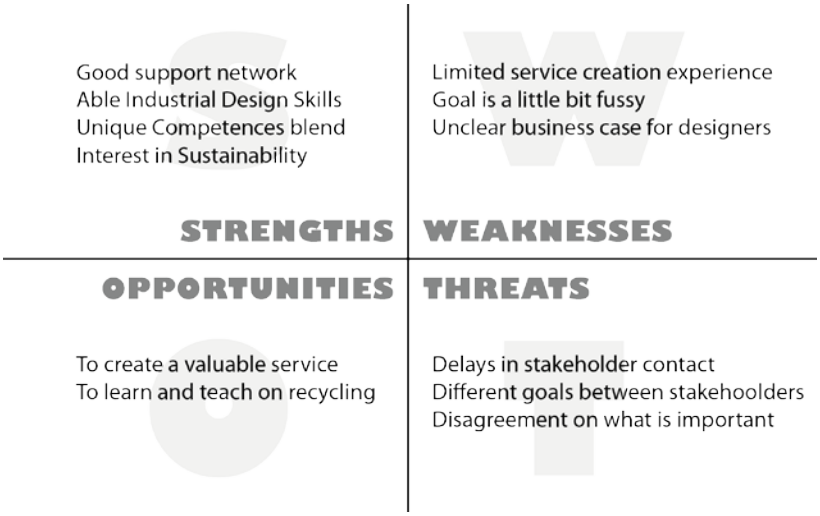


Figure 49. The SWOT analysis conducted in the beginning of the project

This SWOT (Figure 49), created at the outset, is a summary of the expectations and perspective we held before the project started. The strengths and opportunities were all utilized and true, and some strengths such as support network was even more present than we could have hoped for. This was made possible through the study visits at the Cradle-to-Cradle festival in Berlin and CIT Recycling's conference on ”The future of recycling”, but also the wealth of contacts gained through networking within Stena.

On the weakness/threat side, one thing missing could be ”scope too narrow”. Creating a feedback report towards businesses from a recycling perspective has meant learning broadly about recycling and then package that knowledge for someone else to learn the vital parts. At times, creating a template document as a project felt a bit underwhelming. We compensated this by doing very extensive research.

The delays in stakeholder contact proved to be a real threat. Stena requested all company contacts go through them. After a month of waiting for contacts, we decided to contact companies ourselves. This proved easy, but looking back, we should have done so right away. Companies are always careful with their contacts, and we could have shown we were trustworthy by actually securing our own contacts, going against their request. Trust creation by breaking promises.

One related threat that should have been included is the distance to designers. Since the manufacturing companies had the status of cases and were not heavily invested in the project, getting close to them and understand their issues was not a natural thing, and they did not always have time for us.

The service creation has also been hard to judge from our viewpoint. For this thesis, we have provided a free service without the customer having to commit to it, all they have to do is say yes and send an example product. The small electronics company, for instance, did not respond to our correspondence and surveys after the initial contacts despite claiming to be interested in the recycling aspects of their product. The garden equipment manufacturer on the other hand, seemed really interested of a continuation after the initial workshop where we showed samples of the service and feedback report. It remains to be seen if they choose to have a product analyzed in the service - and if they are willing to pay. The business model for Stena is also to tie the customers closer to them to keep the business of waste management from factories, so this service could be part of a complimentary package for big customers in which case the cost for the service would be on Stena's behalf.

5.1.3 What is iteration?

The process of this thesis work shown in this report is a simplification of how this project progressed in reality. Rather than one initial design, evaluation and a redesign these steps were repeated a numerous of times, we iterated. This simplification was decided to be used as, firstly there were many sub-parts of the feedback report that were iterated and secondly different parts were evaluated and redesigned as the issues or ideas for improvement surfaced. In short one can say that the development of the feedback report was full of small iterations and a clear general break between the phases could not be established. This way of work is a little different from the way an ordinary development of a product is done. But in this project this came naturally and can be derived from the fact that it was rather a service than a product that was created during this project.

5.1.4 Graphic and concept design

The graphical development was pretty straight forward. Light and enjoyable to read were the main motto of this phase. As the visual appearance of Stena's home page is quite airy and easy to read the aim of the graphical design of the service was set for the motto and to match the graphical feeling of Stena. We feel we have succeeded in reaching what was set in this aim. The problem has not been the graphical expressions but the functionality of different components such as the scales and the joining "buttons". These were tested and evaluated many times with redesigns as a result. The linearity of the initial scales had to be changed due to the problems it brought to the person analyzing the product, even though they were visually appreciated. The joinings idea was also promising in the beginning but had to be changed as each button needed further explanation in order to fully function.

A mistake was to overlook the importance of the users from Stena, the ones that would conduct the analysis and fill in the report template. This is the main reason for the drastic change in design as the report had to be produced in Microsoft Word instead of in Adobe InDesign as it initially was. One alternative we saw was to only develop a concept of the design in InDesign. This would have resulted in the need for the personnel at Stena to learn InDesign. Another alternative would have been to develop the report as a computer program that would be simple to fill in and with a press of a button would result in a perfect feedback report. This on the other hand would have needed programming skills that we do not fully possess. There were a number of tries made to simplify the reporting through programming in flash, java and connecting that to word, without success. Left was the option to do the feedback report in word. This posed new restrictions to the design but at the same time it leads to a feedback report that is simple to modify by anyone.

In retrospect the design and the functionality of the scales was a little overworked. Eventually, when this analysis of a product would be conducted there would not be time for a such an advanced presentation. This could have been prevented if the time and usage aspect had been addressed more and perhaps included in the requirements specification at an early stage e.g. “The filling of the report can take maximum 5 hours”.

5.1.5 Measurable results

Creating solid metrics to evaluate the service against requirements would be desirable. How would one go about that? For products, it is easy to benchmark - which grip is better, which colour do you prefer of these two? A service is not easily comparable to other services.

Our case companies got the services for free in exchange for their cooperation. The communication with the case participant companies was continuous, but the finished service will involve less back and forth communication. These type of things would of course affect the perceived benefit of a service. On top of that, we want the service to reach out and make a change in an organisation. Even if our service gives the intended insights to a design department and we measure their satisfaction, there is still a possibility the new knowledge is not implemented because of managers not taking part in the insights. Is the service then successful or not? The only solid metrics would be to see a change in the real products of service clients down the line. Due to time constraints of the thesis, no such results have yet been achieved.

5.1.6 Staying out of the processes

With regards to the different aspects of the feedback: *"constructions and material choices, requirement and manufacturing processes and design culture”*, the report mainly deals with physical tips on construction and design. The methodology and processes were hard to go into since different companies have set systems which are mostly out of reach for the service. For the requirements, it is up to the company to evolve the feedback received from the report and the service and implement it into requirements of their products. Stena will want to help them in this pursuit. Design culture is also something intangible, but a workshop held at the garden manufacturer in relation to selling REvolve seems promising in promoting recycling as a priority.

5.1.7 Evaluation layers

How do we evaluate the service and if it is successful? There are a couple of layers to this. The immediate reactions from someone flipping through the report are important, but it is not a successful product until Stena has customers for it, and they are happy with the service. One step further away is when the manufacturers actually change their designs toward more recyclability, and another when the percentage of recycled WEEE has increased. The only meaningful measurable layer of evaluation, however, is the usability of the report and if Stena can sell it. In that aspect we are confident it will be a success, as clients have already expressed interest in the service.

5.2 Conclusions

The aim of this service, and indeed society at large, is to strive towards a cyclic societal system where valuable resources are taken care of and not flushed out to sea or dumped in a landfill. With Sweden as an example, change can happen in relatively short time. The last ten years have seen a drop in landfill and surge in recycling practices - it was only 25 years ago we started sorting municipal waste at all, beginning in Borlänge. Our service is a tool to strengthen this trend and reach out to one of the key stakeholders - the designers of products in our system.

As set in the beginning of this thesis:
"The goal is then to create a feedback mechanism from recyclers to the electronics manufacturers. This feedback should ideally affect constructions and material choices, requirement and manufacturing processes and design culture towards creating products better fit for recycling."

The service created is a result of an extensive research of the subject of recycling and communication with manufacturers which has been implemented into the concept called REvolve. Trough gathering this knowledge and the expertise of Stena we have met the demands expressed by the manufacturers.

Including both general information and product specific facts it is a service that communicate broadly to designers as well as the management, giving companies an opportunity to change from the ground to become a more sustainable manufacturer. With a simple and accessible layout and design the feedback report is easy to understand and grasp.

The feedback mechanism created fills the gap between the recycling companies and the manufacturers from a design for recycling point of view and beyond, tying the recycling industry closer to the manufacturers, hopefully resulting in a mutually beneficial relationship. These types of services have been sought for and the feedback received on the format only confirms the value of the service.

The service provides value to the manufacturer in three ways:

- With a design better fit for recycling, manufacturers will **pay less or charge more** for their product's waste treatment at end of life. The recyclers make more money from these products, and society at large gains from an increase in recycling. It's a **win-win-win** proposition!
- The **brand value for manufacturers is strengthened** if the design is more "green" or eco-friendly, made possible by the service.
- **Staying ahead of competition and legislation.** Already cars have a legal requirement to be recyclable to a certain percent. Electronics will likely go the same direction through legislation such as the EU's Eco design directive. By adopting processes early, costs will be saved in the long run.

Besides that, the branding of the service will make it easier for Stena to sell this service. They have previously taken on these kind of analyses when prompted, but providing a leaflet with a service name will create a desire for the service and make an active selling process easier.

Penetrating companies with information about recycling and rooting it is hard and time will tell if it is possible. Spreading the information between departments and convince the management of the benefits of recycling play a key role - designers, material and design engineers and marketing people all need to be involved. The service and the feedback report is a tool that enables a expansion of information to the affected instances within a company. For Stena Recycling, it is not a final product, it is the start of a conversation about design and a way to reach out to the manufacturers for a meaningful collaboration.

5.3 Further research/development fields of interest

This project has resulted in a feedback concept which is functional as it is but could be further developed. Firstly it should be computerized for an easier handling when transferring data from the analysis into the feedback report. At this stage it would be far too time consuming to edit the data in a graphics software. It would be desirable to have easily filled in form that automatically transfers the data into aesthetically pleasing graphs and other visual elements. Creating an application that would be able to do this is, both outside the framework of this thesis and also out of our expertise and would require more time spent on programing etc.

As the feedback report is, to some extent, custom made for each customer according to their needs and wishes it will change over time and elements will be added, removed and modified, thus the report is continuously improved. Keeping the feedback report flexible is advantageous both as each case is unique but also as a customized report brings the customer closer to a more personal level.

6 References

Active Disassembly. (n.d.). *Video Gallery*. Hämtat från http://www.activedisassembly.com/10_videos.html den 20 07 2011

Adhesives Magazine. (2008, 06 01). *World Adhesive Conference and Expo*. Retrieved 05 11, 2011, from www.adhesivesmag.com/: http://www.adhesivesmag.com/Articles/Feature_Article/BNP_GUID_9-5-2006_A_10000000000000348895

Ahrend. (2009, 04 04). *Ahrend CSR - Because your world matters*. Retrieved 04 29, 2011, from Slideshare: http://www.slideshare.net/Inarvaez/ahrend-csr-because-your-world-matters

Almega. (2011, 06 05). *Almega*. Retrieved 07 13, 2011, from Almega - Debatt & Opinion: http://www.almega.se/web/debatt.aspx

Atrion International. (2006). *REACH Background*. Retrieved 06 08, 2011, from :: REACH Legislation ::: http://www.reachlegislation.com/index.php?option=com_content&task=view&id=90&Itemid=192

Autodesk Inc. (2011, 02 28). *Video Script and Illustrations: Introduction to Whole Systems Design*. Retrieved 07 15, 2011, from Autodesk Educational Community: http://students.autodesk.com/?nd=sustainable_standard&material_id=67&course_id=1

Bhobe, R., Engel-Hall, A., Gail, K., Huotari, J., Koskela, M., Liukas, L., et al. (2010). *Bloom - Mechanical Engineering 310 Spring design proposal*. Stanford: Stanford University.

Bjørn, A. (2011). *Cradle to Cradle and environmental sustainability - a critical appraisal*. Copenhagen: Danmarks Tekniske Universitet.

Brusell Winblad, V., & Öhman, L. (2009). *A Study of Reverse Logistics in the Electronics Industry*. Göteborg: Chalmers University of Technology.

Butler, S. (2009). European Recycling Platform (ERP): a Pan-European Solution to Weee Compliance. i R. E. Hester, & R. M. Harisson, *Electronic Waste Management* (ss. 161-179). Cambridge: Royal Society of Chemistry.

