Partners for Innovation

Case study of set-top boxes in a circular economy

Refurbishment and remanufacturing potential and critical raw material opportunities

Flora Poppelaars | Partners for Innovation

Commissioned by: Joëlle Bosten & Mireille Reijme | Rijkswaterstaat

Rijkswaterstaat carried this out on behalf of the Dutch Ministry of Infrastructure and Water Management.

Content

1. Introduction

1.1. Context and objectives

Electrical and electronic equipment (EEE) is composed of up to 60 elements from the periodic table, including hazardous and scarce materials (Baldé et al., 2017). These materials have a great impact on life due to their energy-intensive extraction and currently inadequate end-of-life processing. As EEE is the world's fastest-growing domestic waste stream (PACE, 2019), their issues are exacerbated. For instance, with increasing material scarcity, critical raw materials (CRM) vital to the core functions of EEE will become more expensive, have greater price volatility, and hinder competitiveness (Rabe et al., 2017).

In view of European legislation (e.g. Critical Raw Materials Act and Ecodesign for Sustainable Products Regulation), it is essential to comprehend design trade-offs with regards to CRM in EEE. Insights from service providers across the circular value chain are needed to grasp how to deal with ecologically relevant, strategic and critical raw materials and recycled content throughout the EEE's lifecycle.

The objective of this study is to gain a better understanding of the design considerations related to refurbishment and remanufacturing and their implications for policy makers. To this end, the case of set-top boxes (STB) is analysed.

1.2. Methodology

Frank Röpke (Business Development Director) and Hugo Wentzel (Global Account Director) of Reconext, a post-sales service provider, were interviewed to learn from practice. The interview was conducted using a semi-structured interview guide.

In addition, desk research was performed to further uncover different facets of the case study of STB.

1.3. Outline

This report first introduces STBs, their product architecture, material composition and typical life cycle (Chapter 2).

It then dives into Reconext and their circular activities (Chapter 3). Drivers and barriers to these activities regarding the products, services and systems around them are discussed.

Finally, implications for Original Equipment Manufacturers (OEMs) and policy makers are reviewed (Chapter 4).

2. Current set-top boxes

2.1. Description set-top boxes

Set-top boxes (STB) are devices sitting on top of television-sets (so to say) and connecting televisions to external sources of signal. It decodes the signal in a manner that can be displayed on television screens. The result is, for instance, in video, audio, or webpage format. The decoded signal can come from cable, satellite, phoneline, ethernet, etc.

The product comes at different complexity levels. The 'Preparatory Study for eco-design requirements of EuPs Lot 18: complex set-top boxes' [1] distinguished two main categories of STBs: 'simple STBs' and 'complex STBs'. Simple ones are FTA (free-to-air) receivers enabling to show unencrypted TV channels. More complex ones include a smartcard or other slot, or recorder.

2.2. Product architecture

Complex STBs are composed of the following components visualized in Figure 1.

