DESIGN FOR RECYCLING

Practical guidelines for designers

DESIGN FROM RECYCLING

PolyCE

GUIDELINES FOR ELECTRICAL AND ELECTRONIC EQUIPMENT

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GOOD DESIGN DELIVERS VALUABLE SOLUTIONS DURING *AND* AFTER USE

CONTENTS

INTRODUCTION & OBJECTIVES

A world without plastic is unthinkable nowadays, and for most of us plastics have become part of everyday life. In the space of about seventy years, the production of plastic has increased from 1.5 million tonnes in 1950 to 368 million tonnes in 2019[1]. Today, in Europe the plastics industry has a yearly turnover of more than 360 billion EUR and the sector employs more than 1.6 million people[2].

2019
368 million tonnes

–

Annual global plastics production

–

1950
1.5 million tonnes

Our society has benefited tremendously from the plastics revolution and the large number of functions this material offers. Nowadays, plastics can be found in all kind of sectors and in countless applications. While innovation in the plastics industry makes it possible to use less for the same functionality, the increased diversity and complexity of plastics used in today's products, such as electrical and electronic equipment, has a huge downside at later stages of the product's lifecycle. It has complicated the opportunity to reuse or recycle them.

As a result, the waste streams generated are of growing concern. Waste electrical and electronic equipment (WEEE) is considered one of the fastest-growing waste streams in the EU[3] and globally. According to the latest Global E-Waste Monitor, a record 53.6 million metric tonnes of electronic waste was generated worldwide in 2019[4].

Today, the main economic driver for WEEE recycling is based on recovering precious metals such as gold, silver or palladium and copper. The recycling of the electronics' plastic housings and inner parts is a major challenge, since the plastics used are composed of a complex mix of many different polymers and additives.

In 2018 the European Commission (EC) has, as part of the first European Circular Economy Action Plan (CEAP), adopted a Europe-wide Strategy for Plastics in the Circular Economy. This strategy has the ambition to transform how plastics and plastics products are designed, produced, used and recycled in the future. And on top of that the EU has set the ambitious goal that ten million tonnes of recycled plastics should find their way into new products on the EU market by 2025. This is more than double the usage compared to the almost four million tons in 2016[5].

The European Commission recently also published a second Circular Economy Action Plan (March 2020), which puts a strong focus on resource intensive sectors, such as electronic devices made out of plastics.

More than 80% of the environmental impact of a product is determined at the design stage[6] and the concept of design for recyclability is a particularly important part of the EU plastics strategy.

Therefore, the initial design of electrical and electronic equipment is key for being recycled at their end of life and design for recycling concepts are needed to meet the recyclers' feedstock requirements.

However, not only design FOR but also design FROM recycling strategies play a key role in closing the material loop and reaching the EC's 2025 target. Today, most of the recycled materials are used in so-called 'bulk products' in construction, transport or infrastructure facilities and mainly for (low) quality reasons. To achieve sustainability-oriented innovation within the plastics industry guidelines and development standards on environmentally conscious design and achievable quality are needed.[7]

Such guidelines are also important to increase the share of recyclates in higher-value applications, such as consumer devices and electronic equipment.

The guidelines we present you in this book are developed to help designers and manufacturers integrate life cycle thinking in the design of electronic products. It considers the Design *for* and Design *from* Recycling strategies, two fundamental approaches to understand circular product development. The guidelines are a result of the Horizon 2020 PolyCE project; a collaboration of European universities, research institutes, recycling- and design companies. They can be used by designers and manufacturers of electrical and electronic equipment to advance in their sustainability goals.

MORE THAN

80%

OF THE ENVIRONMENTAL IMPACT OF A PRODUCT IS DETERMINED AT THE DESIGN STAGE.