Cronwall, C. (2011, 04 20). Site manager, Stena Recycling Borås. (J. Toivonen, & D. Gillblom, Interviewers)

Dewberry, E., & Goggin, P. (1996). *Spaceship Ecodesign*. Retrieved 07 14, 2011, from Co-Design: the interdisciplinary journal of design and contextual studies: http://www.bath.ac.uk/idmrc/themes/projects/delores/co-design-website/edew+pgo.htm

Devoldere, T. (2011, 03 31). Mechanical designer, PHILIPS Innovative Applications. (D. Gillblom, Interviewer)

EFRA. (2010). *Flame Retardants : Integral ot Fire Safety*. Retrieved 07 15, 2011, from European Flame Retardants Association: http://www.cefic-efra.com/Content/Default.asp?PageID=122#electronics

EISA. (2011, 05 11). *Eisa Green Awards*. Retrieved 05 11, 2011, from Eisa: http://www.eisa.eu/awards/6/green.html

Ekman, B. (Performer). (2011, 04 06). *Vad är hållbar utveckling - är den överhuvudtaget möjlig?* Göteborg.

European Aluminium Association. (2011). *Recycling*. Retrieved 05 26, 2011, from European Aluminium Association: http://www.eaa.net/en/about-aluminium/recycling/

European Commission Enterprise and Industry. (2011, 04 29). *Chemicals How does REACH work?* Retrieved 06 08, 2011, from European Commission Enterprise and Industry: http://ec.europa.eu/enterprise/sectors/chemicals/reach/how-it-works/index_en.htm

European Commission Enterprise and Industry. (2010, 12 08). *Sustainable and responsible business Ecodesign*. Retrieved 06 09, 2011, from European Commission Enterprise and Industry: http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/files/brochure_ecodesign_en.pdf

European Parliament and the Council. (2003). Directive 2002/95/EC. *Official Journal of the European Union* .

European Parliament and the Council. (2003). Directive 2002/96/EC. *Official Journal of the European Union* .

European Union. (2011, 06 17). *WEEE - Key Statistics and Data*. Retrieved 07 15, 2011, from European Union Eurostat: http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/wastestreams/weee

Forsgren, C. (2011, 06 05). Head of environmentand technology, Stena Metall. (D. Gillblom, & J. Toivonen, Interviewers)

Goosey, M. (2009). Introduction and Overview. i H. R. E, & H. R. M, *Electronic Waste Management* (ss. 1-39). Cambridge: Royal Society of Chemistry.

Grimes, S., Donaldson, J., & Cebrian Gomez, G. (2008). *Report on the Environmental Benefits of Recycling*. Centre for Sustainable Production & Resource Efficiency (CSPRE). London: Bureau of international recycling.

Hawken, P., Lovins, H. L., & Lovins, A. (1999). *Natural Capitalism: Creating the Next Industrial Revolution*. Boston: Little Borwn Company.

Holmberg, J. (Performer). (2010, 09 20). *The university and transformation towards sustainability*. Göteborg.

Jacobsson, A. (2011, 03 17). (D. Gillblom, Interviewer)

Jordan, C. (2009). *Midway: Message from the Gyre (2009)*. Retrieved 05 25, 2011, from www.chrisjordan.com: http://www.chrisjordan.com/gallery/midway/#CF000313%2018x24

Jönbrink, A.-K. (Artist). (den 09 02 2011). *Ecodesign workshop*. MINC, Malmö.

Kell, D. (2009). Recycling and Recovery. In R. M. Harrison, & R. E. Hester, *Electronic Waste Management : Design, Analysis and Applications* (pp. 91-110). Cambridge: Royal Society of Chemistry.

Kellner, R. (2009). Integrated approach to e-waste recycling. In R. E. Hester, & R. M. Harrison, *Electronic Waste Management* (pp. 111-160). Cambridge: Royal Society of Chemistry.

Kitco. (2011). *5 Year Palladium*. Retrieved 07 25, 2011, from www.kitko.com: http://www.kitco.com/charts/popup/pd1825nyb.html

Klanten, R. (2010). *Data Flow 2: Visualizing Information in Graphic Design*. Berlin: Die Gestalten Verlag GmbH & Co. KG.

Klättermusen. (2011). *Eco index : How big is a product's ecological footprint?* Retrieved 07 15, 2011, from Klättermusen: http://www.klattermusen.se/eco-index_EN.php?lang=EN&curr=EUR

Knutsson, R. (2011, 04 20). Site manager, Stena Technoworld Bräkne-Hoby. (J. Toivonen, Interviewer)

Labs, G. (2010, 01 01). *Books Ngram Viewer*. Retrieved 05 04, 2011, from Google Labs: http://ngrams.googlelabs.com/

Leander, M. (2011, 3 21). Stena Metall. (D. Gillblom, & J. Toivonen, Interviewers)

Lehner, T. (Performer). (2011, 03 23). *Materials recycling again and again until end of times.* Framtidens återvinningsteknik 2011, Teknikdalen, Borlänge.

Mital, A., Desai, A., Subramanian, A., & Mital, A. (2008). *Product Development : a structured approach to consumer product development, design, and manufacture.* Amsterdam: Butterworth-Heinemann.

Nilsson, M. (2011, 07 24). *Ny förklaring till resistenta bakterier*. Retrieved 07 25, 2011, from Svenska Dagbladet: http://www.svd.se/nyheter/inrikes/ny-forklaring-till-resistenta-bakterier_6345640.svd

Oak Ridge Associated Universities. (1998). *Radioactive Quack Cures*. Retrieved 05 10, 2011, from Health Physics Historical Instrumentation Museum Collection: http://www.orau.org/PTP/collection/quackcures/quackcures.htm

Palmer, B. (Performer). (2011, 04 15). *Living as an Idealist in an Unforgiving World.* Chalmers, Göteborg.

Pardos Marketing. (2005, 11 9). *MARKET OVERVIEW: MULTILAYER FILMS, RAPRA, BRUSSELS 2005*. Retrieved 07 15, 2011, from Pardos Marketing: http://www.pardos-marketing.com/paper_b02.htm

Potting, J., & Kroezey, C. (2010). CRADLE TO CRADLE: OLD WINE OR NEW SPIRITS? (P. Chapman, Ed.) *Integrated Environmental Assessment Management* , *6*, 315-317.

Rexfelt, O. (2011, 02 03). Researcher and Assistant Professor. (J. Toivonen, & D. Gillblom, Interviewers)

Rockström, J. (2009, 09 23). *Figure 1 . Beyond the boundary*. Retrieved 05 06, 2011, from Nature: http://www.nature.com/nature/journal/v461/n7263/fig_tab/461472a_F1.html

Rusta. (2011, 05 08). *Rusta - hushållsmaskiner*. Retrieved 05 08, 2011, from Rusta: http://www.rusta.se/brodrost_800w_frukostset_p90350100.html

Schneidermann, B. (1999). *Using vision to think.*

Sjölin, S. (2011, 04 15). R&D & Technical support. (D. Gillblom, & J. Toivonen, Interviewers)

Skrifvars, M. (2011, 05 05). Researcher and Professor, School of Engineering, University of Borås. (D. Gillblom, Interviewer)

Stenkjær Paulsen, A., & Hellhammer Johannesen, P. (2011). *Closing the supply chain as a means to implement Cradle2Cradle.* Copenhagen: Aalborg Universitet.

Stevens, G. C., & Goosey, M. (2009). Materials Used in Electrical and Electronic Products. In R. E. Hester, & R. M. Harrison, *Electronic Waste Management* (pp. 40-74). Cambridge: Royal Society of Chemistry.

Sundin, E. (2004). *Product and process design for successful remanufacturing*. Linköping: Linköping Institute of Technology.

The Natural Step. (2011). *Our Approach*. Retrieved 06 08, 2011, from The Natural Step: http://www.naturalstep.org/en/our-approach

Torring, M. (2011). (J. Toivonen, & D. Gillblom, Interviewers)

United Nations University. (2008). *2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment*. Bonn: United Nations University.

Vezzoli, C., & Manzini, E. (2008). *Design for Environmental Sustainability*. London: Springer-Verlag.

World Commission On Environment and Development. (1987). *Our Common Future*. Oxford Oxfordshire: Oxford University Press.

Worley, S. V. (2010, 01 15). *Color Me A Dinosaur*. Retrieved 05 04, 2011, from Weather Sealed: http://www.weathersealed.com/tags/crayons/

Åström, J.-O. (Performer). (2011, 03 23). *Om de första leden i återvinningskedjan*. Framtidens återvinningsteknik, Teknikdalen, Borlänge.

7 Appendices

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Appendix 1

The excerpt from the WEEE directive showing the materials and substances proscribed (The European Parliament and The Council of the Europeaen Union, 2003).

ANNEX II

Selective treatment for materials and components of waste electrical and electronic equipment in accordance with Article 6(1)

1. As a minimum the following substances, preparations and components have to be removed from any separately collected WEEE:

— polychlorinated biphenyls (PCB) containing capacitors in accordance with Council Directive 96/59/EC of 16 September 1996 on the disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCB/PCT) (1),
— mercury containing components, such as switches or backlighting lamps,
— batteries,
— printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimeters,
— toner cartridges, liquid and pasty, as well as color toner,
— plastic containing brominated flame retardants,
— asbestos waste and components which contain asbestos,
— cathode ray tubes,
— chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC),
— gas discharge lamps,
— liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 square centimeters and all those back-lighted with gas discharge lamps,
— external electric cables,
— components containing refractory ceramic fibers as described in Commission Directive 97/69/EC of 5 December 1997 adapting to technical progress Council Directive 67/548/EEC relating to the classification, packaging and labeling of dangerous substances (2),
— components containing radioactive substances with the exception of components that are below the exemption thresholds set in Article 3 of and Annex I to Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation (3),
— electrolyte capacitors containing substances of concern (height > 25 mm, diameter > 25 mm or proportionately similar volume)

These substances, preparations and components shall be disposed of or recovered in compliance with Article 4 of Council Directive 75/442/EEC.

2. The following components of WEEE that is separately collected have to be treated as indicated:

— cathode ray tubes: The fluorescent coating has to be removed,
— equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation (EC) No 2037/2000 of the European Parliament and of the Council of 29 June 2000 on substances that deplete the ozone layer (4).
— gas discharge lamps: The mercury shall be removed.

3. Taking into account environmental considerations and the desirability of reuse and recycling, paragraphs 1 and 2 shall be applied in such a way that environmentally-sound reuse and recycling of components or whole appliances is not hindered.

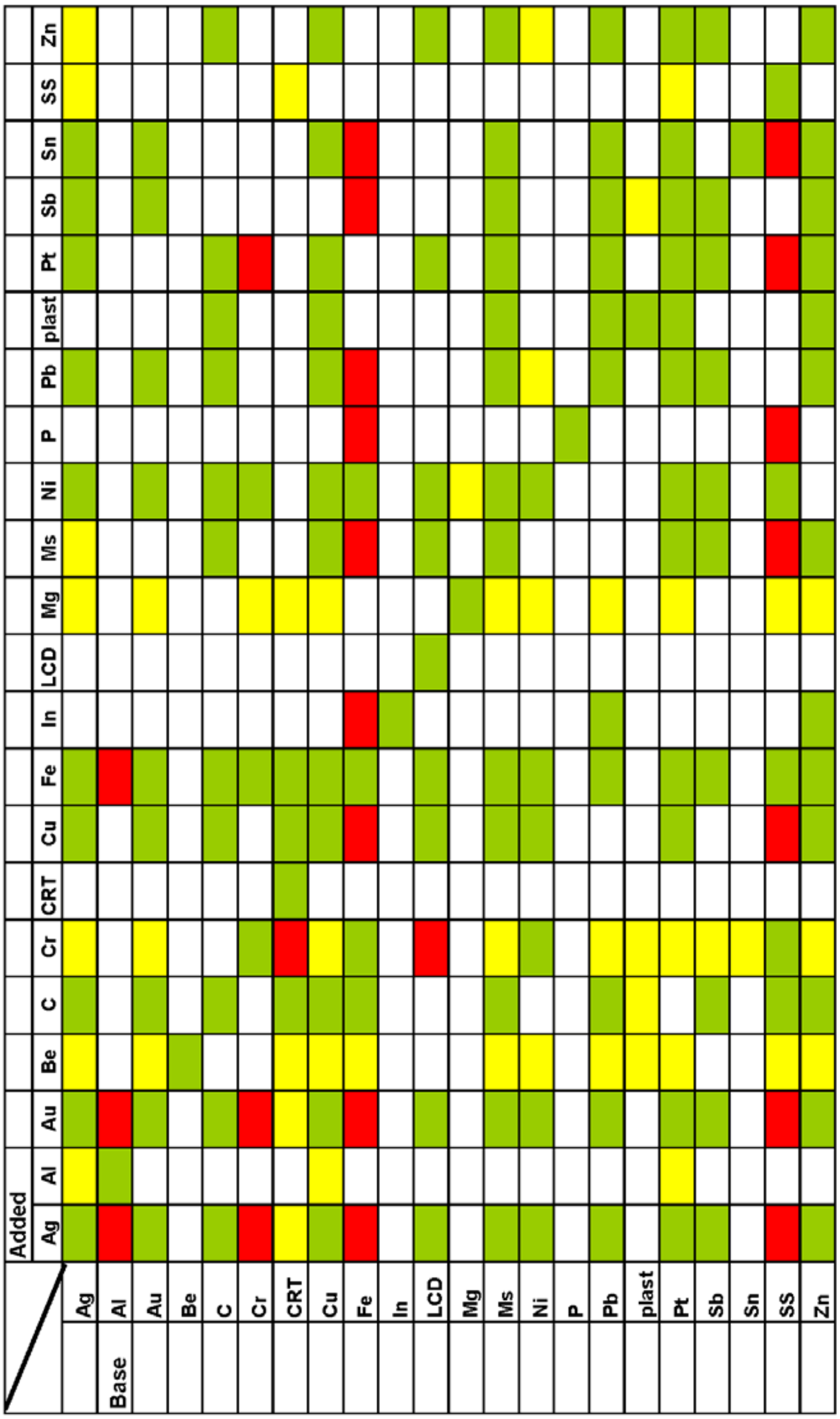
4. Within the procedure referred to in Article 14(2), the Commission shall evaluate as a matter of priority whether the entries regarding:

— printed circuit boards for mobile phones, and
— liquid crystal displays

are to be amended.