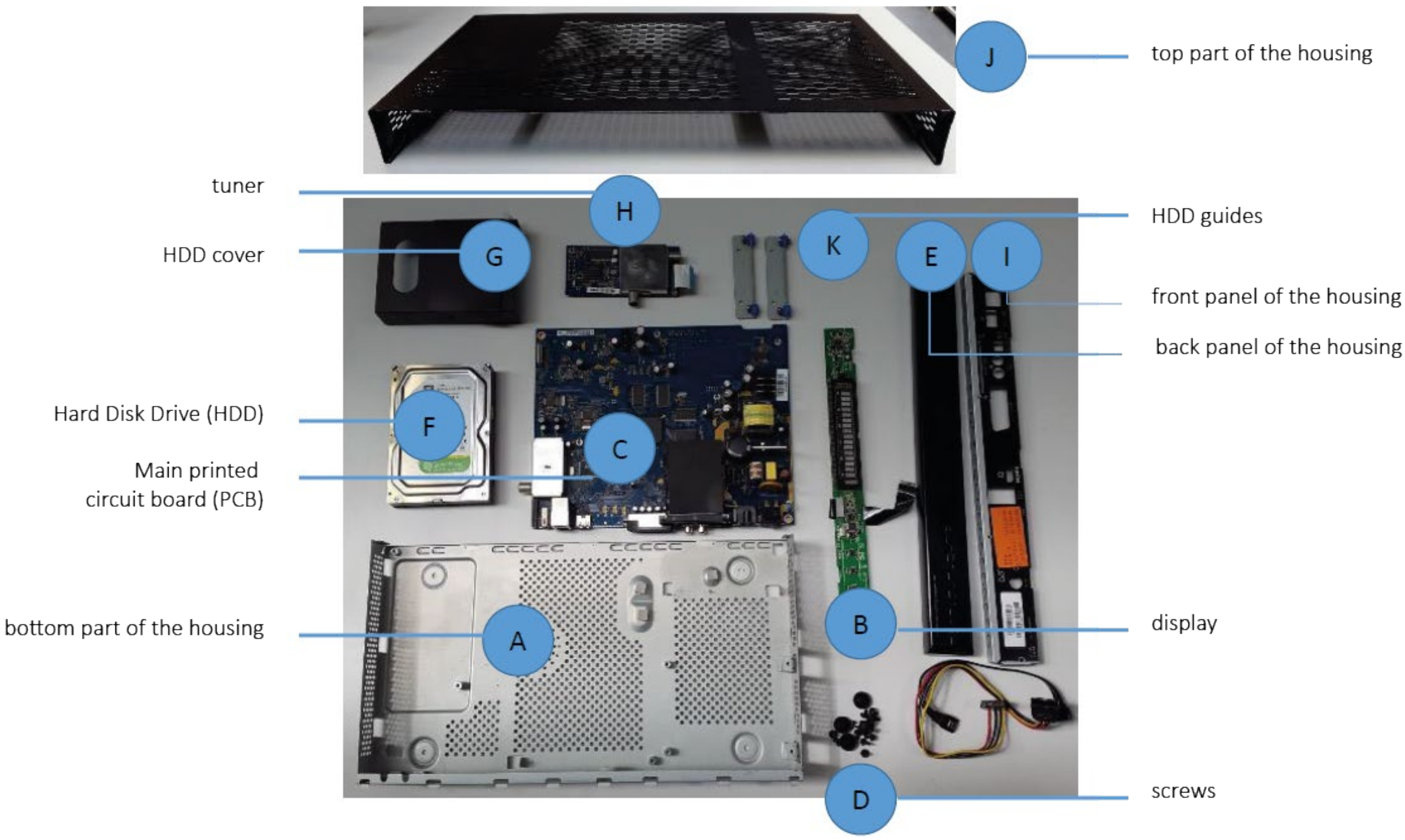
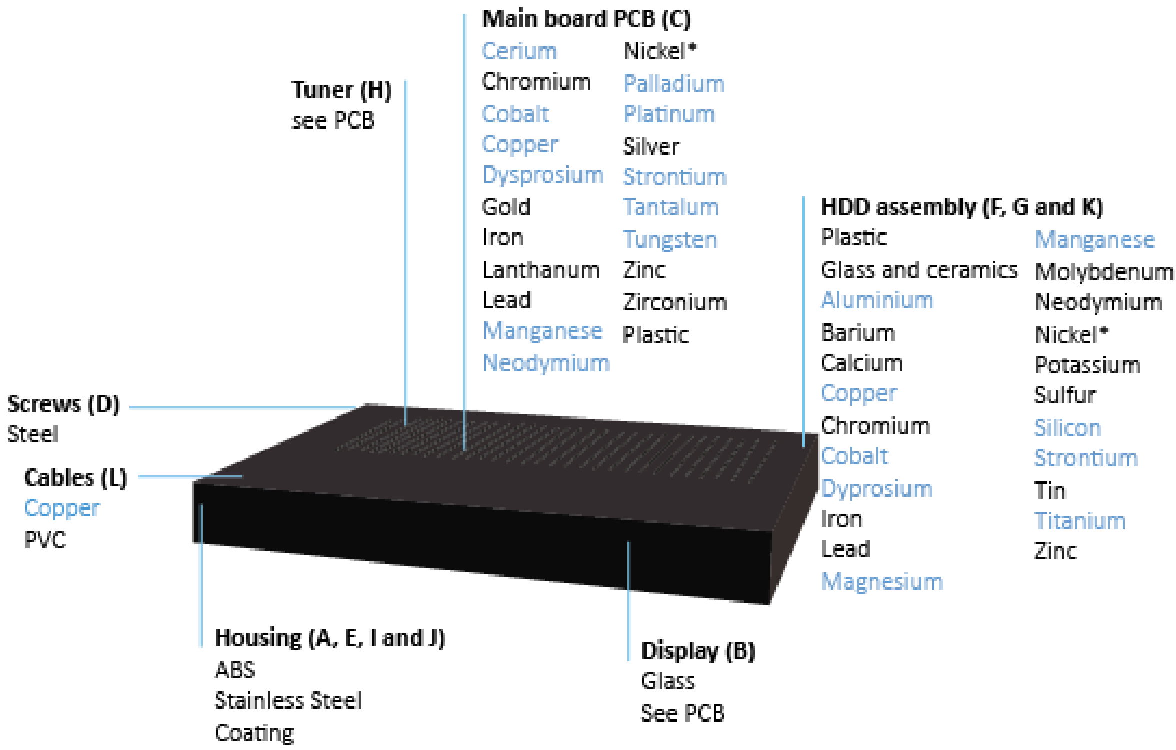


Figure 1. Main components of a complex STB. Source: Reconext

The STBs are delivered to the consumer within their packaging, have a user manual and can be accompanied by a remote control.

