Information exchange requirements for cradle to cradle implementation in an industrial setting: EoL treatment of flat screen televisions

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Abstract To accomplish a Cradle to Cradle approach, which implies closing the material loop and avoiding downcycling, it is imperative to improve the physical separation processes. Therefore, a holistic life cycle approach, in which different actors in the lifecycle are involved, is required to allow the exchange of key information. This study describes a generic structure for a relational database that allows the required product information to be exchanged between manufacturer and recyclers, as well as the possible benefits for these companies to have this information available. The further goal of this database is to enable an evaluation and optimization from an economic and environmental point of view of the product design and alternative end of life treatment scenarios.

1 Introduction

When applied properly the Cradle to Cradle (C2C) concept enables to approximate a closed material loop wherein the materials are used over and over again to make new products without substantial quality losses. The C2C concept is based on how waste is treated in nature: the waste of one organism is the food of other(s) [1]. However, in contrary to nature where there is no disequilibrium, waste treatment has become a critical issue in our society. Due to the rapid evolution in technology and increasing volume of products Waste Electric and Electronic Equipment (WEEE) is one of the most critical waste categories [2]. One of the ongoing technology changes is the shift from Cathode Ray Tube (CRT) to Liquid Cristal Display (LCD) televisions. Today only a limited number of LCD displays return for recycling. However, the total quantity of LCD televisions that have been put on the European market (25 member states) by 2010 is estimated to be around 1.5 million tonnes [3].

The collection of LCDs larger than 100 sq. cm is currently performed separately in accordance with the European WEEE directive [5]. Generally, these flat screens are first reduced in size, and the mercury of the Cold Cathode Fluorescent back light lamps is separated. Then the separation of ferrous and the non-ferrous metals, is performed with a magnetic and an Eddy current separator. After these operations the rest fraction is composed of mainly plastics, PCBs and some small ferrous and non-ferrous parts. From this fraction, all low density plastics, mainly Polystyrene (PS) and Acrylonitrile Butadiene Styrene (ABS), are extracted based on floatation techniques. Plastics with a higher density (e.g. plastics with flame retardants) are incinerated with energy recovery. Besides these material losses, a lot of precious metals get lost in this process as most of the Printed Circuit Boards (PCBs) end up in the structural metals and the rest fractions. As a result, a considerable amount of materials is downgraded in the current recycling process because of impurities or concentration reduction. The main steps in the conventional recycling process are shown in Figure 1.

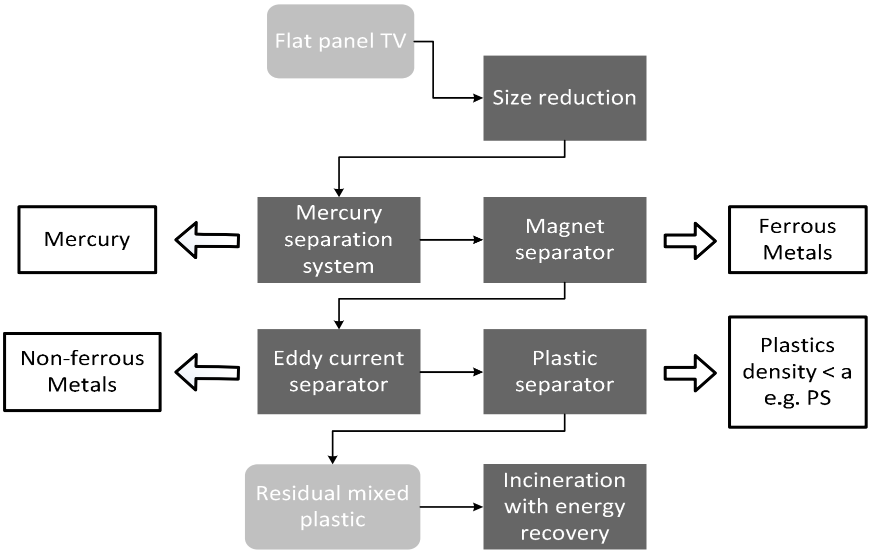

Figure 1: Recycling Processes in conventional EoL treatment of LCD televisions

From a C2C point of view the main problem is that most of the current recycling processes are based on shredding. All the efforts for identification and separation to prevent downcycling are performed after this first destructive step, where all materials, well clustered in the product, are mixed thus significantly affecting the entropy of the system.