(1) OJ L 243, 24.9.1996, p. 31.
(2) OJ L 343, 13.12.1997, p. 19.
(3) OJ L 159, 29.6.1996, p. 1.
(4) OJ L 244, 29.9.2000, p. 1. Regulation as last amended by Regulation (EC) No 2039/2000 (OJ L 244, 29.9.2000, p. 26).

Appendix 2



A green field implies that the mix is ok
A yellow field implies that the mix is questionable
A red field implies that the mix is inappropriate

Appendix 3

Checklist for the design and Manufacture of Consumer Parts for Recyclability and Disposability

		Implemented? Bad – Good					
		1	2	3	4	5	Comments
1.	Design the product and its component to be reusable, refurbishable, or recyclable, in that order						
2.	Minimize the number of parts and adopt a near-net shape approach: Fewer parts make sorting materials during recycling easier When a number of parts are combined into one complex part, both factory assembly and disassembly are aided						
3.	Avoid the use of separate fasteners; some portions of these fasteners may be retained in basic parts and contaminate them during recycling						
4.	Use snap fit connectors between parts is preferable , as these connectors do not introduce a dissimilar material and are easy to disassemble						
5.	Utilize the minimum number of screw head types and sizes used in fasteners in one product or portion of the product; the recycler need not change tools to loosen and remove fasteners						
6.	Use the fewest number of fasteners to reduce disassembly time						
7.	Design parts to be easily visible and accessible to aid in disassembly						
8.	Design the product to be easily disassembled even if some parts are corroded						
9.	Minimize the number of materials in the product to reduce the sorting of parts for recycling Standardize materials as much as possible Avoid the use of multiple colors in a part Avoid the use of dissimilar materials that cannot be separated or are difficult to separate from basic materials Use of thermoplastic materials is preferable to thermosetting plastic materials Solvent , friction, or ultrasonic welding of plastic parts is preferable to adhesive welding If adhesive bonding is used, find an adhesive material that is compatible when the components are recycled Water-soluble adhesives for labels and the items are preferred Welded joints are preferred to braces or soldered joints						
10.	If the number of different materials cannot be reduced choose materials that are compatible and can be recycled together						
11.	Avoid the use of composite materials such as glass or metal reinforced plastics						
12.	Avoid metal-plated plastics						
13.	Standardize the product components to aid in eventual refurbishing of the product; if major elements are standardized, they can be salvaged and reused more easily						
14.	Use molded in nomenclature rather than labels or separate name plates for product identification						
15.	If separate label must be used on plastic part, choose a label material and adhesive that are compatible with the material of the base part						
16.	Use modular design to simplify assembly and disassembly						

Appendix 4

Återvinning av er produkt

Denna enkät är en del av ett exjobb på Teknisk Design, Chalmers kring design för återvinning (DFÅ), och borde ta max 5 minuter om du är snabb och ärlig.
DFÅ handlar om att kunna konstruera produkten för att lätt kunna separera rena material och komponenter för återanvändning, återtillverkning och återvinning. Vårt exjobb går ut på att skapa en tjänst för att stödja företag att bli bättre på DFÅ.

Med produkten menar vi produkten ni skapar på ert företag.

Sprid gärna enkäten till kollegor inom produktutveckling!
Vi skickar en glass till vinnaren.

Hälsningar,
David Gillblom och Jan Toivonen
073 070 82 81 070300 45 26

* Required

Vad är din roll i utvecklingen av nya produkter? *

- Konstruktör
- Utvecklingschef
- Materialinköpare
- Designer
- Other:

Vilket företag jobbar du på? (frivilligt)

Hur insatt är du i återvinningen av produkten? *

	1	2	3	4	5	6	
Inget efter att den är såld							Jag har koll på allt som händer i kedjan

Har ni märkt någon efterfrågan från kunder vad gäller återvinning? *

	1	2	3	4	5	6	
Kunderna fnyser när man nämner det							Det är det viktigaste för dem

Vilka nackdelar förknippar du återvinningsbarhet med? *

- Kostnader
- Kvalitetsminskning

- Försvagat varumärke
- Merarbete (tid) för oklar vinst
- Försämrar miljömässigheten om man analyserar hela produktens livscykelpåverkan - energianvändning osv.
- Other:

Vilka fördelar förknippar du återvinningsbarhet med? *

- Kostnadminskning / Värdeskapande
- Kvalitetsförbättring
- Varumärkesstärkning
- Underlättar reparationer
- Det känns meningsfullt att göra
- Återbruk av komponenter/material vilket är billigare än nytt
- Other:

Vem är viktigast att påverka för att öka återvinningsbarheten i er produkt? *

- Konstruktören
- Utvecklingschefen
- Policy- och styrdokument (kravspecifikationer, standarder)
- Materialinköpare
- Leverantörer
- Ekonomiavdelningen
- Företagsledningen
- Other:

Ev. Kommentar - vilka hinder finns det för ökad återvinning av er produkt?

Om du fick feedback kring er produkt och återvinning, vad av följande skulle vara intressant? *

- Förstå hur det fungerar nu - vad händer med produkten?

- [ ] Tips på förbättringar i konstruktionen, med hög detaljnivå relevant till min produkt (tex. den här komponenten kan fästas så här)
- [ ] Goda exempel
- [ ] Tips på förbättringar i materialval
- [ ] Generella tips på förbättringar (tex: plastkomponenter fästs med fördel såhär)
- [ ] Framtidsutsikter inom återvinning
- [ ] Other:

Hur skulle du vilja få information om återvinningsbarheten i er produkt? *

- [ ] Presentation
- [ ] Rapport
- [ ] Affisch
- [ ] Workshop
- [ ] Support / Handledning
- [ ] Inte intresserad
- [ ] Other:

Övriga kommentarer?

Vill du veta mer om vårt arbete är du välkommen att höra av dig, fyll isåfall i kontaktuppifter nedan!

Eller ta kontakt med oss på gillblom@gmail.com eller jantoivonen@gmail.com !

Appendix 5

Vad är din roll i utvecklingen av nya produkter?	Vilket företag jobbar du på? (frivilligt)	Hur insatt är du i återvinningen av produkten? 0-6	Har ni märkt någon efterfrågan från kunder vad gäller återvinning? 0-6	Vem är viktigast att påverka för att öka återvinningsbarheten i er produkt?	Om du fick feedback kring er produkt och återvinning, vad av följande skulle vara intressant?	Vilka nackdelar förknippar du återvinningsbarhet med?
Utvecklingschef	Stena Recycling	5	4	Företagsledningen	Förstå hur det fungerar nu - vad händer med produkten?, Tips på förbättringar i konstruktionen, med hög detaljnivå relevant till min produkt (tex. den här komponenten kan fästas så här), Framtidsutsikter inom återvinning	Merarbete (tid) för oklar vinst
Konstruktör, Materialinköpare, Designer, Hållbarhetsansvarig	Klättermusen AB	4		Alla ovanstående... för oss är arbetet med leverantörer viktigt, liksom styrdokument/specar och kunskap hos designern.	Tips på förbättringar i konstruktionen, med hög detaljnivå relevant till min produkt (tex. den här komponenten kan fästas så här), Tips på förbättringar i materialval, Generella tips på förbättringar (tex: plastkomponenter fästs med fördel såhär), Framtidsutsikter inom återvinning	Kostnader, Begreppet kan urvattnas; Svårighet att kommunicera återvinning, svårt för kunden att veta vad som avses (hel produkt, delar etc) och otydligheter vad gäller exempelvis "energiåtervinning" (dvs förbränning) som kommuniceras av andra.
Konstruktör	Household appliances manufacturer	1	2	Utvecklingschefen	Tips på förbättringar i konstruktionen, med hög detaljnivå relevant till min produkt (tex. den här komponenten kan fästas så här), Generella tips på förbättringar (tex: plastkomponenter fästs med fördel såhär)	Merarbete (tid) för oklar vinst
Ansvarig för nyutveckl av diskmaskiner	Household appliances manufacturer	4	5	Konstruktören	Förstå hur det fungerar nu - vad händer med produkten?, Tips på förbättringar i konstruktionen, med hög detaljnivå relevant till min produkt (tex. den här komponenten kan fästas så här), Goda exempel, Tips på förbättringar i materialval, Generella tips på förbättringar (tex: plastkomponenter fästs med fördel såhär), Framtidsutsikter inom återvinning	Kostnader
Utvecklingschef		2	2	Konstruktören	Goda exempel	Merarbete (tid) för oklar vinst

Vilka fördelar förknippar du återvinningsbarhet med?	Ev. Kommentar - vilka hinder finns det för ökad återvinning av er produkt?	Hur skulle du vilja få information om återvinningsbarheten i er produkt?	Övriga kommentarer?
Kostnadminskning / Värdeskapande, Varumärkesstärkning, Det känns meningsfullt att göra		Rapport	
Kostnadminskning / Värdeskapande, Varumärkesstärkning, Underlättar reparationer, Det känns meningsfullt att göra, Återbruk av komponenter/material vilket är billigare än nytt	- Okunskap i hela kedjan. Leverantör-inköpare-designer-marknadsförare-säljare-återförsäljare-slutkund. - Bristen på materialåtervinnare som kan hantera små volymer och blandningar av material och komponenter. - Bristen på mellanhänder, aktörer som kan bryta ner en produkt till bra materialfraktioner. - Bristen på specifikationer för DFÅ. - Bristen på framtidskunskap - vad kan återvinnas om 10 år när produkten ska bli råmaterial igen. - För billiga råmaterial - det är fortfarande dyrare att återvinna komplexa produkter än att bryta jungfrulig råvara.	Presentation, Rapport, Workshop, Support / Handledning	För mig är några punkter för bättre återvinning: - En överblick av återvinningsbranschen och olika aktörers möjligheter. - Starten på en designspecifikation DFÅ som kan utvecklas över tid, helst open source och med flera olika aktörer inblandade så att det finns driv i processen. - Någon form av nivåindelning i olika återvinningstekniker mht resulterande materialkvalitet (grad av down-/upgrading) och i förlängningen "farligheten" i ingående processer. - Ett framtidsforum med kopplade forskare som diskuterar utvecklingsfrågor både tekniskt, miljömässigt och etiskt, exempelvis: blandning av oljebaserade och förnybara polymerer, återvinning eller kompostering av förnybara polymerer, separering av biologiska material från tekniska, hantering/utvinning av ytbehandlingar och andra kemikalier ut använda produkter.
Underlättar reparationer		Rapport	
Varumärkesstärkning, Underlättar reparationer, Det känns meningsfullt att göra		Rapport	
Miljö		Affisch	

Appendix 6

CASE SMALL ELECTRONICS

Special treatment	scale	Debondable	Snap-fits	Ultrasonic Weldi	Slide on/in	Screws	Rivets	Glue	Bayonet	Shape Memory	Tabs and slots
ease of manual disassembly	0-5, x2 hazmat	6	4	0	6	6	0	0	8	10	
resealable	0-3	0	3	0	3	2	0	0	3	1	
materials separable	0-5	5	5	0	5	5	0	0	5	5	
Shredding											
Joined parts (same, compatible, non-compatible)	0-5	5	5	5	5	5	5	5	5	5	
Joint (same, compatible, non-compatible)	0-5	0	5	5	5	0	3	0	4	2	
Separability (low, medium, high)	0-7	0	7	7	7	2	0	0	5	5	
Sumtotal	max 35	16	29	17	31	20	8	5	30	28	
Average	max 6	2,666666667	4,833333333	2,833333333	5,166666667	3,333333	1,333333	0,833333	5	4,666666667	

CASE WASHING MACHINE

Disassembly	scale	Debondable	Snap-fits	Ultrasonic Weldi	Slide on/in	Screws	Rivets	Glue	Bayonet	Shape Memory	Tabs and slots
ease of manual disassembly	0-5, x2 hazmat	4	3	0	5	4	0	1	5	2	5
resealable	0-3	1	2	0	3	2	0	0	3	1	3
materials separable	0-5	3	5	0	5	5	0	1	5	3	5
Shredding											
Joined parts (same, compatible, non-compatible)	0-5	4	5	2	5	4	4	3	5	4	5
Joint (same, compatible, non-compatible)	0-5	0	5	5	5	2	4	2	5	2	5
Separability (low, medium, high)	0-7	2	7	3	7	2	2	2	7	4	7
Sumtotal	max 35	14	27	10	30	19	10	9	30	16	30
Average	max 6	2,333333333	4,5	1,666666667	5	3,166667	1,666667	1,5	5	2,666666667	5
		Debondable	**Snap-fits**	**Ultrasonic Weldi**	**Slide on/in**	**Screws**	**Rivets**	**Glue**	**Bayonet**	**Shape Memory**	**Tabs and slots**
Sum both esl (*0,8) & washing machine		**4**	**8**	**4**	**9**	**6**	**3**	**2**	**9**	**6**	**10**

Appendix 7

The feedback report developed in the concept design phase.