2.3. Material composition

The material composition of STBs is shown in Figure 2 based on a typical bill of materials (BOM). A BOM is a list of the raw materials, (sub-)assemblies, (sub-)components and their quantities required when manufacturing a product. Reconext provided several BOMs (see Appendix A) and the specific material composition of PCBs was complemented with research papers and reports [1, 2, 3]. Strategic and Critical Raw Materials as defined in Annex II of the Critical Raw Materials Act [4] are indicated in blue.



** Assuming the nickel is not battery grade (battery grade nickel is in Annex II of the CRMA)*

*** As no detailed BOM of a tuner was found, it is assumed that the material composition is comparable to that of the main board PCB*

Figure 2. Material composition of a STB

2.4. Typical lifecycle of set-top boxes

Acquisition

In contrast to other electronic devices that are sold from retailer to consumer, STBs are usually provided to consumers as part of a service. Service operators (e.g. Sky, Orange or KPN) will send or install the STBs for their customers to be able to enjoy their services.

Lifetime

The typical economic lifetime of STBs is estimated at 3-4 years [1, 5].

End-of-use

The flows of STBs at the end-of-use are visualised in Figure 3. Further research is required to quantify the streams.

Figure 3. Flows of STBs at the end of use

- As the STB is provided as part of the service of the operator, it reaches its end-of-use after a couple of cycles at different houses, after 3 years or when it is upgraded by the operator. Roughly 15% of the install base returns on yearly basis to be reconditioned for reuse in a different household. Yearly, around 85% of the total install base will thus remain in use with the current consumer, but with time all the STBs of the install base will attain their end-of-use.
- When consumers change operators (i.e., ending their current contract) or get a device upgrade, **operators** can ask consumers to send back their STBs. Of these returned STBs, approximately 1/3 is reused directly for another consumer, 1/3 is sent to be refurbished/remanufactured (i.e., newer models), 1/3 is directly scrapped and sent to recycling (i.e., older models). More recently operators will not collect the devices intended for scrap, consumers are asked to utilize national collection schemes (e.g. at collection points organized by Stichting OPEN in the Netherlands).
    - In the case of refurbishment/remanufacturing, the STBs are sent to after-sales partners like Reconext to ensure that as much value and utility is kept from the products, components and materials. Depending on the residual value and needs of the operator, the products will be prepared for reuse, refurbished, remanufactured and recycled. More information on these processes is provided in Chapter 3. Scrapped devices are directly sent to a recycling partner.
- When the STBs are not returned to the service operator at the end-of-use, consumers can bring them to their local waste centre or waste electrical and electronic equipment (WEEE) collection points managed by the **national producer responsibility organization** (PRO). The STB will then be mixed with a variety of WEEE streams. The recycling process in advanced EU recycling facilities will follow the steps visualized in Figure 4.

- A share of the STBs is expected not to be returned into the loop and will be **lost in municipal household waste**. It was estimated that the landfill ratio (i.e., products that are not recovered) is 28% [1].