1. Plastics Europe, 2020. Plastics – the Facts 2020: An analysis of European plastics production, demand and waste data. www.plasticseurope.org/en/resources/publications/4312-plastics-facts-2020
2. www.plasticseurope.org/en/resources/market-data
3. https://ec.europa.eu/environment/waste/weee/index_en.htm
4. www.itu.int/en/ITU-D/Environment/Documents/Toolbox/GEM_2020_def.pdf
5. EC (2019) - Assessment report of the voluntary pledges under Annex III of the European Strategy for Plastics in a Circular Economy
6. https://ec.europa.eu/jrc/en/research-topic/sustainable-product-policy#:~:text=The%20Ecodesign%20of%20Energy%2DRelated%20Products%20(ErP)&text=It%20is%20estimated%20that%20over,throughout%20their%20entire%20life%20cycle
7. See CEN-CLC/BTWG 11 – Sustainable Chemicals: past and future initiatives

DESIGN *FOR & FROM* RECYCLING

DESIGN *FOR & FROM* RECYCLING

Four years ago, a consortium of 20 expert organisations joined forces to investigate how to improve the circular use of plastics in products. Our goal was to significantly reduce the use of virgin plastics and increase the use of recycled plastics in electronic devices.

This project, called the PolyCE project, was commissioned and funded by the European Commission and presented a challenge to transform the lifecycle of plastic materials used for electronic devices into a sustainable one. Within the PolyCE consortium we looked for solutions to (better) recycle the fast-growing amounts of plastics from e-waste (waste caused by electronic devices). This waste consists of different kinds of plastics and the challenge is to better facilitate separation and maintain material purity in recycling processes. These guidelines are based on the results of the PolyCE project executed between 2017 - 2020 and reflect the status at this moment in time.

WHO IS THIS BOOK FOR?

The guidelines in this book are developed for a specific group: designers and engineers of electronic devices. The guidelines focus on circular plastics design and explain how to design plastic housings and inner parts in a circular manner.

EU DEFINED PRODUCT CATEGORIES FOR RECYCLING

The waste stream resulting from electrical and electronic equipment has been divided by the EU into six categories. The treatment of waste in each category requires different steps and the six categories help to organise the recycling streams and processes. As a result the waste input for recycling is clearly organised when entering recycling. The benefit is that processing becomes easier and the clustered waste streams contain less variety in material types. The categories have specific recycling challenges of their own and to make your product fully circular you need to know which challenges apply to your product category. The first step is to match your product to the right category and investigate how the recycling system is organised to determine what rules to apply.

Figure 2.1 shows the waste categories as defined by Directive 2012 - 2019/EU of the European Parliament and of the Council of July 4, 2012 on Waste Electrical and Electronic Equipment (WEEE).

The guidelines we developed focus on how to improve the circular design of plastic product housings and inner parts; two product elements that end up in all these recycling categories. Developing a fully

Fig. 2.1 WEEE Recycling categories defined by the EU

circular product incorporates a broader complexity of topics and these differ by category. For example, a fridge uses different technologies (including e.g. cooling liquids) and materials to meet the product requirements compared to a hairdryer.

Our guidelines are a first step on the road to a complete set of instructions which in the end are needed to cover each product category. Be aware that starting your own circular development activities will provide you with unique learnings and will involve collaboration with the recycling industry. This market is very much in development, not all rules are known and your actions will contribute to build crucial knowledge and partnerships.

Listed in the appendix of this book you can find a list of experienced recyclers to connect with. Their insights and know-how will provide important inputs to your own activities. If you would like more information on recycling guidelines for PCB's, electronic components, cables and wiring, metals and gases & liquids we recommend you visit www.eera-set.eu. This will give you an overview of the current recycling market. As we will work our way towards giving you practical guidelines for product design, keep in mind that the new product also needs to be viable and has a matching business case.

Always follow an integrated approach to find answers to:

- what and how to design on a product and part level
- how to recycle or reuse the materials
- ensure waste recovery (WEEE recyling) takes place in a realistic manner and delivers value.