Asko w6444

Design for recycling analysis

This report will guide you through the recycling aspect of your product. Recycling today is a matter of behaviour, materials, logistics, construction aspects. The value, purity and quantity of a material in a product is important, but also how easily it is extracted and separated into a separate material flow for effective and efficient recycling.

When talking about recycling, on of the basic guidelines is the recycling stairs.

REliability - Slowing down the flow of materials, through an extended lifetime for products.

REduce the amount of material used through light and smart construction. Reducing the number of materials used will reduce material transports and improve the logistics of recycling.

REuse - Reusing or repurposing the whole product or components will delay the end-of-life treatment, saving energy and material.

REcycle materials - The materials are separated and melted and can be used as new raw materials in new products.

REcovery of energy - Burning the materials is not really recycling, but today many uncommon plastics are incinerated to recover the energy.

Landfill - Today very little waste goes to landfill compared to just ten years ago. Only substances that are not fit for either recycling or incineration end up here.

The scales and gradings used in this report is a communication tool more than it is an exact science. The main purpose is to provide an easily grasped overview and then discuss more in-depth concepts in the text.

STENA Innovative recycling

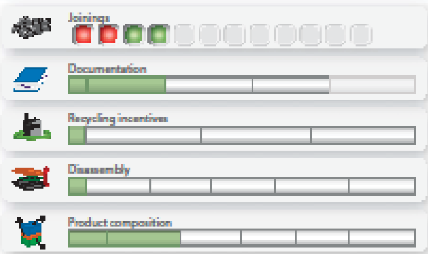
Introduction

The washing machine is built to last in a harsh environment. Parts are fastened firmly with many screws and weights are added to stabilize the construction. With its long lifespan and energy intensive usage, the recyclability aspects have faded off into the background. The design for assembly approach is evident but design for disassembly is largely non-existent.

Designing for disassembly and recycling could benefit Asko in several ways. Repairs could be less time consuming. Disassembly and removal hazardous materials and valuable materials could be more cost effective. Designing with disassembly and recycling in mind could also be used to strengthen the brand as environmentally conscious and hence gain market shares.

The first step when a washing machine lands at the recycling plant is a sanitation where hazardous materials are removed, e.g. capacitors with oil, anything containing hydrogen or CFC's. While new machines likely won't have hydrogen in them, there is no way of knowing what materials will be regulated for extraction 10 years from now. Any electronics bundle that is easily extracted is done

The second step is shredding of the machine in a big grinder. The result is a mix of material approximately the size of cornflakes. This is then taken through a series of mechanical sorting stages (magnetic, density, optical) to separate ferrous and non-ferrous metals, different plastics, plastics with and without brominated flame retardants. The metal fractions go to smelters such as Boliden for renewing the flows, the common plastics are recycled. In general the steel and copper is what creates the value of the washing machine in the recycling chain.



RECOMMENDATIONS

- Use fewer types of plastics
- Clearly state what flame retardants are used.
- Consider if there are any components that could be reused, and then make them accessible in the design.
- Think about how the product can be designed for easier repairs.
- Use slots and tabs instead of screws
- Consider introducing refunds or leasing systems for the machines

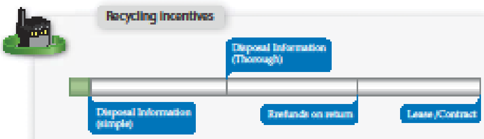
"Cast iron weights are prefered to concrete"

- Sandor Sjölin R&D Manager

Documentation

The plastics are clearly marked, but what flame retardant is being used in the circuit board casing is not defined. This is a violation of standard, and should be quite easy to implement. Also there is some inconsistency in the marking of the metals. The important thing for recycling is communication over time - the information needs to be found when it is time to recycle the machine in some years time. This can be through a database accessed through the internet, or a bill of materials encapsulated in the machine through RFID or simply written somewhere in the innards of the machine.

Recycling incentives



The producer liability legislation states that the producer of an electronic product is responsible for taking care of their products after usage. Companies as Stena Recycling offer their service disposing the products in the best way. The problem is that consumers do not always know what to do with their products when they have served their purpose. Informing the customer on where to dispose of the product is a must and it is not enough to put a wheelie bin mark in the back of the manual. A thorough description on how to properly dispose of the machine is better if the customer is expected to do it. Disposing products correctly can be encouraged through incentives or through leasing contracts. Leasing or in other ways ensuring that the machines are retrieved to Asko could be beneficial as Asko would be in control of all the materials and components could be recovered and reused.

Recommendations:

In a washing machine, there are several parts that can be reused. The engines often have a long lifespan and could be reused. The iron weights are possibly quite static in their design and could be reused in manufacturing of new washing machines, as long as new machine designs are made compatible.

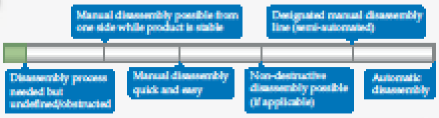
On "Repairwork-day" in Munich in 1997, citizens could bring their broken white goods for repair by experts free of charge. The surprising result was that more than two-third of the household machines could be restored by minor repair work.

EXAMPLE:

THE KODAK SINGLE USE CAMERA

One of the best examples of a well-functioning takeback system is the Kodak single use camera that roamed the market before the dawn of digital cameras. Marketed as a "disposable camera", the camera actually was repackaged and reused multiple times before being disposed of. The main reason for the success is of course the strong incentive to hand in the camera - to process the roll of film inside and receive the photographs. This was, of course, the purpose of buying the camera in the first place.

Disassembly



Active disassembly
Using a debondable adhesives to fasten the vibratin/sound dampener enables simple removal for re-usage in new products.

In general the disassembly is laborious and it seems as the machine is assembled without the recycling context. The amount of screws could be lowered if solutions with tabs and slots was used (more on this in the "Joinings" part). This would make and easier and faster disassembly as there would be less usage of screwdrivers or other tools. The front panel is tiresome to disassemble as, in total, 3 screws and 52 snap-fits need to be opened to extract circuit boards. Also the fact that seven electrical connection are snap-fitted to the circuit boards is a problem. Snap-fits in combination with relatively little space for fingers or other tools to remove the connectors also increases the disassembly time.

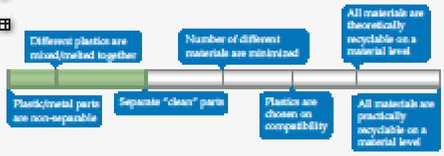
The front cover is fastened with both screws and snap fits and as there are no information on how to disassemble this panel. As the screws that could be found were unscrewed the panel still was fastened to the frame and had to be forced open. This force resulted in two broken snap-fits. In an shredding situation the plastic snap-fits would end up in together with the metal parts and be incinerated never to be recovered. In case the panel was removed to repair the i.e. water pump it would have been impossible to assemble the front without buying new snap-fits.

ON the inside ow the side walls there is sound/vibratio

The clamps securing the rubber tubes need special tools or pliers and much force to be opened and opening the clamps means destroying them (figure below). These clamps are not a problem when shredding the machine but when manually disassembled for e.g. repairs these will be time consuming to open.

Designing for a disassembly from one direction i.e. the back would simplify the disassembly, thus saving time.


Product composition

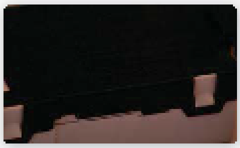


The product consists of a number of materials: metals, plastics, rubber, glass and so on. Added to that there are many different types of plastics with different additives. Fewer materials are always better, to easier reach a critical mass in recycling. This is especially true for plastics, which today is not recycled enough.

When analyzing the washing machine the use of different plastics with different additives seems excessive. Fewer material types equals more of the same types again leading to larger masses in the recycling. The use of additives often have their advantages but in an automated disassembly process some materials can be problematic as their properties are modified similar to other materials.

For instance a PP with talc additive (PP T20) has almost the exact density of ABS. Sorting of plastics is based on density, so the use of PP+T20 leads to a contaminated ABS fraction. The result is a blend of materials with different properties than a either materials had. "Cleaner" materials without additives are favorable to get a high quality recycled material.

Not only using recyclable materials but also using recycled materials would be beneficial from an environmental point of view. Taking a look at the whole line of products and co-ordinating the use of material types between departments and designers could be an good idea to minimize the number of plastics. Recycling plastic also lowers the carbon footprint, for every kilo plastic recycled instead of virgin the saving is 3-4 kgs of CO^2.

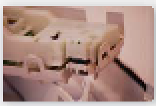
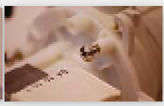
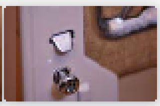


Joining

This is a table of some joining types, and their implications for recycling. Red is bad, green is good. Pressed button means it is used in the product now.

When plastics are fastened to metals with screws some of the plastic will end up polluting the metal flow when the product is fragmented/shredded. An example of this is the nylon guides that are screwed to the frame. The plastics incinerate when the metal is melted but too high amounts of plastics and other materials can cause an uncontrolled heat flux, which is not appreciated. As the plastics are incinerated the engineering complexity of the carbon chains are lost. Some energy is gained but the work put into creating the plastic is lost. Snap-fits are preferred to screws when two different materials are joined together. The downside of snap-fits is that they are hard to manually dissemble. This is evident in the instrument panel (se figure below)asembly where 52 snap-fits have to be opened to extract the circuit boards for repairs or exchange. These snap-fits could be substituted with a construction where the pieces are slided into each other and possibly only snapped in one place to secure the movement sideways.

Joining metals with metal screws is fine as long as there is no desire for a simple disassembly of the parts. An alternative for screws is to use tabs that fit into slots and need fewer screws or other fasteners to secure the part. This method was successfully used in the back of the washing machine and could be used to a greater extent in other areas of the machine (se figures below).

Concluding remarks

Look at your washing machine. Now imagine that all parts have a defined purpose at end of life. What parts are going to be reused? What parts need to go to materials recycling? How modular is the construction in terms of repairability? Imagine that your washing machine washed up on a deserted island where there was a pile of other old machines from different product generations. How compatible are they, and could you put together a functioning machine from parts?

Some parts in the machine are fairly static in their design. The cast iron weights, for instance, seems a good candidate for reuse. The electrical motor, while being the most valuable material wise, is also a component with a good longevity and could be suited for a second life – either being sold to the service organisation or put into new machines. As always, the logistics would be a challenge but the brand strengthening of the "no stone unturned" attitude would hold a great value.

By consistently using the same parts throughout product generations, the service and repair becomes increasingly cheaper. A great vision for Asko would be to have 30 years of washing guaranteed when a customer wants to buy a washing solution. How would this work? The only answer would be some sort of leasing or subscription business model, where Asko is responsible for the laundry room being functional, including making sure the machines are upgraded in a timely fashion and always stocked up on detergent. This could be optimized using telecom solutions so service is only performed when needed, to the delight of all wallets and fuel cost accounts.

VISION: A WASHING MACHINE MADE FROM ONE SINGLE RECYCLABLE MATERIAL

Why spend a lot of money on superior materials when one could use "good enough" plastics? The reason is that the assembled system becomes pessimized from a recycling point of view, when a lot of different plastics are used. Many small plastic streams won't fill the quotas to reach a logistical/economical feasibility. Of course only using one material is not feasible either, but as a way to spark ideas it would be an interesting prospect to research further. One plastic and one metal, plus motor and electronics? Just tinkering with these ideas will spur innovation.

With increasing material costs in the future (as oil prices go up), having a closed loop system with reverse logistics in a leasing business model would mean that Asko won't have to buy components, since the old components can be reused or recycled, and are already owned by Asko!

Appendix 8

The feedback report from Redesign phaze

REvolve

Feedback report –
Design for recycling analysis

Design for recycling analysis

This report is a part of the REvolve service programme and will guide you through the recycling aspects of your product. Recycling today is a matter of behaviour, materials, logistics, and construction aspects. The value, purity and quantity of a material in a product is important, but also how easily it is extracted and separated into a separate material flow for effective and efficient recycling.

Index

A note on the ratings

The scales and grades used in this report is a communication tool more than they are an exact science. The ratings are judged by our experts, except joinings which are created using the flowcharts in the appendix. The main purpose is to provide an easily grasped overview and then discuss more in-depth concepts in the text.

The RE-ladder

One of the basic recycling guidelines is the recycling ladder, a hierarchy of recycling processes. When developing a product, one should aim to reach as high as possible - e.g. reuse before recycle, recycle before energy recovery. For some products the order is slightly different, but as a mental model it is a powerful tool.

REliability - Slowing down the flow of materials, through an extended lifetime for products.