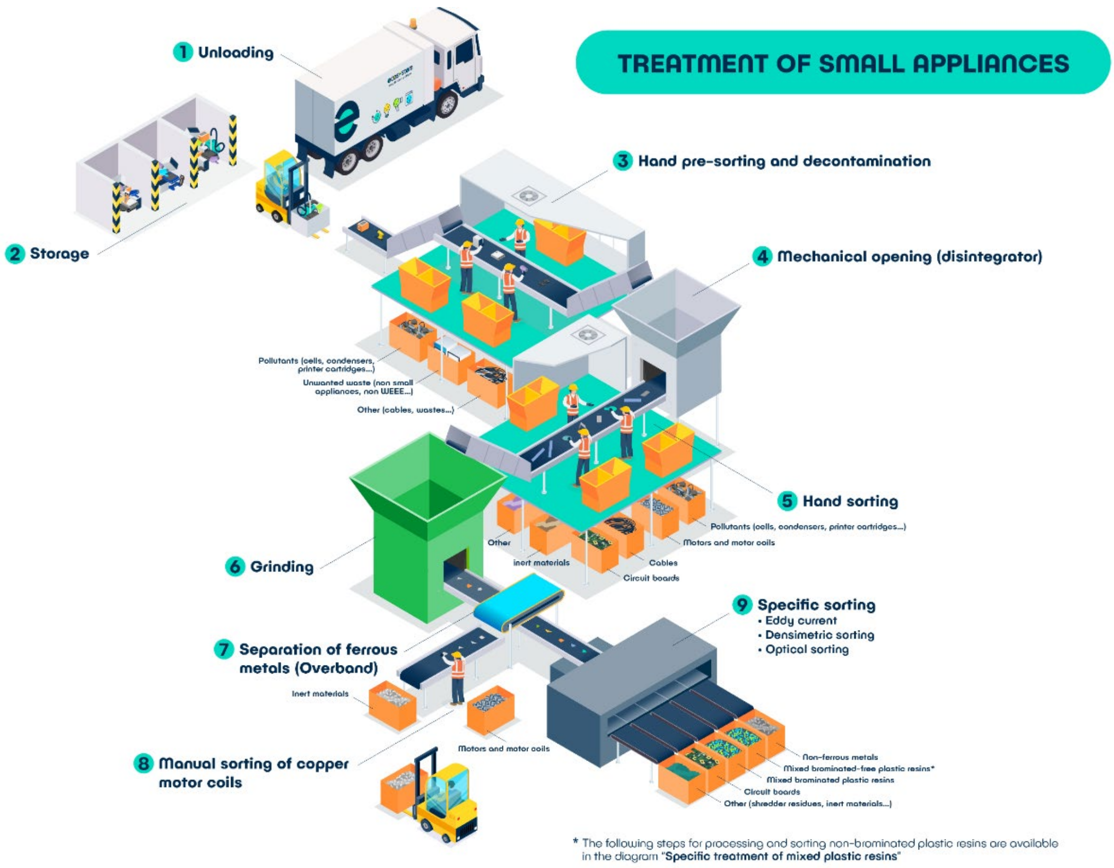


Figure 4. WEEE recycling process for small appliances at advanced EU recycling facilities. Source: ecosystem [6]

3. Repair, refurbishment and remanufacturing of set-top boxes

To combat losses in value, several companies such as Reconext ensure that IT products are used longer. In this chapter, the company and their circular activities are presented. Drivers and barriers stimulating or impeding these circular activities are then listed.

3.1. Reconext

Reconext started as a traditional repair company for televisions (which used to be called Teleplan). Since then, they have expanded their post-sale services to prepare for reuse by refurbishing and remanufacturing all types of devices. This includes consumer products such as laptops, as well as less visible products such as network and data storage solutions (e.g. servers and solid-state drives) and Customer Premises Equipment (CPE) from operators (e.g. set-top boxes and modems). Their customers include manufacturers, operators of cable, satellite, and mobile devices, retailers, and insurers.

3.2. Reconext's circular activities

Reconext does not make new products, but ensures that as many used devices, components and materials as possible are given a new life. The process is as follows:

Step 1. The needs of the customer (e.g. STB service operator) are discussed. What functions are the products expected to retain? To what extent should the product be refurbished or remanufactured? What is economically acceptable? The services are not always performed for a customer. On some occasions, Reconext purchases devices and can consequently choose how to proceed beyond the requirements of customers.

Step 2. The value retention processes are prepared. Typically, the STB will be provided in batches. Based on the expressed needs, the specific STB are analysed. The product architecture, components and materials are identified (with or without manuals provided by the customer). The varying scale of the technical quality of the products and components is evaluated (e.g. wear and tear, defects, poor maintenance, and aesthetics). Based on these findings, the required level of value retention is defined and test benches are developed using a list of criteria.

The used devices sent by Reconext's customers are usually not made to be repaired, reconditioned or recycled. The company therefore develops its own test benches and dismantling lines to get to know the products better and to leverage the residual value as much as possible. They share their knowledge about product architecture, standardization, disassembly and vulnerable parts with customers to promote Design for Repair, Refurbishment and Remanufacturing.

Step 3. Employees evaluate the state of the STBs in the test benches according to the set criteria. Depending on the assessment, the product is sent through a different process.

Step 4. The value retention is done in 4 different ways.