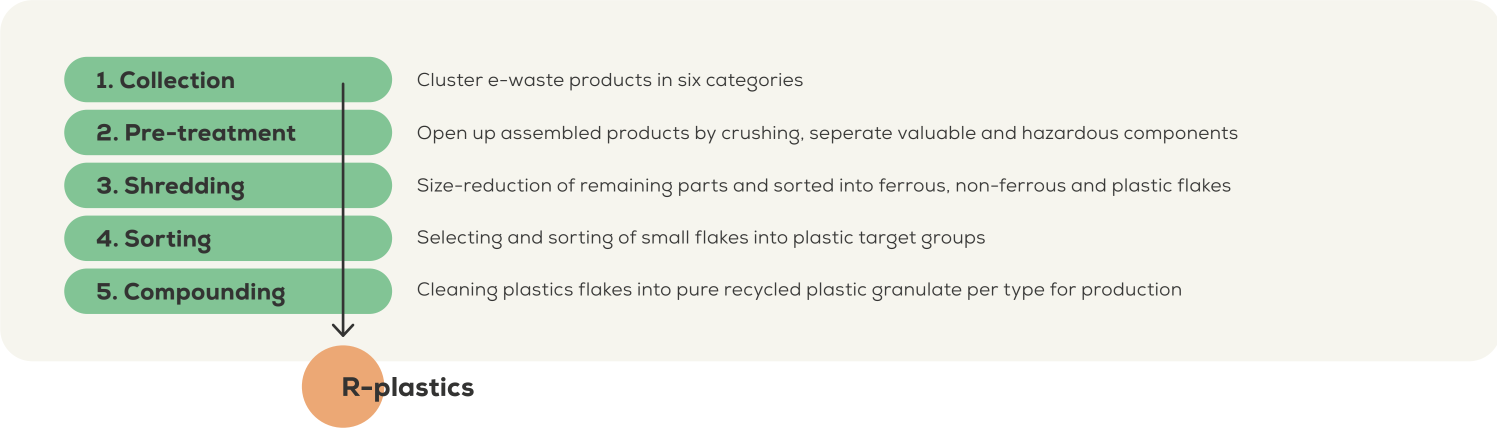
Your goal in the end should be to work towards a sustainable and functional system for your company. A system that extracts maximum value from waste by supplying material to reuse in desired qualities, or creates value from the recycling steps developed to prevent pollution.

HOW PRODUCT RECYCLING IS ORGANISED

It's important to note that the six product categories for recycling may not be fully operational to the extent that you might need. This means that when you have determined the category of your product you need to investigate how material recycling is organised or needs to be organised. Once this is clear you can define your products' recycling strategy and understand what Design *for* Recycling rules to apply.

Let us look at an example;
in Category 5 - Small Equipment, the end-of-life products are usually not disassembled (taken apart). Figure 2.2 shows the steps in which the e-waste is processed and transformed into bulk material for reuse.

Fig. 2.2 Recycling steps



1. COLLECTION
Stores, municipalities and companies collect and cluster electronic devices (e-waste) following the six EU categories.

2. PRE-TREATMENT
Open up assembled products by crushing them, manual sorting and collecting separate components such as batteries, capacitors, toner cartridges, impurities (e.g. wood and paper) and hazardous elements (e.g. chemical liquids). Collection of valuable items like pcb's and electric motors.

3. SHREDDING
Shredding of remaining parts. Liberation and sorting of ferrous, non-ferrous materials and plastics. The metal fractions are seperated and sent to the metallurgical industry for further treatment.

4. SORTING
Fine shredding of plastics into small flakes, to be sorted in pure polymer fractions, such as PP, PS, ABS, PC/ABS, PC. Remaining polymer types and flame retardant flakes (not valuable for recycling or regulated by legislation) are disposed of or incinerated.