REduce the amount of material used through light and smart construction. Reducing the number of materials used will reduce material transports and improve the logistics of recycling.

REuse - Reusing or repurposing the whole product or components will delay the end-of-life treatment. Reuse saves energy, reduces virgin material use and omits shaping processes.

REcycle materials - The materials are separated and melted and can be used as new raw materials in new products.

REcovery of energy - Burning the materials is not really recycling, but today many uncommon plastics are incinerated to recover the energy.

(Landfill) - Today very little waste goes to landfill compared to just ten years ago. Only substances that are not fit for either recycling or incineration end up here.

The Recycling Process

The Global System

In 2007, EU countries disposed of an estimated 6.5 million tonnes of WEEE and it is estimated that by 2015, this figure could nearly double. Although the WEEE directive of the EU is in effect to regulate e-waste handling, there is still a part of the waste illegally ending up in developing countries such as Ghana and Pakistan. For the U.S., approximately 80% of electronic waste is exported, mostly to China that craves raw materials in their production.
The e-waste is burned out in the open, wasting good plastic materials while subjecting the people to toxins from flame retardants and heavy metals. The valuable materials are then extracted. This is not acceptable, and Stena Recycling works hard to ensure that the whole recycling chain is safe for the workers involved and the surrounding environment.

When WEEE reaches Stena - Manual Screening and Disassembly

All waste electronic equipment (WEEE) in the E.U. have to go through a manual screening before being processed mechanically. This step is called first treatment. The mixed electronics is poured out onto a conveyor belt where disassembly experts look for products containing hazardous or valuable materials.

Old CRT T.V.s are taken aside to properly handle the leaded glass and extract the valuable copper coil, computers are dismantled to reach the circuit boards filled with platinum and gold. Some newer LCD TV's have fluorescent backlights containing mercury, which need to be carefully extracted. All electronic cords hanging loose are cut off manually, also for the valuable copper. Gadgets with batteries are taken aside and put into a separate fraction. The decision to disassemble a product or not is a fast, subjective judgement from the worker unless there is regulations that a product must be disassembled. The crucial factor is time for disassembly versus the potential reward. This is why making valuables easy to access is important. As the conveyor belt tallies along, the workers put home electronics waste (mp3 players, hair dryers etc.) on one side of the belt and household electronics (blenders, toasters etc.) on the other. These two flows are then sent to the shredder separately.

Shredding

The e-waste is crushed and shredded into cornflake sized pieces and then sorted into different material fractions through various processes such as magnetic, mechanical and optical sorting. The resulting fractions are ferrous metals, non-ferrous metals and different plastics fractions - PP, ABS, PS, brominated. The metal fractions go to smelters such as Boliden for renewing the flows. The plastics are sorted in float tanks with different density. A problem for recyclers now is the influx of exotic new plastics. For instance, PP with 20% talc has the same density as ABS plastic. The ABS fraction becomes polluted with PP which means the recycled ABS' properties is compromised.

After the shredding, some materials that can't be sorted properly end up as a lower value mixed fraction. Why can't they be sorted properly? The reason is that many products are joined together in a way that leaves mixed material fractions even after shredding.

Stena is currently doing research on using microwaves to extract the final pieces of metal and plastics through a pyrolytic process. This would enable 100% recycling for most electronic waste. A microwave could be microwaved so it can become a new microwave.

Nature as a waste dump - a bad thing

Electronics ending up in nature is a waste. Materials that are perfectly fit for recycling are dissipated, toxins are released and energy is lost when virgin materials have to replace recycled.

Loss of recycling - Even though an aluminium can is inert and non-toxic if it ends up in nature, it is bad for nature. Why? The answer is energy use. A can made from virgin material uses 20 times more energy than a recycled one.

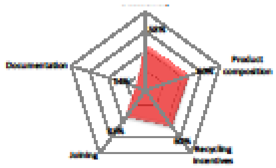
Material dissipation - Copper, gold and indium (used in LCDs) are all a limited resource and will run out the next few decades unless the material flows are controlled more tightly.

Toxins - Flame retardants are required by law in printed circuit boards, and brominated retardants are commonplace. When released in nature, these substances mimic hormones and are accumulated in animals, disrupting reproduction. Older electronics made before the RoHS directive can contain lead.

Summary

The coffee machine is a complex machine with many components and functions. The design is built around a central frame making the components easily accessible. As there are many components that are interconnected the layout of the components become important to make everything fit while still having room for repairs, maintenance and disassembly. The design, use of materials and joining method all affect the recyclability. Some subassemblies are easily extracted, such as the grinder and coffee brewer module, other parts are more "locked in" behind sheet metal panels.

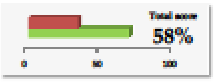
Summarizing score chart



Recommendations

- Create slots and tabs in the sheet metal for easy assembly and disassembly.
- Consider, with the help of your resellers, if there are any components that could be reused, and then make them accessible in the design.
- The access is good half-way, but for instance the circuit board is laborious to unmount. It is one of the valuables the recycler wants easy manual access to.
- Fewer types of screws would shorten disassembly times, and thus the recycling fee.
- The use of few base materials is great!
- Recycled material use is limited and could be increased.

Disassembly



Why is disassembly important?

A time consuming disassembly might be the difference between separating a valuable circuit board from a product, and shredding it all together. This scale assesses, among other, this issue. The disassembly should be made easy other reasons as well. Components might break and need to be replaced. There might be batteries in the product that have to be removed, that is the law. There might be valuable components that could be treated in a better way if they could be extracted from the product pre-shredding. For hazardous materials that need to be extracted, the price of recycling is higher the longer time disassembly takes, eventually affecting the manufacturer who holds the producer liability. With less effort needed and a higher level of recycling comes a higher score in this area.

Disassembly Analysis

The back and side covers as well as the door are disassembled from the main body with a number of screws and are removed fairly easily. It is evident that the structure has been designed for an easier access of the components, which is very good from many point of views (figure 2). This benefits besides from the assembly personnel also maintenance and repairmen. This is especially true if the components are assembled or disassembled in the right order. Disassembling in any other order is difficult as some components obstruct the removal of other. An example of this is the circuit-boards located on the backside of the machine, which are obstructed by the engine turning the coffee mixer (figure 1). Another example is the circuit board in the

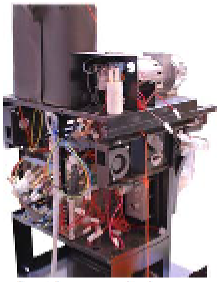


Figure 1. Open structure making the components relatively accessible.

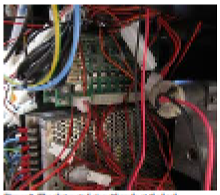


Figure 2. The obstructed circuitboards at the back.

front panel, which is tiresome to access and remove as there are many panels and covers in the way that need to be removed first (Figure 3).

Even though there are no components that must be removed as it is today making valuable components more easily accessible could be worthwhile in the future.

360 degree access

The components are also located all around the main body, which means extra turning and rotating of the machine in order to reach the desired parts. The machine has good possibilities for an easy disassembly thanks to the open layout, which should be used to a greater extent. Locating the components and fasteners on one side would decrease time consumption when disassembling the machine.

One other problem is that many components are fastened with many screws, and many different screw types. If one would want to manually disassemble the machine this would result in a time consuming manual disassembly. But as long as the screws and the materials they fasten are same material or compatible this will not be any problem in a shredding process of today.

Active disassembly

Using a debondable adhesive to fasten the vibration/sound dampener enables simple removal for re-usage in new products.

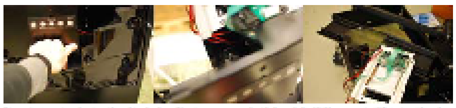
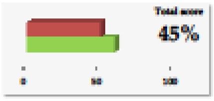


Figure 3. Accessing the circuitboard in the door. Plastic cover removed with force (left). Hidden screw (middle). circuitboard assembly still to be disassembled (right).

Joinings



There are many ways to join part together. Some methods are more suitable than other. The choice is often made on what is easily assembled or what seems to be the most economical method, which often results in an incomplete or incorrect recycling. This table shows of some joining types, and their implications for recycling. A colored/pressed butt on means that the method is used in the product now. In general a red colored buttons is bad from a recycling aspect while a green colored is good. The color might change depending on the situation e.g. snap-fits are good if there is no intention of opening them manually while a manual disassembly would be time consuming and troublesome. The color is customized to the product currently analyzed.

Slide-on

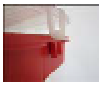
Sliding plastic parts together. Easy to disassemble and separates when shredded. This is used for the plastic lid of the door, where pegs slide into holes. Depending on the application it could sit as tight as snap-fits when assembled (e.g. if a third component is blocking the parts from sliding apart accidentally).

Glue

Spreads the load evenly over a large surface area. Won't be separated properly when shredding or disassembling manually. Glue should be avoided since the glue itself is never compatible with recycling processes for plastics and metals. If glue ends up with the metals it will burn in the remelting process, but if a plastic part is contaminated with glue it will have a negative impact on the recycled material's properties. The coffee machine uses glue to adhere the insulation foam onto the water kettle. Since the foam-to-metal ratio is quite big the risk is that the metal won't separate with the magnets and thus end up in the waste fraction when shredded. One interim workaround for this could be to only glue the ends of the foam to the kettle, so that as much metal as possible remains clean.

Snap fits (for shredding)

Snap-fits (for re-opening)

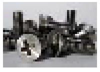


If designed correctly snap-fits will break when shredded, they are thus easily separated from other materials. If implemented where repairmen or users need access to the inside, the design needs rounded snaps and convenient gripping to open, which oft en makes it bulky in construction. Since the Cem machine does not utilize many plastic parts there are no snap-fits. The plastic guide pegs that are used now for the door lid are great - keeping it simple and accessible without any lock-ins.

Bayonet

A "wing-nut", twisted 90 degrees to hold hole-punched components together. Opening and closing is easy. If designed correctly, it would separate easily when shredded or extracted with a simple twist by hand. Preferably the bayonet "key" should be made in the same material as the part(s) it is attached to.

Single type of screws

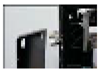


Only one type of screws used in main construction for faster disassembly, as only one tool is needed. The coffee machine has understandable different sizes of screws depending on the application. However, the panels are attached with both philips and torx with no apparent reason for there to be mixed types. For both assembly and disassembly the same screws would be beneficial.

Rivets

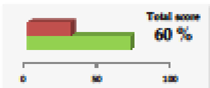
Rivets won't always break when shredded resulting in materials not separating properly. If using rivets, it is important to use rivets of the same material as the parts joined (and they need to be the same material as well.) The Cem machine does not use rivets, which is great.

Slot and tab



Allows pieces to be "puzzled" together eliminating need of screws or other joinings. Easily disassembled both manually and when shredded. This technique is used for the attachment of the coffee brewer plug-in that hangs on two big screws. Another type of slot and tab is when the tabs are bent out from the sheet metal and put into a slit slot. This could be utilized throughout the coffee machine, saving a lot of screws. It can be combined with a locking screw or bayonet for larger parts, still the assembly and disassembly steps should be significantly reduced and the number of parts in general would be lowered.

Product composition



Keeping a product as simple as possible is, from a recyclers point of view, always preferable. Using same material in different components and parts result in healthier material flows, increasing the economical feasibility of recycling. Combining materials in a way so that they are separable in the disassembly process, manually or when shredding, is an advantage as the risk of materials ending up polluting other material flows is eliminated. Using pure and recyclable materials is the best but this is not always possible for many reasons. Using materials that are compatible with each other in the recycling process increases the value of the disposed product as less material is wasted.

Composition analysis

In general the machine consists of few materials, which is appreciated and desirable as the sorting of the shredded machine will be more efficient, result in a higher degree of recycling and larger quantities of the materials. Metals are the mainly used materials in this machine, but also plastics and rubber. In general the metals are easily separable from the other materials and would separate nicely when shredded. The number of materials in this machine is quite low, which is very positive. Parts glued together (figure 4) such as the isolation on the water tank are hard to separate. In this case the risk of metals ending up in the wrong "bin" together with the insulation is high and is most likely to occur to some extent. The water valve and the connecting tubes are thoroughly fastened and will most probably end up as in the mixed fraction that will be incinerated (figure 5). These are not huge problems but still affect the recyclability of the machine and could be taken into account or future development. There is also quite a lot of cabling used (figure 6). Designing in a way where components are closer to each other and the cables do not need to be as long is preferable.

Figure 4. Insulation glued to the tank will result in more loss of material than if glue wasn't used.

Figure 5. Water valve that would, to a great extent end up in the wrong material flow.

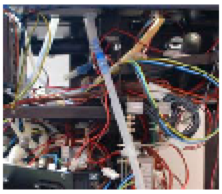
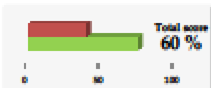


Figure 6. Cabels spread all over the insides of the machine. Less cabel used and an easier removal of cabels is prefered.