- The company tests and evaluates the products received and performs complete **repairs** of broken or defective components.
- The **refurbishment** process involves minor cosmetic or functional interventions on the products, such as replacing a battery or refinishing the surface. Reconext inspects and assesses the products received, cleans and refurbishes them, and takes care of repackaging, aftermarket sales and warranty management.
- Through a **remanufacturing** process, an old product can be restored to its original (or even better) condition, performance and warranties with as few new components as possible. These components then come from various old products (also known as 'part harvesting').
- Components that can no longer be used or repaired are **recycled** by partners.

3.3. Drivers to circular activities

These circular activities are driven by various factors:

- **Economic value** is the most important driver. The value of STBs is not considerable in itself, but with volumes come cost effective processes. The larger the batch of product to be processed, the most interesting it becomes economically.
- **Environmental value**. Except for the top 3 operators, typical customers have not quantified their environmental impact. This is however changing as European legislation such as the Corporate Sustainability Reporting Directive (CSRD) is pushing for more thorough environmental reporting, setting objectives for the sustainability transition and a proper communication to consumers on the environmental impact of products. These reporting requirements cascade into the commercial department of the customers and influence procurement and tenders for circular processing activities. Some member states, for instance France with their AGEC law, even have legislation requiring public buyers to acquire a minimum percentage of reused/refurbished products or minimum share of recycled materials for certain product categories.
- **Scarcity**. When virgin resources become scarce, the importance of circular processing is accentuated. The disruption of supply chains was experienced recently during the covid-19 pandemic which impacted plastics production, use and waste. On the short term, the recycling of critical raw materials is challenging [7]. Geopolitics is driving a strategy transition. The Critical Raw Material Act is expected to change the impulse. Note that a combination of different circular strategies is needed to decrease the demand and improve the supply of CRM. Recycling alone cannot reach the required levels as illustrated in Figure 5.

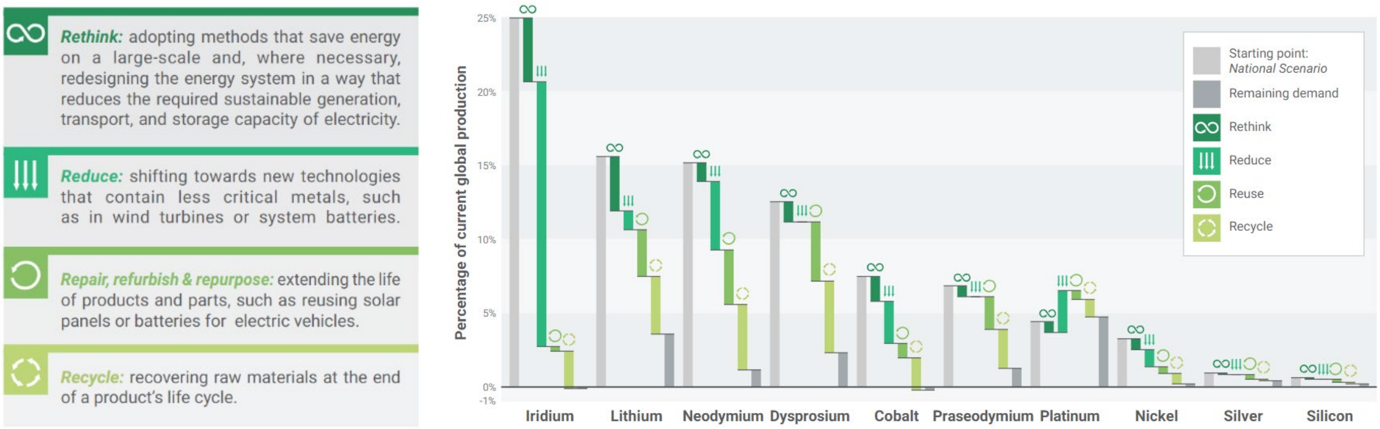


Figure 5. Potential of circular strategies in the case of critical metals for the sustainable energy system in the Netherlands in 2040-2050. Source: Metabolic, Copper8, Polaris Sustainability, Quintel and CML - Leiden University [8]

- **Social value.** Linked to the economic value, the circular activities can be performed in by people with disability and in prisons to promote inclusion.
- **Information.** More information on the product architecture and components is made available, which facilitates their circular processing. There used to be a lack of repair manuals and disassembly maps, and refurbishment entities were lucky to even see the product before reception. This is now changing thanks to e.g. EU legislation.