To face these problems, a close cooperation between the different actors of the product's lifecycle, being the manufacturer of the product, the organization responsible for the collection at the EoL, the recycler and the raw material supplier, offers opportunities. A proper information exchange constitutes the essential foundation of such cooperation. Today in the European context, recycling companies do not cooperate with manufacturing companies, which implies that there is no information exchange between them. As a result, the recyclers do not well know the material content and how these materials are physically connected in the products they are processing.

The Flemish project Perfecting Research on Intelligent Material Exploitation (PRIME) achieves this cooperation between the different actors of the product life cycle by the participation of Philips, a Flat screen Televisions manufacturer, Van Gansewinkel, a collection and recycling group, and Umicore Precious Metals Refining, an integrated precious metals smelter-refinery and recycler of precious and special metals. No public waste collection organizations are directly involved in the PRIME project. However, in a later stage, the project will formulate suggestions about legislation to governmental institutions. The main goal of the project is to improve the current recycling performance, through a holistic vision on materials flows, business models and design.

In the next section of this paper the information available at the manufacturer's side is analyzed. The subsequent section discusses the information requirements from the recycler point of view. The fourth section treats the potential benefits of the proposed scheme. The fifth section describes the proposed database within the PRIME project. In the final section some conclusions are drawn and outlines for future work are formulated.

2 Product Information Available at the Manufacturer

The current European regulation for Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) obliges information exchange between manufacturers and suppliers about the so-called Substances of Very High Concern (SVHC). The main differences compared to previous substance restrictions are: (1) the requirement to declare SVHC, (2) calculate the SVHC at article level (instead of homogeneous material) and (3) update the list of SVHC every 6 months [6]. Because of the long SVHC potential candidate list (1500 substances) and the required updating periodicity, automated information exchange is required for large manufacturing companies. Furthermore, some manufacturing companies, such as Philips, not only request a Regulatory Compliance Declaration (RCD) of the SVHC content of every article, they also encourage their suppliers to provide a Full Material Declaration (FMD) eliminating the need of updating the RCD every time regulation changes [7]. Therefore, Philips together with other manufacturers jointly support the development of BOMcheck (Bill Of Materials check), a web based portal to systematically collect declarations from suppliers [8]. The challenges of implementing such a system are related to convincing all the suppliers and training them to use the system. Currently it seems that, once the advantages of the system are properly explained to the suppliers, the resistance to join BOMcheck decreases. However, providing a FMD proofs to be difficult for most suppliers because of confidentially issues or because the required information is not available at present. Nevertheless, Philips foresees that in the near future they will make FMD compulsory for certain risk commodities such as plastics [7]. As long as this full material declaration is not compulsory for suppliers, the final product manufacturer does not possess complete material content information.

For example, the reuse of plastics from back covers of FTVs is currently not performed, because the differentiation among plastics with and without banned flame retardants is infeasible on an industrial scale [9]. As a result back covers with any type of flame retardant are currently incinerated with energy recovery. However, if material content information would be available and shared, it can allow to identify and to treat components separately. In this way the material loop could be closed. The advantage for manufacturers is that they can get access to cheaper materials with correct and well-known specifications. These alternative supply chains will also provide them a strategic advantage, as it will lower the bargaining power of the material suppliers.

3 Information Requirements by the Recycler

The first phase of the recycling process generally consists of multiple physical separation processes based on different physical properties of the materials. The main purpose of this first phase (commonly called pre-processing) is to create recyclates with the appropriate quality for metallurgical, thermal and (in) organic processing in the second phase (commonly called end-processing for material recovery). The recovery rates of the second phase are determined by the thermodynamic and chemical properties of the materials as well as the interaction between different elements present in the fractions obtained from the physical separation processes [10].