Recycling incentives



To some extent people are lazy and if not given the right means or incentives the disposal of a product could become careless. As a manufacturer, controlling the products lifespan and providing better incentives and preconditions is more likely to yield a correct disposal. Marking a product with the "wheelie-bin" is required by law and is not enough. People need to know where to dispose the product and how. Getting refunds has proven to be a good way to motivate people. Leasing the products makes takeback and recycling of the products easier.

Crem International's situation

A responsible manufacturer takes control over the disposal of the product and works to under- stand the conditions and motivations of their customers. Since Crem International produces rebranded machines for resellers but also is its own brand, the question of who the customer is, is a little bit fuzzy. Is it the reseller or the gas station owner? Who is in charge of the recycling of old machines - the companies with service organisations such as Jede with a direct contact with users, or Crem International? There is a producer responsibility according to the WEEE directive, but if no one uses their right to return the product to Crem International at end-of-life, is there a problem?

The four levels of takeback

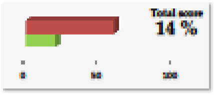
There are four levels of takeback incentives available to producers: the shrug of indifference (the legal baseline), the peptalk ("please recycle"), refunds on return (pant in Swedish) and the best way: leasing, where the producer remains the owner of the product. Taken to the extreme, the producer can even lease out the machine with energy use included in the price. This creates a producer incentive to lower energy consumption of the product. Why is leasing so good?

- The user does not have to worry about maintenance and care of the product.
- The producer controls the components.
- As materials grow more expensive, not having to buy back the materials will become increasingly profitable.

Circularity in flows vs. reuse

In recycling, having circular material streams is always sought for. But even better is to reuse parts or subassemblies in a tighter loop. This maintains the material and shape complexity not to mention the energy to reach that complexity - compared to the destructiveness of shredding and recycling, just as explained in the re-ladder at the outset of this report. For Crem, this implies having control over the streams of end-of-life machines to not lose out on the complexity values they contain. The good news is that leasing out products is the best way to remain in control over the materials. Even if it is Crem's resellers doing the leasing, the products are still somewhat accessible for Crem. Consumer goods manufacturer have a much tougher time trying to get their products back for reuse of components, since customer's are much harder to incentivize to re- turn products.

Documentation



Documentation refers to the level of information that is given from the manufacturer to the recycling company. Lets say, if the recycler know in advance that a product contain hazardous materials or include batteries that have to be removed before further processing that product can be separated from the main waste stream and dealt with properly. It is not only important for the recycler that materials are easily identified, but it is also important for the manufacturer as it works as an quality assurance that ensure that the manufacturer has knowledge and control of their materials. Correctly marked materials result in a correct handling and correct price.

The coffee machine's secrets

The materials used in the machine are poorly labeled. The metal casing is not marked at all, the same goes for the plastics, with a few exceptions (figure x). As plastic parts over 25 g must be marked according to law, solving this problem should be a high priority. If a product contains hazardous materials or includes batteries the recycler

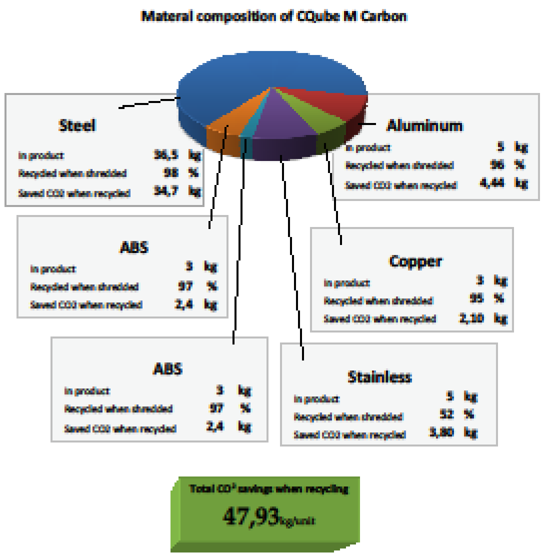
has a legal obligation to manually remove it before further processing. However this is not applicable for the coffee machine. A bill of materials is a legal requirement for electronics. This is for the recycler to know what kind of processes to employ when offering to process the product. There are several ways to inform the recycler. Including a bill of materials on or in the machine, easily accessible would simplify and speed up the information gathering as there is no need to search for the information further away than the machine. Having a database accessible on the internet is also a valid solution. The core is to secure the information transfer over time, since it might be a while before the coffee machine reaches end of life.

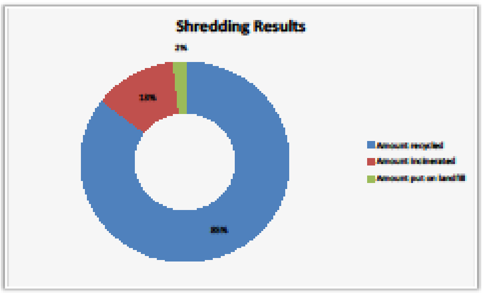
Future: A technology that is up and coming is RFID tags (Radio Frequency ID). Today these tags are used as ID-badges, access cards etc. These unique tags can then be accessed through scanning the tag with a RFID reader, accessing a database link or the serial number of the machine. This technique could be used for storing information of products that could be accessed by recyclers, but also repairmen, distributors etc. for easy access to the machine's history.

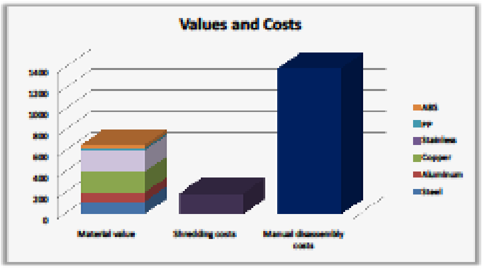
A treasure map

Guiding the recycler to the components that need to be removed or are valuable can be crucial as a too time consuming search for the valuable or hazardous components result in that the product is shredded together with the valuables, which is suboptimal from a recycling perspective. This could be as simple as having these parts clearly visible and reachable which definitely is the case with the coffee machines, great!

Data and facts sheet



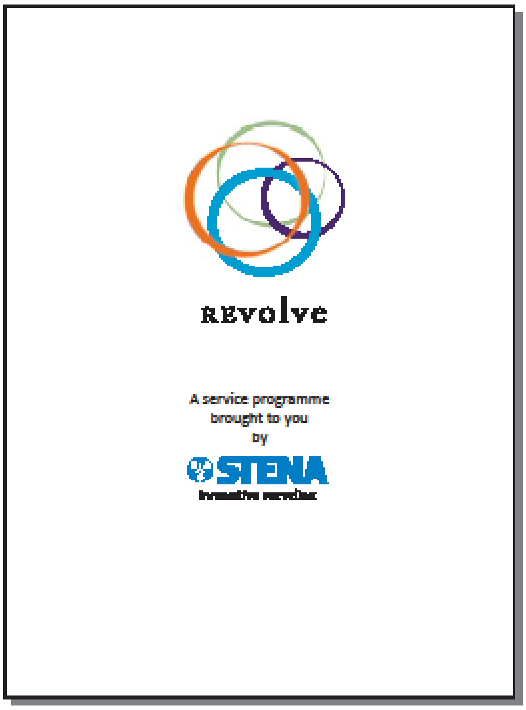

Shredding Results
Amount recycled
Amount incinerated
Amount put on landfill


Values and Costs
1400
1200
1000
800
600
400
200
0
Material value
Shredding costs
Manual disassembly costs
ABS
PP
Stainless
Copper
Aluminum
Steel

Appendix 9

The Leaflet introducing the service

1



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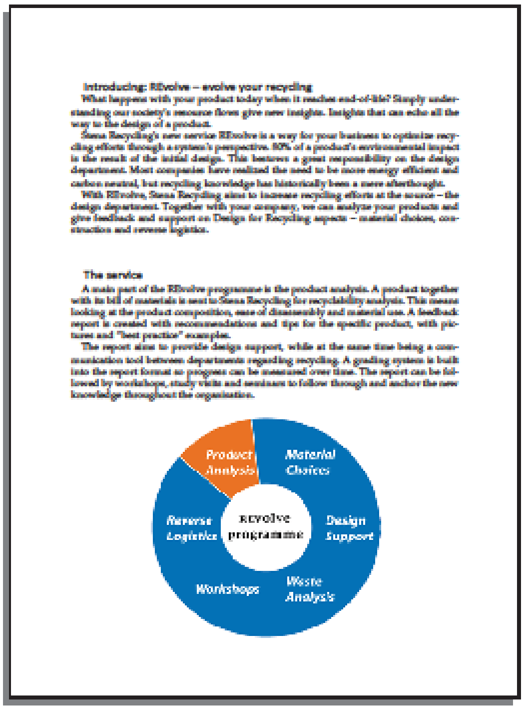


Introducing: REvolve – evolve your recycling

What happens with your product today when it reaches end-of-life? Simply understanding our society's resource flows give new insights. Insights that can echo all the way to the design of a product.

Stena Recycling's new service REvolve is a way for your business to optimize recycling efforts through a system's perspective. 80% of a product's environmental impact is the result of the initial design. This bestows a great responsibility on the design department. Most companies have realized the need to be more energy efficient and carbon neutral, but recycling knowledge has historically been a mere afterthought.

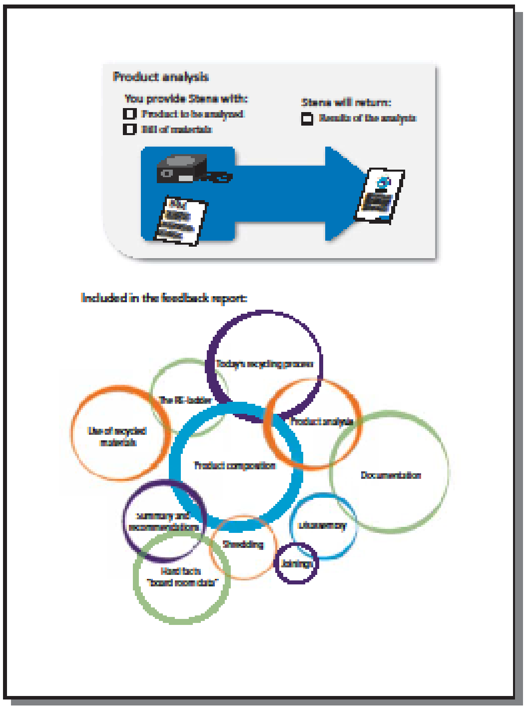
With REvolve, Stena Recycling aims to increase recycling efforts at the source – the design department. Together with your company, we can analyze your products and give feedback and support on Design for Recycling aspects – material choices, construction and reverse logistics.

The service

A main part of the REvolve programme is the product analysis. A product together with its bill of materials is sent to Stena Recycling for recyclability analysis. This means looking at the product composition, ease of disassembly and material use. A feedback report is created with recommendations and tips for the specific product, with pictures and "best practice" examples.

The report aims to provide design support, while at the same time being a communication tool between departments regarding recycling. A grading system is built into the report format so progress can be measured over time. The report can be followed by workshops, study visits and seminars to follow through and anchor the new knowledge throughout the organization.

3



Appendix 10

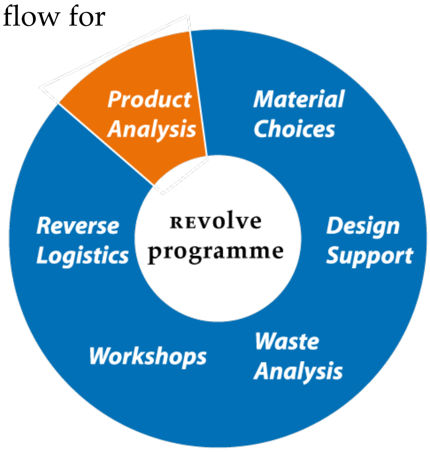
REVOLVE

Feedback report – Design for recycling analysis

STENA
Innovative recycling

Design for recycling analysis

This report is a part of the REvolve service programme and will guide you through the recycling aspects of your product. Recycling today is a matter of behaviour, materials, logistics, and construction aspects. The value, purity and quantity of a material in a product is important, but also how easily it is extracted and separated into a separate material flow for effective and efficient recycling.



A note on the ratings

The scales and grades used in this report is a communication tool more than they are an exact science. The ratings are judged by our experts, except joinings which are created using the flowcharts in the appendix. The main purpose is to provide an easily grasped overview and then discuss more in-depth concepts in the text.

STENA
Innovative recycling

The RE-ladder

One of the basic recycling guidelines is the recycling ladder, a hierarchy of recycling processes. When developing a product, one should aim to reach as high as possible - e.g. reuse before recycle, recycle before energy recovery. For some products the order is slightly different, but as a mental model it is a powerful tool.

REliability - Slowing down the flow of materials, through an extended lifetime for products.

REduce the amount of material used through light and smart construction. Reducing the number of materials used will reduce material transports and improve the logistics of recycling.

REuse - Reusing or repurposing the whole product or components will delay the end-of-life treatment. Reuse saves energy, reduces virgin material use and omits shaping processes.

REcycle materials - The materials are separated and melted and can be used as new raw materials in new products.

REcovery of energy - Burning the materials is not really recycling, but today many uncommon plastics are incinerated to recover the energy.