3.4. Barriers to circular activities

Nevertheless, various barriers hinder these circular activities:

- **Lack of available information.** Although more information on the devices is shared, not all the required data is available. To illustrate this issue:
  - Bill of Materials (BOM)are typically only at a component level and not at a material level. For example, this means that the BOM will mention components such as "housing" and "PCB", and not the materials they are made from (e.g. the specific plastics polymer, stainless steel and the coating in the case of the housing). Unravelling the exact material composition by characterizing and weighing the different chemical elements inside of the components is difficult. Printed circuits boards are essential parts with the most financial value and include CRMs in the different chips and other components soldered to the board. However no database characterizing their materials is available. Research projects such as Circular Circuits investigate this further.
  - Even with extensive testing, the exact lifespan of components remains uncertain. This data is important to assess the opportunities for component reuse.
  - The level of reusability of chips on PCBs is also still unknown. The reuse of components certainly occurs but is not explicitly mentioned.
- **Costs.** Moving away from the linear economy encompasses costs. Although repairing and refurbishing has a clear environmental benefit, it remains challenging to develop the most cost-effective processes based on the residual value. Investments are needed

to get to know the product and identify the best process steps as the product has not been designed with repair, refurbishment and remanufacturing in mind. Moreover, these circular processes are still considered ‘extra service’ by customers instead of an integral part of the service to consumers. The cost of virgin resources is relatively low, which stimulates the production of new products over value retention. It is for instance cheaper to extract virgin neodymium than to retrieve it from used products.

- **Behaviour: companies and consumers preferring new.** Another major challenge is to persuade companies and consumers that they do not need new products. Refurbished products can be just as good quality as new ones but are better for their wallets and the environment. Do new products really meet new needs? Can these needs also be fulfilled by refurbished products? Behaviour at the end-of-use should also change to increase collection rates and discourage physical destruction of e.g. storage equipment.
- **Scattered reverse logistics.** Operators used to recover their own products from the consumers at the end-of-use. However, it is no longer profitable to pick up products from consumers due to postal costs if they are not going to be used directly afterwards. Therefore, they are now relying on the national Producer Responsibility Organizations for their collection. As a result, the STBs end up in a mixed WEEE stream with diverse fractions with varying quality instead of the previously concentrated volume and high-quality product stream.
- **Adverse product architecture and design.** Certain design choices impede the circular processing of the products. The products can be difficult to open. While some products such as servers have been designed to be upgraded by the consumers and thus are made easy to disassemble, others (e.g. CPE and switches) are not. Moreover, marketing-driven design decisions (e.g. utilizing fabric in housings) can impede reuse. Also, some design choices to improve recycling (e.g. not using screws or coating) can hinder durability and the reuse of components. On top of this, the design of STB components is not standardized, which could help increasing volumes and thus decreasing costs. Complex set-top boxes are continuously updated. Without standardization, compatibility of STB components is problematic.
- **Uncertainties due to upcoming legislation.** Companies across the EU electronics value chain are aware of changes in the legislation but are uncertain about their implications and what is expect to come from policy makers in the near future. Investments in circular processing and design changes can thus be slowed down.
- **Quality control.** The refurbishment and remanufacturing activities depend on the product category and requirements of the service operator. The quality of the result can also vary depending on the service provider performing the circular activities.
- **Other factors.** Intellectual property and for instance the presence of a logo can hinder the reuse of components or the modification of products to make them fit for refurbishment and remanufacturing.

4. Recommendations

Based on the interview, various recommendations were drawn for OEMs and policy makers.

4.1. Implications for OEMs and brand owners

- Improve available information
    - The set-top box manufacturer/brand owner could be the orchestrator of all the parties in the value chain (e.g. firmware of operator, middleware, and collector of the STB). All the information required for the circular processing of end-of-use STB (including the availability of components, their reusability, the uncertainty about the lifespan of components, etc.) should be combined in digital product passports accessible to the circular processing service providers.
    - Going beyond digital product passports, manufacturers could provide more information about component/chip reusability in the product design itself. Colour coding (e.g. red for components containing hazardous substances and blue for critical raw materials) or number coding could help improve the products' potential for refurbishment and remanufacturing.
    - Ideally, repair manuals and disassembly maps would be developed for every product and accessible to the service providers. If not possible, the product to be processed should be available before batch reception so the service provider can study its product architecture and assess the required processing.
    - Some manufacturers could leverage their knowledge of the production process and the machines for the reversed process of disassembly. Apple for instance has disassembly robots to take apart mobile phones and their components [8]. For example, the tungsten and rare earth magnets in taptic engines are retrieved by their disassembly robot Dave [9].
    - Components reuse could be monitored to assess the potential of multiple use times. As a result, more knowledge could be shared on the lifespan of components.
    - Inspiration could be drawn from the automotive industry with their International Material Data System (IMDS). Manufacturers have jointly developed a database collecting all materials utilized in automobile manufacturing. This effort may however be very challenging for the EEE industry due to the number of manufacturers and importers.
- Costs
    - Driven by their commitment to sustainability, frontrunners such as Sky, Orange and KPN see the value of circular processing and have internal and external buy-in. Circular activities are considered production units, not as an extra service. They therefore dare to invest in the processes and ensure that the most circular processing principles are applied (i.e., not only repairing and refurbishing but also making sure that the residual fractions are recycled).