These two phases are often performed by separate companies, which requires a proper information exchange between these companies to optimize the material recovery. For example, modern smelters directly treat printed circuit boards (PCBs), making shredding and sorting steps on the boards itself at the pre-processor unnecessary. In the first step of the metal recovery process of Umicore Hoboken hydrocarbon-containing compounds in the e-scrap (e.g. epoxy, plastic) are used as a substitute for coke, as a reducing agent and as an energy source [11]. Consequently, in the separation processes of FTVs there is no need to extract the plastics from the PCBs. On the other hand, large structural pieces of aluminium, such as cooling fins, connected to these PCBs are recovered in the slag, which is an additive for the concrete industry. To avoid an excessive loss of valuable materials each time a trade-off needs to be made at the pre-processor between separating and valorizing more aluminium from the boards, and the losses of precious metals that are associated with the separation process [12] Often improvements in physical separation technologies are proposed as solution, which requires information about the product. Another approach to optimize the physical separation processes is designing the products in a way that supports the sorting processes. Both approaches require dialogue, cooperation and information sharing between the manufacturer, the pre-processor and the end-processor. From an economic perspective, disassembly of waste of electric and electronic equipment (WEEE) is under the current circumstances generally characterized by a low to negative profitability [13]. For this reason it is currently difficult for recyclers to compete with lower wage countries and to prevent the export of WEEE [14]. However, having proper product information available, (partial) disassembly will become more economically feasible, because it can result in higher purity materials streams. The availability of the proper material content information and data on the product configuration provides also valuable information when considering automated disassembly, which is currently limited by the variation of the returned products, requiring a great capacity of recognition and intelligence [4, 15].

The efficiency of the separation processes is largely affected by the input of these processes. This because, the product design has a dominant influence at the moment of improving the recyclability [16-18]. Many efforts have been done in the field of Design For Recycling and Disassembly (DFR or DFD). A promising DFD concept to make disassembly economically feasible is Active Disassembly (AD) [19]. Products designed for AD are products that contain connections for which a specific external trigger or a combination of triggers can initiate a simultaneous unfastening process [13, 20]. In the field of DFD, products are mostly designed either to optimize the manual disassembly or to automate the (active) disassembly process. For this reason, it is crucial for recyclers to know which EoL scenarios are taken into account during the design phase. The implementation of a product tagging system, such as Radio Frequency Identification (RFID), can be required in order to allow the recycler to identify the appropriate EoL scenario. For example, if an AD functionality would be built in an FTV the proper information about the triggers as well as the ability of treating these products separately is essential.

4 PRIME PROJECT

Over the last 20 years, the improvement of the EoL treatment of electric and electronic products has been intensively studied. A lot of models for optimizing the disassembly level, and linking the outputs to further processing already exists [21] [22]. However, in Europe, only few of the earlier developed models have been implemented in commercial software tools that can support the recycling processes. In 2002, Boks analyzed several tools deployed to evaluate EoL scenarios, pointing out that the integration in industrial environments was mostly absent [23]. In a more recent study in 2009 Van Schaik stated that the detailed data needed for modeling recycling performance is not made readily available in industry, although this information should be available in the CAD systems at the manufacturer site [16]. The main reasons identified for this limited industrial implementation are the following:

- Most studies that include all the elements in the recycling process, such as reverse logistics, disassembly, clustering, and shredding assume a predetermined disassembly sequence and depth [21]. This implies a simplification of the product design description, which entails that no alternative disassembly techniques can be considered.
- Lack of proper information about processing cost and the value and quality of the recycled materials [23].
- The scope of earlier projects was limited to part of the EoL chain. As a result, the tools developed within these projects are generally oriented to support either the manufacturer or the recycler, without considering a holistic approach. [24].