(Landfill) - Today very little waste goes to landfill compared to just ten years ago. Only substances that are not fit for either recycling or incineration end up here.

The Recycling Process

The Global System

In 2007, EU countries disposed of an estimated 6.5 million tonnes of WEEE and it is estimated that by 2015, this figure could nearly double. Although the WEEE directive of the EU is in effect to regulate e-waste handling, there is still a part of the waste illegally ending up in developing countries such as Ghana and Pakistan. For the U.S., approximately 80% of electronic waste is exported, mostly to China that craves raw materials in their production.

The e-waste is burned out in the open, wasting good plastic materials while subjecting the people to toxins from flame retardants and heavy metals. The valuable materials are then extracted. This is not acceptable, and Stena Recycling works hard to ensure that the whole recycling chain is safe for the workers involved and the surrounding environment.

When WEEE reaches Stena - Manual Screening and Disassembly

All waste electronic equipment (WEEE) in the E.U. has to go through a manual screening before being processed mechanically. This step is called first treatment. The mixed electronics is poured out onto a conveyor belt where disassembly experts look for products containing hazardous or valuable materials.

Old CRT T.V.s are taken aside to properly handle the leaded glass and extract the valuable copper coil, computers are dismantled to reach the circuit boards filled with platinum and gold. Some newer LCD TV:s have fluorescent backlights containing mercury, which need to be carefully extracted. All electronic cords hanging loose are cut off manually, also for the valuable copper. Gadgets with batteries are taken aside and put into a separate fraction. The decision to disassemble a product or not is a fast, subjective judgement from the worker unless there is regulations that a product must be disassembled. The crucial factor is time for disassembly versus the potential reward. This is why making valuables easy to access is important. As the conveyor belt tallies along, the workers put home electronics waste (mp3 players, hair dryers etc.) on one side of the belt and household electronics (blenders, toasters etc.) on the other. These two flows are then sent to the shredder separately.

Shredding

The e-waste is crushed and shredded into cornflake sized pieces and then sorted into different material fractions through various processes such as magnetic, mechanical and optical sorting. The resulting fractions are ferrous metals, non-ferrous metals and different plastics fractions - PP, ABS, PS, brominated. The metal fractions go to smelters such as Boliden for renewing the flows. The plastics are taken through a series of fluid tanks with salt water of different density. The heavier plastics type sink and the others float to the next with a little less dense fluid, and thus different plastics are sorted from each other.

A problem for recyclers now is the influx of exotic new plastics. For instance, PP with 20% talc has the same density as ABS plastic. The ABS fraction becomes polluted with PP which means the recycled ABS' properties are compromised.

After the shredding, some materials that can't be sorted properly end up as a lower value mixed fraction. Why can't they be sorted properly? The reason is that many products are joined together in a way that leaves mixed material fractions even after shredding.

Stena is currently doing research on using microwaves to extract the final pieces of metal and plastics through a pyrolytic process. This would enable 100% recycling for most electronic waste. A microwave could be microwaved so it can become a new microwave.

Nature as a waste dump - a bad thing

Electronics ending up in nature is a waste. Materials that are perfectly fit for recycling are dissipated, toxins are released and energy is lost when virgin materials have to replace recycled.

Loss of recycling - Even though an aluminium can is inert and non-toxic if it ends up in nature, it is bad for nature. Why? The answer is energy use. A can made from virgin material uses 20 times more energy than a recycled one.

Material dissipation - Copper, gold and rare earth metals (used in e.g. magnets and LCDs) are all a limited resource and will run out the next few decades unless the material flows are controlled more tightly.

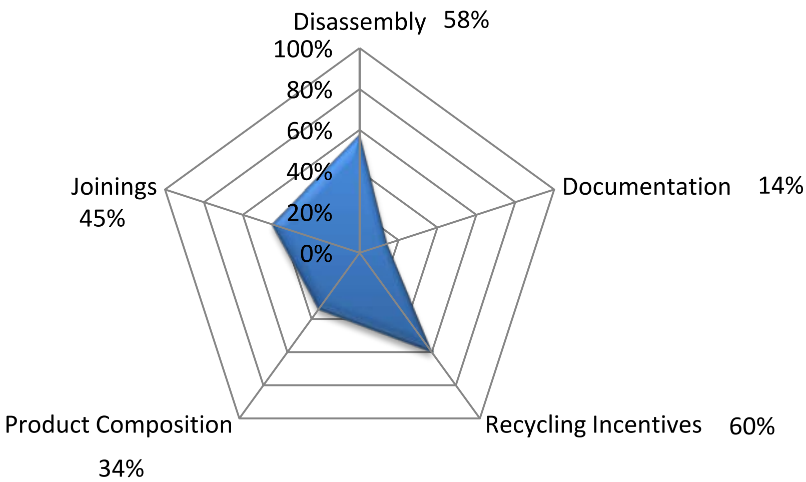
Toxins - Flame retardants are required by law in printed circuit boards, and brominated retardants are commonplace. When released in nature, these substances mimic hormones and are accumulated in animals and humans, disrupting reproduction. Older electronics made before the RoHS directive can contain lead.

Summary

Short description of findings of the analysis

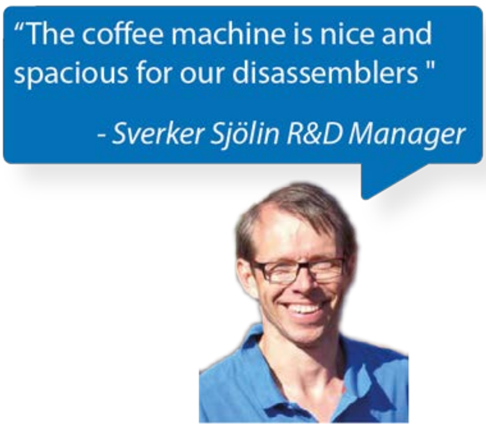
Summary of goods and bads of the product.

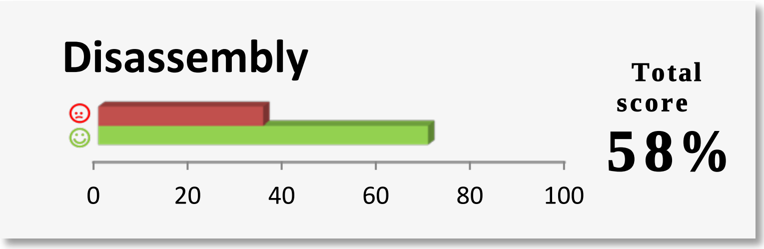
Summarizing score chart



Recommendations

- Create slots and tabs in the sheet metal for easy assembly and disassembly.
- Consider, with the help of your resellers, if there are any components that could be reused, and then make them accessible in the design.
- The access is good half-way, but for instance the circuit board is laborious to unmount. It is one of the valuables the recycler wants easy manual access to.
- Fewer types of screws would shorten disassembly times, and thus the recycling fee.
- The use of few base materials is great!
- Recycled material use is limited and could be increased.





A time consuming disassembly might be the difference between separating a valuable circuit board from a product, and shredding it all together. This scale assesses, among other, this issue. The disassembly should be made easy other reasons as well. Components might break and need to be replaced. There might be batteries in the product that have to be removed, that is the law. There might be valuable components that could be treated in a better way if they could be extracted from the product pre-shredding. For hazardous materials that need to be extracted, the price of recycling is higher the longer time disassembly takes, eventually affecting the manufacturer who holds the producer liability. With less effort needed and a higher level of recycling comes a higher score in this area.

Disassembly analysis

Accessibility

Are the components easy to access?

Valuables

Are the valuables and hazardous components easily located and removed?

Time consumption

Does it take long time? Why?

Understanding in what order to disassemble

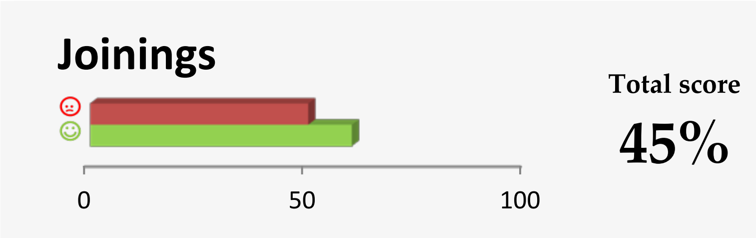
Many screws to unscrew etc?

Doing it

How troublesome is it?

Propositions

Some general tips and advices

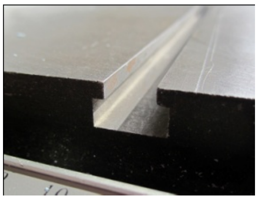


There are many ways to join part together. Some methods are more suitable than other. The choice is often made on what is easily assembled or what seems to be the most economical method, which often results in an incomplete or incorrect recycling. This table shows of some joining types, and their implications for recycling. A colored/pressed button means that the method is used in the product now. In general a red colored buttons is bad from a recycling aspect while a green colored is good. The color might change depending on the situation e.g. snap-fits are good if there is no intention of opening them manually while a manual disassembly would be time consuming and troublesome. The color is customized to the product currently analyzed.

A colored, "pressed" button means that the joining type is currently used in the product. Red is bad, green is good. The gray buttons show joining types that are not used, while the colored line show if that type would be positive or negative to use in the construction.

Slide-on

Sliding plastic parts together. Easy to disassemble and separates when shredded. This is used for the plastic lid of the door, where pegs slide into holes. Depending on the application it could sit



as tight as snap-fits when assembled (e.g. if a third component is blocking the parts from sliding apart accidentally).

Glue

Spreads the load evenly over a large surface area. Won't be separated properly when shredding or disassembling manually. Glue should be avoided since the glue itself is never compatible with recycling processes for plastics and metals. If glue ends up with the metals it will burn in the remelting process, but if a plastic part is contaminated with glue it will have a negative impact on the recycled material's properties.

Snap-fits (for shredding)

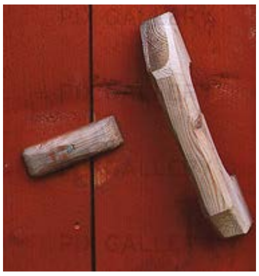
Snap-fits (for re-opening)

If designed correctly snap-fits will break when shredded, they are thus easily separated from other materials. If implemented where repairmen or users need

access to the inside, the design needs rounded snaps and convenient gripping to open, which often makes it bulky in construction.

Bayonet

A "wing-nut", twisted 90 degrees to hold hole-punched components together. Opening and closing is easy. If designed correctly, it would separate easily when shredded or extracted with a simple twist by hand. Preferably the bayonet "key" should be made in the same material as the part(s) it is attached to.

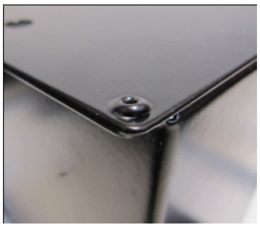


Single type of screws

Only one type of screws used in main construction for faster disassembly, as only one tool is needed. For both assembly and disassembly the same screws would be beneficial.

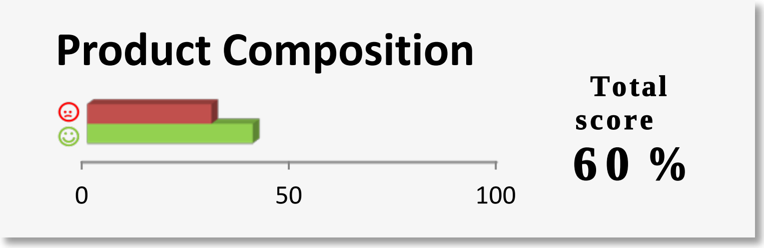
Rivets

Rivets won't always break when shredded resulting in materials not separating properly. If using rivets, it is important to use rivets of the same material as the parts joined (and they need to be the same material as well.)



Slot and tab

Allows pieces to be "puzzled" together eliminating need of screws or other joinings. Easily disassembled both manually and when shredded. Another type of slot and tab is when the tabs are bent out from the sheet metal and put into a slit slot. This could be utilized, saving a lot of screws. It can be combined with a locking screw or bayonet for larger parts, still the assembly and disassembly steps should be significantly reduced and the number of parts in general would be lowered.



Keeping a product as simple as possible is, from a recyclers point of view, always preferable. Using same material in different components and parts result in healthier material flows, increasing the economical feasibility of recycling. Combining materials in a way so that they are separable in the disassembly process, manually or when shredding, is an advantage as the risk of materials ending up polluting other material flows is eliminated. Using pure and recyclable materials is the best but this is not always possible for many reasons. Using materials that are compatible with each other in the recycling process increases the value of the disposed product as less material is wasted.

Composition analysis

Materials

How many different materials are there?

Mixed materials

Are materials joined in a way that they won't be separated when shredded?

Recyclability of materials

Are the materials recyclable? Do they have a high value?

Batteries and hazardous materials

Are there any dangerous materials that need a separate handling? Implications?

Valuable materials

Is there anything valuable that could be extracted?