  - Certain critical raw materials are essential to produce STB components and assemblies. To avoid disruptions and secure the CRM/relevant components, repair, refurbishment and remanufacturing activities could be leveraged.
- **Foster behaviour change.** Recent research on behaviour change can help brand owners to guide their customers towards refurbished electronics [11, 12] and collection solutions [12, 13].
- **Design STBs for repair, refurbishment and remanufacturing.**
  - Products should be designed taking circular design guidelines into account [14]. Think for instance of modularity, enabling easy disassembly and enabling component replacements and upgrades.
  - To avoid marketing-led design decisions negatively impacting the refurbishment and remanufacturing potential of products, designers' and engineers' Key Performance Indicators (KPIs) could be linked to sustainability and circularity.
  - Designers and engineers need to be aware of the different use lives of their products, (sub)assemblies and components. They could further research the state of the components after use and experiment to what extent they can be reused. Hotspot mapping could for instance be used to enable critical and strategic components to be disassemble first and easily [15].
  - Manufacturers and brand owners can ask partners such as Reconext for advice on their products' refurbishment potential to improve their designs and their resellability.
  - The technical maturity of STBs and their components should be further studied.
  - Manufacturers and brand owners could collectively initiate the standardization of parts of the STB.
- **System organization.** From the standpoint of the refurbisher and remanufacturer, large volumes of a components (i.e., thousands) will enable cost-effective processing. Ideally, service operators having the relationship with the consumer would make the return of STBs after use compulsory. The collected STBs from one specific brand would then be stored until a large enough batch is returned for processing.
- **Novel business models.** In line with this, manufacturers could ensure the return of their components and products through the implementation of novel business models. Chips-as-a-service would for instance enable the use of chips on PCBs for a certain price per month and would make their return after use obligatory.
- **Quality control of refurbished STBs.** Currently the term refurbished can be employed to refer to a myriad of interventions, which results in different quality levels. To avoid discrepancies in the quality of refurbished STBs and negative consumer experiences, OEMs and circular service providers could agree on quality control criteria for refurbished STBs. Techniek Nederland, a Dutch business association of technical service providers, for instance developed the Refurbished quality mark for mobile phones. The quality mark assures consumers that the product had been controlled on at least 50 criteria and that the service providers can be audited. This would enable a formalized definition of the term refurbished for STBs.

4.2. Implications for policy makers

- **Improve available information.** Policy makers could make teardown manuals compulsory for OEMs and brand owners to be shared with circular service providers. These manuals would describe how to disassembly the product and include zoomed-in photos of chips to see exactly what the components are.
- **Reduce costs of refurbishment and remanufacturing.** Rather than taxing labour, the taxation of raw materials use could encourage refurbishment and remanufacture, and reduce the use of virgin material. The environmental value would therefore be reflected more in the financial value of the product.
- **Circular product architecture and design.**
  - If manufacturers want to reuse harvested components or use the recycled materials of circular service providers, they could be obliged to reduce the time needed to disassemble their components and/or products.
  - Specifying the framework within which designers and engineers should design does not have to be entirely standardized as this would be too limiting.
  - A repairability index is important to instil repair thinking into design practices and enable to measure the progress.
  - There are tensions between design guidelines for repair/refurbishment/ remanufacturing, and recycling (e.g. use of screws to foster repeated assembly/disassembly but impede recycling versus use of snap-fits that can break easily). Recycling is the loop of last resort. As seen for the case of the Dutch sustainable energy system, a combination of the different circular strategies is needed to improve the supply of CRM and decrease their demand [8]. Legislation should not merely focus on recycling targets and design guidelines. Repair, refurbishment and remanufacturing activities extend the lifespan of products and components and thus retain more value and utility than recycling.
  - When defining a minimum lifespan, make a distinction between product and component level. This could stimulate the further reuse of components that have not attained their expected lifespan yet.
- **System organization.** Reverse logistics is crucial to achieve scale. By paying a fee to producer responsibility organizations, the responsibility to collect operators' products can be thought as "dealt with". Policy makers could incentivize service operators to make their customers return their STBs after use.
- **Refurbishment and remanufacturing standards.** Support the development of refurbishment and remanufacturing standards. Encourage business associations to develop such standards for STBs and organize audits. Having standards could help improve consumers' trust in refurbished products [12].