All these problems are related to appropriate information collection and information exchange between the different parties in the product life cycle. PRIME provides a unique opportunity to deal with these problems, as all the companies involved in the life cycle of FTVs participate in this project. The first problem of appropriate information collection at the manufacturer side is handled within the PRIME project by the development of a relational database structure, which allows describing a product in a more generic way. This database structure is presented in the next section.

The second problem and the link with product configuration will be treated in the next phase of the PRIME project, where all companies involved in the project will support the collection of process information. The third problem is overcome by the commitment of the companies in this project. The proposal of a business model that sustains this collaboration is one of the expected outcomes of the project, as manufacturers and recyclers envision economic benefits from this collaboration to allow an industrial implementation.

The PRIME project focuses on FTVs, which are interesting products to analyze because of the high number of FTVs currently on the market, the high value material content, and the fact that FTVs are collected separately because of regulations. The opportunity within the PRIME project is that detailed information about the FTV configuration and material specifications of Philips, and information about the processing costs and values of the recycled materials of Van Gansewinkel and Umicore is openly exchanged. One of the main targets of this project is to prove that the economic benefits can compensate the effort for proper information exchange. Figure 2 depicts the interaction between the companies involved in PRIME, regarding material, information and economic benefits that can result from a proper information exchange.

A future possibility to furthermore support the exchange of product information and the investment in ecodesign and tagging systems by the manufacturer is to set up a system where the manufacturer is directly compensated by the recycler, as illustrated in Figure 2. For example, a direct payment for access to product information can be an incentive for implementing sustainable product development, whereas the current system of "ecotaxes" in Belgium rather penalizes than promotes products with environmental friendly designs [25, 26]. In other words, the availability of the proper information to increase the efficiency of recycling can open opportunities for alternative business models which will improve the ecologic and economic benefits of recycling.