Usage of Recycled materials

Which parts could be made out of recycled materials

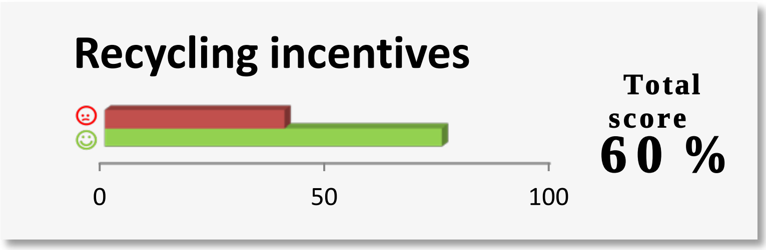
Recycled materials

Using recycled or secondary materials is a double win for the environment.

1. No materials were incinerated or put in landfill.
2. No need to mine new materials.

Using recycled instead of virgin materials, with some exceptions, mean that the CO2 footprint is lowered. Recycled materials can often be used without any modification of product geometries etc. as their properties are nearly the same as virgin materials are. This is true with metals, which there are well developed recycling processes for. Recycled plastics, on the other hand are degraded to some extent depending on material and degredation from usage. Some plastics can be recycled up to 6-7 times before they have lost a considerable amount of the original properties.

Today the recycled materials are often mixed into the virgin materials in small amounts, without change in properties. Pure recycled parts could be used if the product is designed with the intention of using recycled materials. If the recycled material has lower strength, the dimensions and geometries could be changed in order to secure the construction requirement. If the issue is the surface quality, recycled materials could be used in b-surfaces i.e. surfaces that are seldom seen by the user. Parts inside products, c-surfaces that never come in contact with the user do not have to have as high requirements visible parts when it comes to finish, colour etc. These could be made out of materials that are recycled several times.



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The four levels of takeback

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- The user does not have to worry about maintenance and care of the product.
- The producer controls the components.
- As materials grow more expensive, not having to buy back the materials will become increasingly profitable.

Company status

To what extent does the company have control of their products?

Recycling at any cost?

Transportation logistics is very important when it comes to recycling. Consider styrofoam, which is notoriously hard to recycle. Why? Actually the recycling part is easy, styrofoam is made from pure polystyrene. It's the logistics of it.

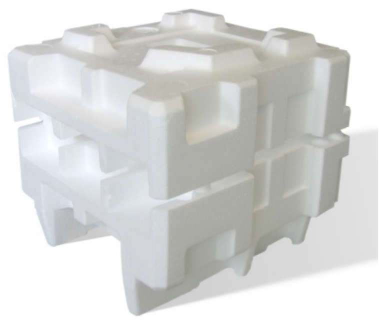
The light styrofoam is mostly air. Transporting all this air in big trucks to the recycling facility is too costly for the amount of recycled plastics one would get back, not to mention the emissions it would cause compared to virgin materials. This is the reason styrofoam as package material is not a stellar idea.

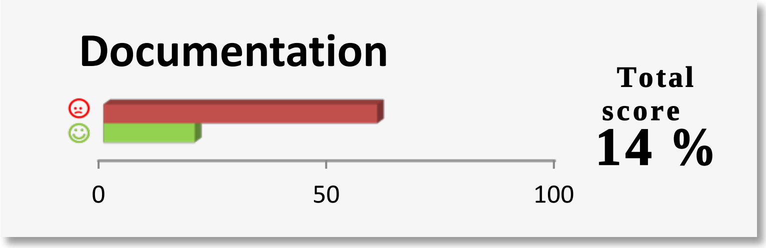
EoL

What happens to the product at eol? How do the incentives look like?

Circularity in flows vs. reuse

Look at what could be relevant to the company: circular flows and reuse.





Documentation refers to the level of information that is given from the manufacturer to the recycling company. Let's say, if the recycler know in advance that a product contain hazardous materials or include batteries that have to be removed before further processing that product can be separated from the main waste stream and dealt with properly. It is not only important for the recycler that materials are easily identified, but it is also important for the manufacturer as it works as an quality assurance that ensure that the manufacturer has knowledge and control of their materials. Correctly marked materials result in a correct handling and correct price.

Legislation/markings

Are the materials marked correctly?

Bill of materials

Is there a bill of materials easily available?

Guidance to valuables and hazardous materials

Are valuables and hazardous materials easy to locate and remove?

Future: A technology that is up and coming is RFID tags (Radio Frequency ID). Today these tags are used as ID-badges, access cards etc. These unique tags can then be accessed through scanning the tag with a RFID reader, accessing a database link or the serial number of the machine. This technique could be used for storing information of products that could be accessed by recyclers, but also repairmen, distributors etc. for easy access to the machine's history.

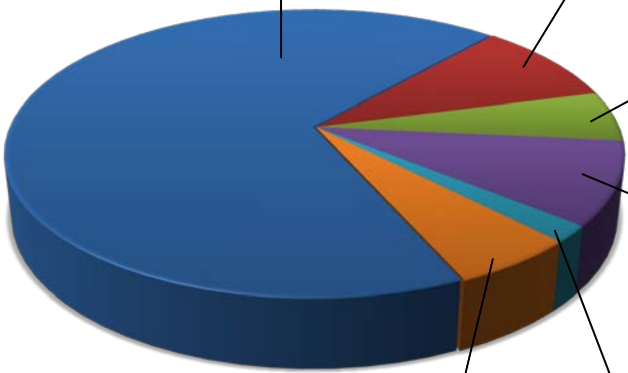
Data and facts sheet

Steel

In product	36,5	kg
Recycled when shredded	98	%
Saved CO2 when recycled	34,7	kg

Aluminum

In product	1	kg
Recycled when shredded	96	%
Saved CO2 when recycled	3,4	kg



Copper

In product	3	kg
Recycled when shredded	95	%
Saved CO2 when recycled	2,1	kg

ABS

In product	3	kg
Recycled when shredded	97	%
Saved CO2 when recycled	2,4	kg

Stainless

In product	5	kg
Recycled when shredded	52	%
Saved CO2 when recycled	3,8	kg

PP

In product	1	kg
Recycled when shredded	75	%
Saved CO2 when recycled	0,5	kg

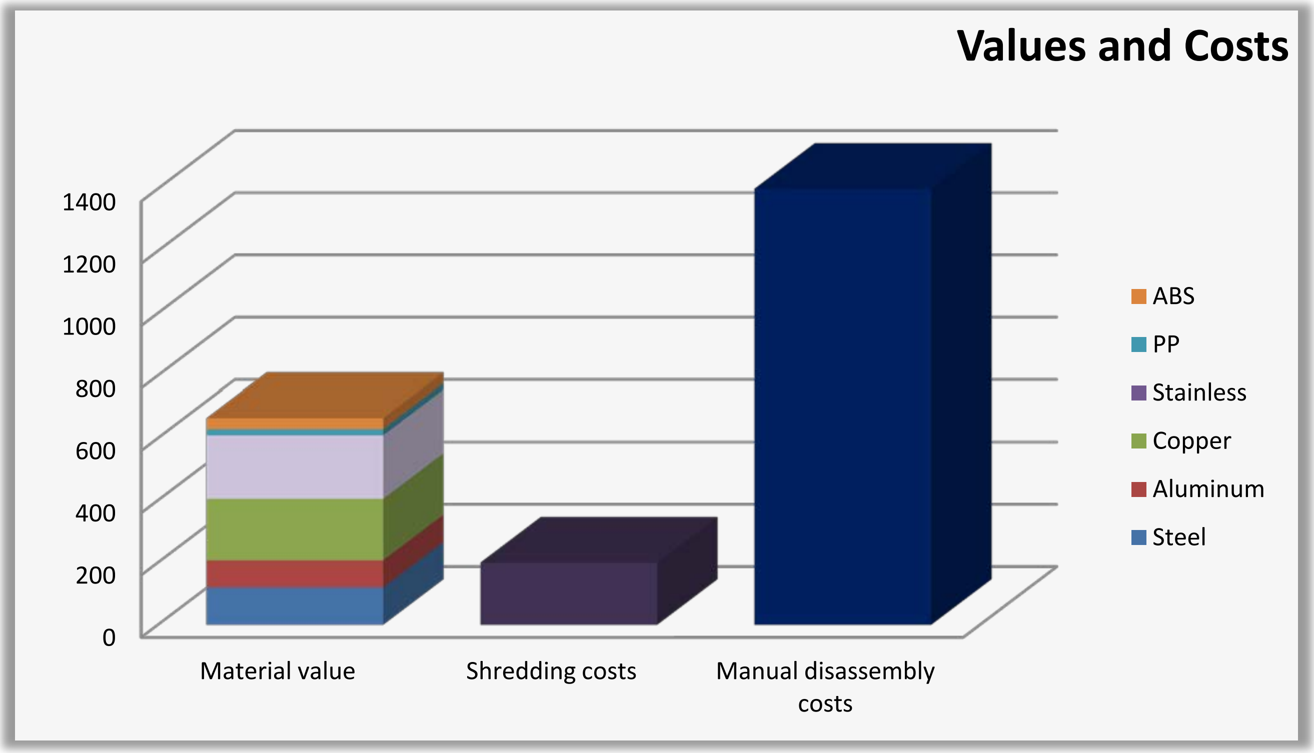
Total CO^2 savings when recycled

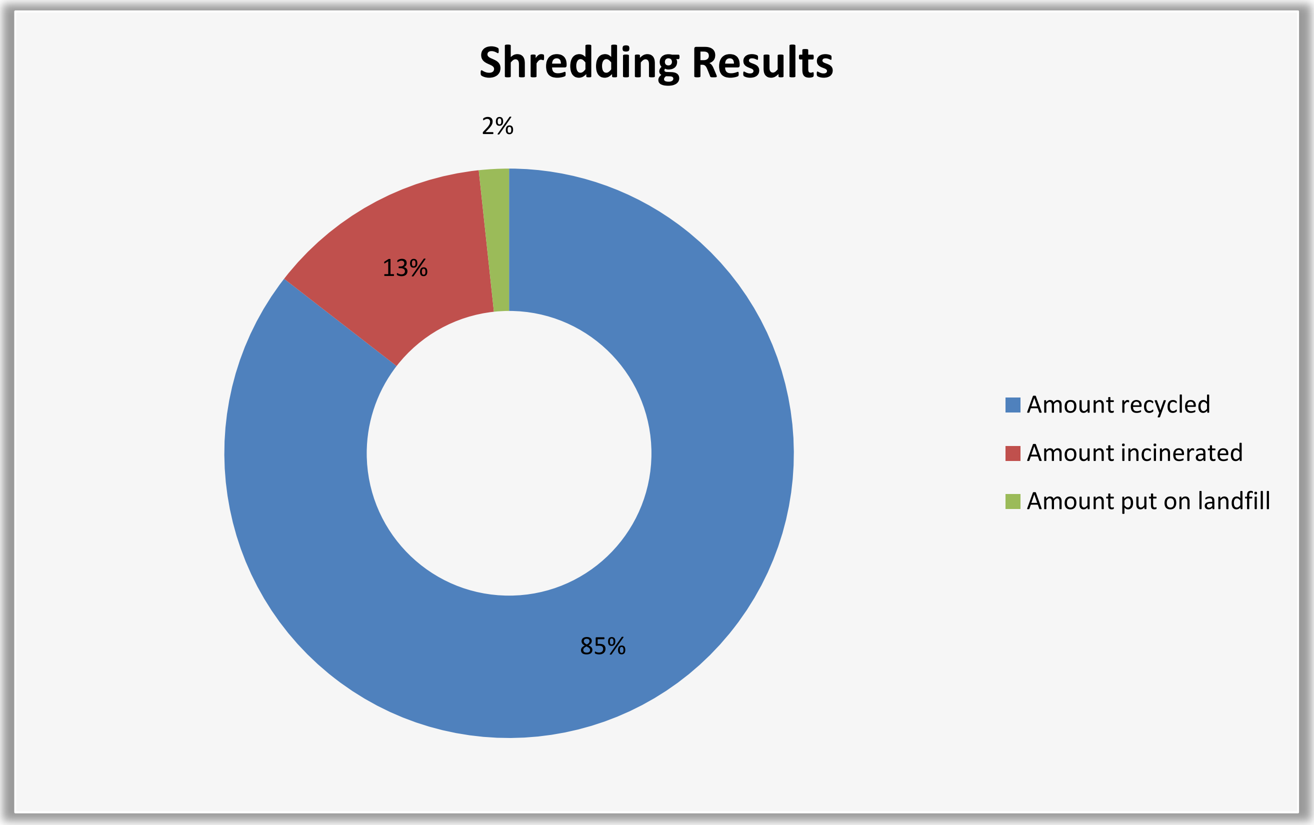
47,93 kg/unit

Carbon dioxide and some common examples

1kg of CO^2 = 17 h of vacuum cleaning
10kg of CO^2 = 3 years and 4 months light from a 9 W lamp
100kg of CO^2 = 2 years and 3 months of 42" LCD-TV watching
1000kg of CO^2 = combustion of 278 liter of gasoline

based on energy comsumption in Sweden 2008
Source: Swedish Energy Agency


Values and Costs
1400
1200
1000
800
600
400
200
0
Material value
Shredding costs
Manual disassembly costs
ABS
PP
Stainless
Copper
Aluminum
Steel


Shredding Results
2%
13%
85%
Amount recycled
Amount incinerated
Amount put on landfill