References

[1] Bio Intelligence Service & Fraunhofer IZM, “Preparatory Study for eco-design requirements of EuPs Lot 18: complex set-top boxes,” 2008.

[2] M. Ueberschaar and V. Rotter, “Enabling the recycling of rare earth elements through product design and trend analyses of hard disk drives,” *Journal of Material Cycles and Waste,* pp. 266-281, 2015.

[3] S. Owada and T. Nakamura, “Novel pretreatment process of critical metals bearing e-scrap by using electric pulse disintegration,” *Journal of Sustainable Metallurgy,* 2018.

[4] European Parliament and Council, “Critical Raw Materials Act,” *Official Journal of the European Union,* 2024.

[5] Reconext representatives, *Activities of Reconext.* [Interview]. 18 January 2024.

[6] Ecosystem, “Understanding recycling,” [Online]. Available: https://en.ecosystem.eco/en/article/understanding-recycling. [Accessed January 2024].

[7] European Commission, “Study on the critical raw materials for the EU,” 2023.

[8] Metabolic, Copper8, Polaris Sustainability and CML - Leiden University, “Towards a circular energy transition - Exploring solutions to mitigate surging demand for critical metals in the energy transition,” 2021.

[9] C. Rujanavech, J. Lessard, S. Chandler, S. Shannon, J. Dahmus and R. Guzzo, “Liam - An Innovation Story,” 2016. [Online]. Available: https://www.apple.com.cn/environment/pdf/Liam_white_paper_Sept2016.pdf. [Accessed 12 05 2024].

[10] Apple, “Apple expands the use of recycled materials across its products,” 19 April 2022. [Online]. Available: https://www.apple.com/ma/newsroom/2022/04/apple-expands-the-use-of-recycled-materials-across-its-products/. [Accessed 12 May 2024].

[11] ReCIPSS, “Publications,” [Online]. Available: https://www.recipss.eu/publications/. [Accessed 12 May 2024].

[12] T. Wallner, Consumer centric design for refurbishment - How designers can enhance consumer acceptance of refurbished products, Dissertation: Delft University of Technology, 2023.

[13] F. Poppelaars, “Design for divestment in a circular economy,” *Sustainability ,* 12(4) 2020.

[14] J. Macleod, Endineering, 2021.

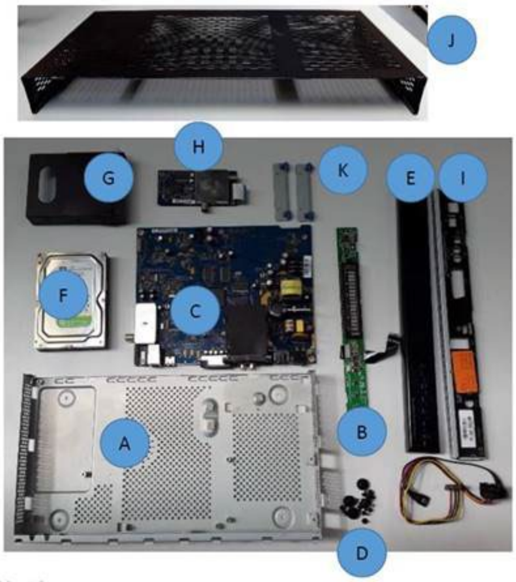
[15] Delft University of Technology, “Our courses on Circular Economy,” [Online]. Available: https://online-learning.tudelft.nl/topic/circular-economy/. [Accessed 12 May 2024].

[16] B. Flipsen, C. A. Bakker and I. C. de Pauw, “Hotspot Mapping for product disassembly: A circular product assessment method,” in *Electronics Goes Green 2020+ (EGG): The Story of Daisy, Alexa and Greta*, 2020.

Appendix A

Detail

Ref	Component	Details	Weight (g)
A	Bottom	Steel	713,2
B	Display	PCB	78
C	Main Board PCB	PCB Inc. Heat sink	489,6
D	screw	Steel	8,5
E	Front panel	Plastic	86,5
F	HDD	Steel	444,4
G	HDD cover	Plastic	56,6
H	Tuner	PCB	67,7
I	Back panel	Steel	146,3
J	Top	Steel	513,2
K	HDD guides	Steel	45,3
L	Cables		38



Private & Confidential