5. COMPOUNDING
Cleaning and preparing of recycled plastics to be suitable for new products.

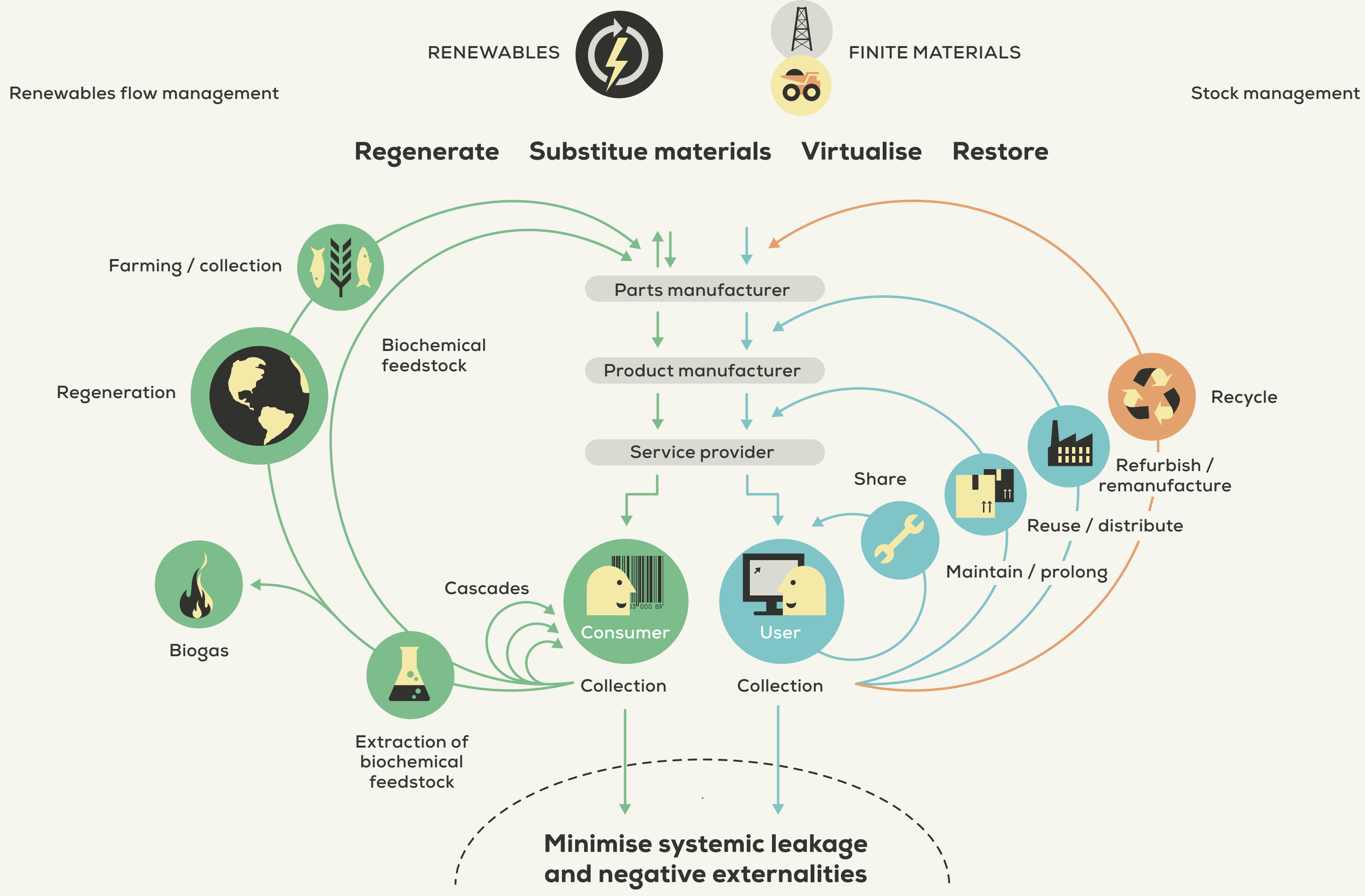
Knowing that Small Equipment will be shredded at end-of-life means that applying design *for* recycling rules to the design of the plastic parts should result in an easier collection of all plastic types used in the product. Doing so you will enable the recyclers to collect the plastics in their process easier and in a way that enables the material to keep its original qualities as much as possible. This makes them better fit for reuse in more product categories as their quality is less polluted and closer to its virgin version.

In order to successfully design a circular product using Design *for* Recycling principles you need to determine how the parts of the product can best be reused. Recyclability has to be a mandatory product requirement for development. Note that in order to determine your products' circularity completely you need to investigate more than the Design *for* Recycling and Design *from* Recycling principles described in this book.

The model made by the Ellen McArthur Foundation and shown in figure 2.3 gives a good overview of the total circular economy system. Our guidelines are a part of the recycling section highlighted in red. More information on the full scope of circularity can be found on their website www.ellenmacarthurfoundation.org.