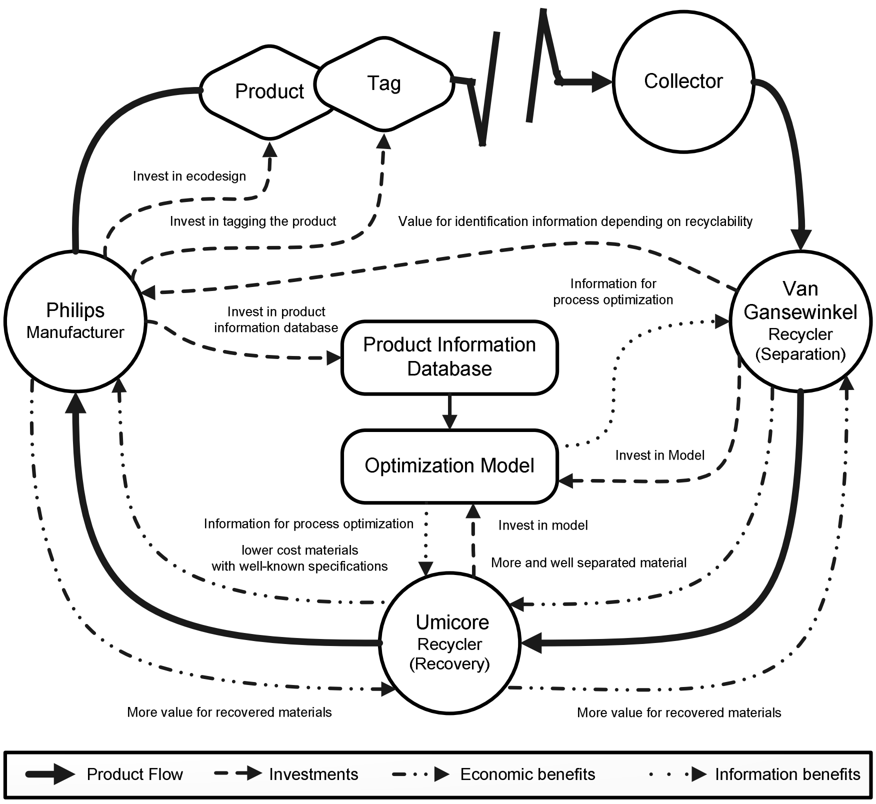

Figure 2: Flows of Information and economic benefits

5 Database Building

In the implementation of the database, materials are described using a standard taxonomy understood by all the involved parties unambiguously. For this purpose, as is done in other studies, the CAS number is used as a standardized naming system [27-29]. In the database developed for the PRIME project, the materials are furthermore organized in a hierarchical way, forming a parent-child relationship. This allows describing them at different levels of abstraction. The lowest level of abstraction is the chemical constitution of a material and all higher levels are based on physical properties of the materials. In this way, the hierarchical structure can also be used for modeling physical and metallurgical separation processes. This material database also forms the basis for building material compatibility matrices and separation matrices, which allow calculating the cost and revenue for the treatment of materials based on the purity of the streams. In a later phase, the database can provide economic and environmental advice for EoL scenarios of different products.

The structure of the product is described hierarchically in the developed database in order to reflect the structure present in the Bill of Materials (BOM) of the manufacturer, grouping components by functionality. The lowest level in this hierarchical structure is denominated 'Component', and represents elements that cannot be further disassembled considering non-destructive techniques. Connections between components are included in the product description generating a network structure. In this network structure, the product is described as relations between three elements: components, cables and connectors as encountered at the EoL by the recyclers.

Figure 3 shows these elements. In this database, a connection is the relation between two or more components joined by one or more connectors. In order to calculate the cost of releasing a connection, the following parameters were included for the connectors: Type of connector (e.g. Integral attachment, Energy bonding, Adhesive bonding), Quantity of connectors, Accessibility, Visibility, Force, EoL condition, and the direction of disassembly (±X, ±Y, ±Z) [30]. The relation between the different connections of components is preserved by including information on which connections obstruct others. This information allows determining different disassembly sequences or ways to extract a specific component. Finally, information about the materials of connectors and components is also included in the database. As a result of this generic way of describing a product, alternative ways of disassembly can be considered in a model using this database.

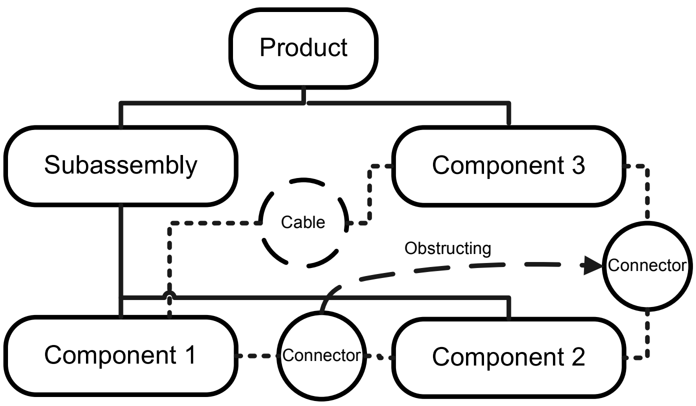

Figure 3: Database structure

6 Conclusion

To improve, from a C2C point of view, the recyclability of materials by preventing downcycling and closing the material loop, it is imperative that all the actors of the product life cycle actively cooperate. The first step for implementing this interaction is to understand which information is required for adding value to the EoL treatment. Secondly, the product information, which the manufacturers can collect in cooperation with their suppliers, should be structured in an unambiguously interchangeable way. An opportunity for manufacturers, who have this product information in such a well structured way, is that they can sell it to the recyclers, as it can improve the recycling output. Such a system can give an incentive to the manufacturer to invest in product design and product identification systems to allow a better recyclability. The database presented in this paper is the first step within the PRIME project to enable such an information exchange between the manufacturing and recycling companies involved in the project. The main characteristics of the developed database are the standard hierarchical material taxonomy and the generic network structure adopted to describe flat screen televisions. The advantage of this generic database structure is that it enables to consider alternative ways of disassembly. This database is also the foundation for the further development of a mathematical model for optimizing the EoL treatment from an economical and environmental point of view.

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