RECYCLABILITY HAS TO BE A MANDATORY PRODUCT REQUIREMENT

Fig. 2.3 Full circular eco system by Ellen McArthur foundation



CIRCULAR PRODUCT DESIGN & CIRCULAR PLASTIC DESIGN

Applying circular thinking in product development and production is currently experiencing a growing interest. The main reasons to act more sustainably are driven by economic, political and personal motives. The combination of these drivers creates the balance that is needed to make circular design and production profitable. These drivers are:

- a growing consumer awareness to use resources in more sustainable ways
- political agendas to reduce CO_2 and pollution levels
- economic drivers to recycle materials for reuse

According to the World Economic Forum, the amount of e-waste will increase from 50 million tons today to 120 million tons in 2050. Today, the main economic driver for WEEE recycling stems from the recovery of precious metals such as gold, silver, palladium and copper. The recapture of these obvious valuable materials from pcb's is already happening through what is called an 'urban mining' process (mining from e-waste). The downside however is that this process often leaves other potentially recyclable materials like plastics go to waste due to their lower economic value. One of the important things to do to harvest these materials for reuse is to change the way we design products. Design them *from* Recycled materials and *for* Recycling at end of life. A development approach which is getting more traction by the commitment of OEM manufacturers and the EU (see Circular Plastics Alliance).[8]

Applying this approach successfully will create new economic value; recycled plastic materials will retain more of their original quality (close to virgin plastics[9]) and pollution is prevented on multiple levels by making them suitable for re-use.

The guidelines in this book focus on implementing circular thinking in a step-by-step manner. They help you to build a bigger picture of positive impact, to create improvements by learning, to make and implement circular solutions into your design and mass production processes.

UNITING TWO WORLDS

Before we dive into the guidelines that will help to start implementing circular design activities, let's introduce the two main design approaches you can choose from and their context. The approaches to choose from are:

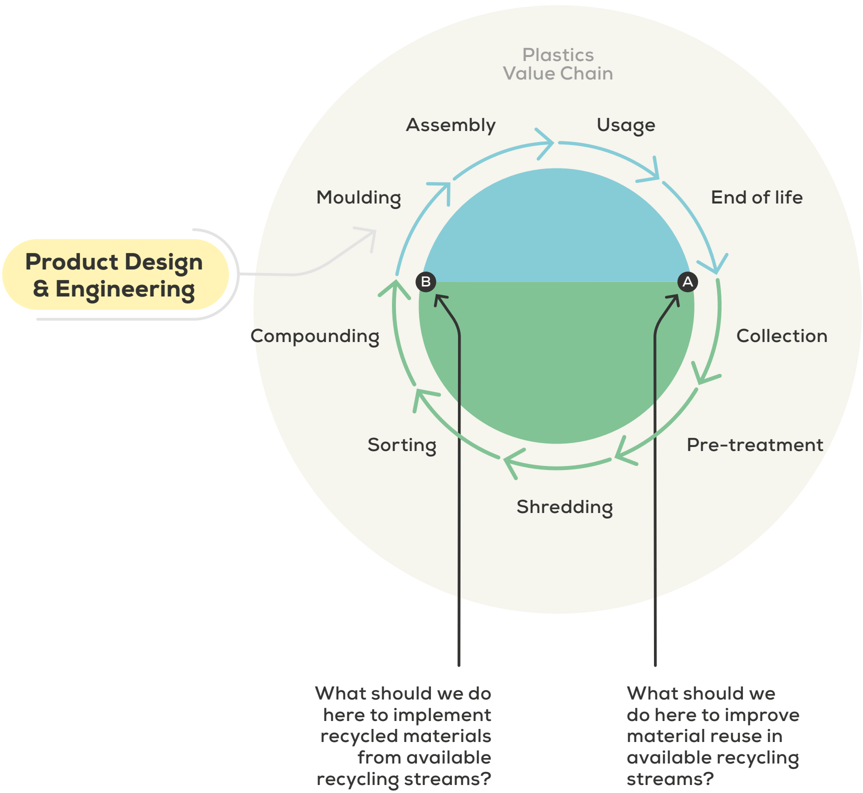
- **to Design *for* Recycling**
  Create a product that enables better and easier recycling at end-of-life

- **to Design *from* Recycling**
  Create a product (partly) built from recycled materials

8. https://ec.europa.eu/growth/industry/policy/circular-plastics-alliance_en

9. Virgin plastic is the direct resin produced from a petrochemical feedstock, such as natural gas or crude oil, which has never been used or processed before.

Fig. 2.4 Circular development according to Pezy Group

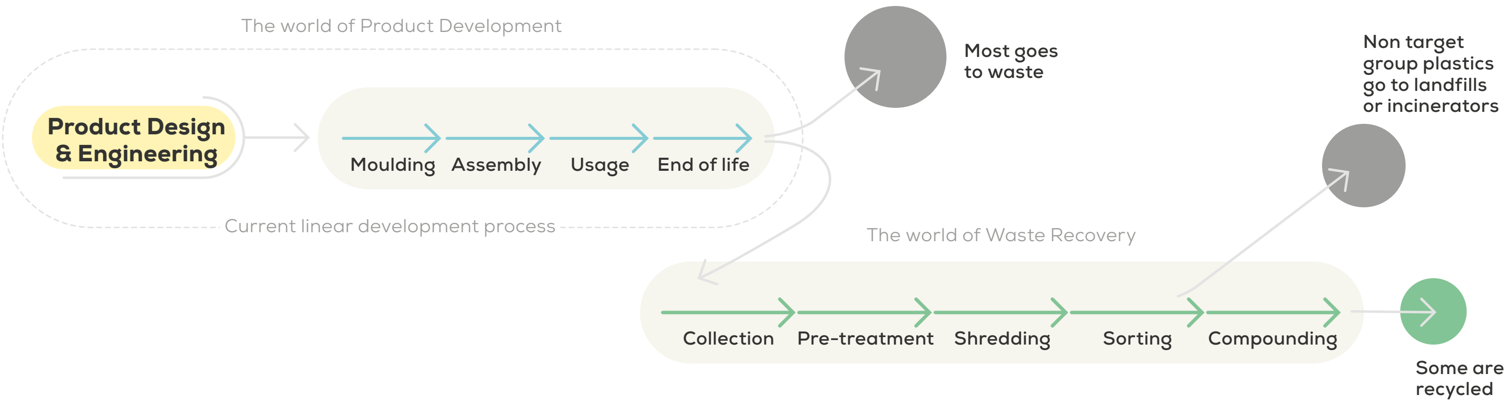


To make a choice between *'for or from'* you need to know the context in which the two are to be considered. If we look at the full life cycle of a product we distinguish two relevant 'worlds':

- **the 'world' of Product Development** (blue part in figure 2.4) focusses on product ideation, development and production. Product designers, engineers, moulders, manufacturers and consumers collaborate to create valuable products.

- **the 'world' of Material Recovery'** (green part in figure 2.4) focusses on the product's end of life and involves waste collection and recycling. Municipalities, waste collectors and waste processors create value from waste.

Fig. 2.5 Linear development according to Pezy Group



Today these two worlds operate independently from each other (fig. 2.5). Product development and the waste cycle processes (ie. recycling) take place in a linear manner.

An important condition to create circular products (fit *for* recycling and made *from* recycled materials) is to switch from a linear to one integral approach where the *whole* value chain is considered (fig. 2.4).

INTRODUCING GATES 'A' AND 'B'

Shifting product development from linear to circular will come with big challenges. To successfully develop circular products we *have* to start connecting the 'two worlds' to make them operate in a circular way and regard them as one. Doing so is fundamental and defines the Design *for* Recycling approach. Investigating all the aspects involved is the only way to determine the requirements that will make your product circular.

If we combine the two worlds (fig. 2.4) it also becomes clear that how we design a product at inception determines the possible 'rebirth' of recyclable and/or recycled materials. Preventing the product to end up as waste at its end of life. Today product development always starts with a focus on the product itself and what it takes to get it produced. To make your product circular it is crucial to incorporate, at project start, how your product will be recycled. The two gates are the connecting points between the two worlds and play an important role in bringing them together;

- **'Gate A' Design for Recycling**
  – at this gate the designer has the task to develop a design made for optimal recycling in a qualitative and quantitative way.

- **'Gate B' Design from Recycling**
  – at this gate the designer has the task of implementing recycled materials where possible.

Most products that enter Gate A today (at end of life), show us that they have not been designed for the world of Material Recovery. Design *for* Recycling has not been applied. Gate B often shows missing links between the output of material recovery (available recycled materials) and the input on specifications needed for product designers to be able to create a good Design *from* Recycling.

Before we go further into the differences of Design *for* and *from* Recycling, be aware that both will co-exist and cooperate in your project.

CIRCULAR DEVELOPMENT LEVELS

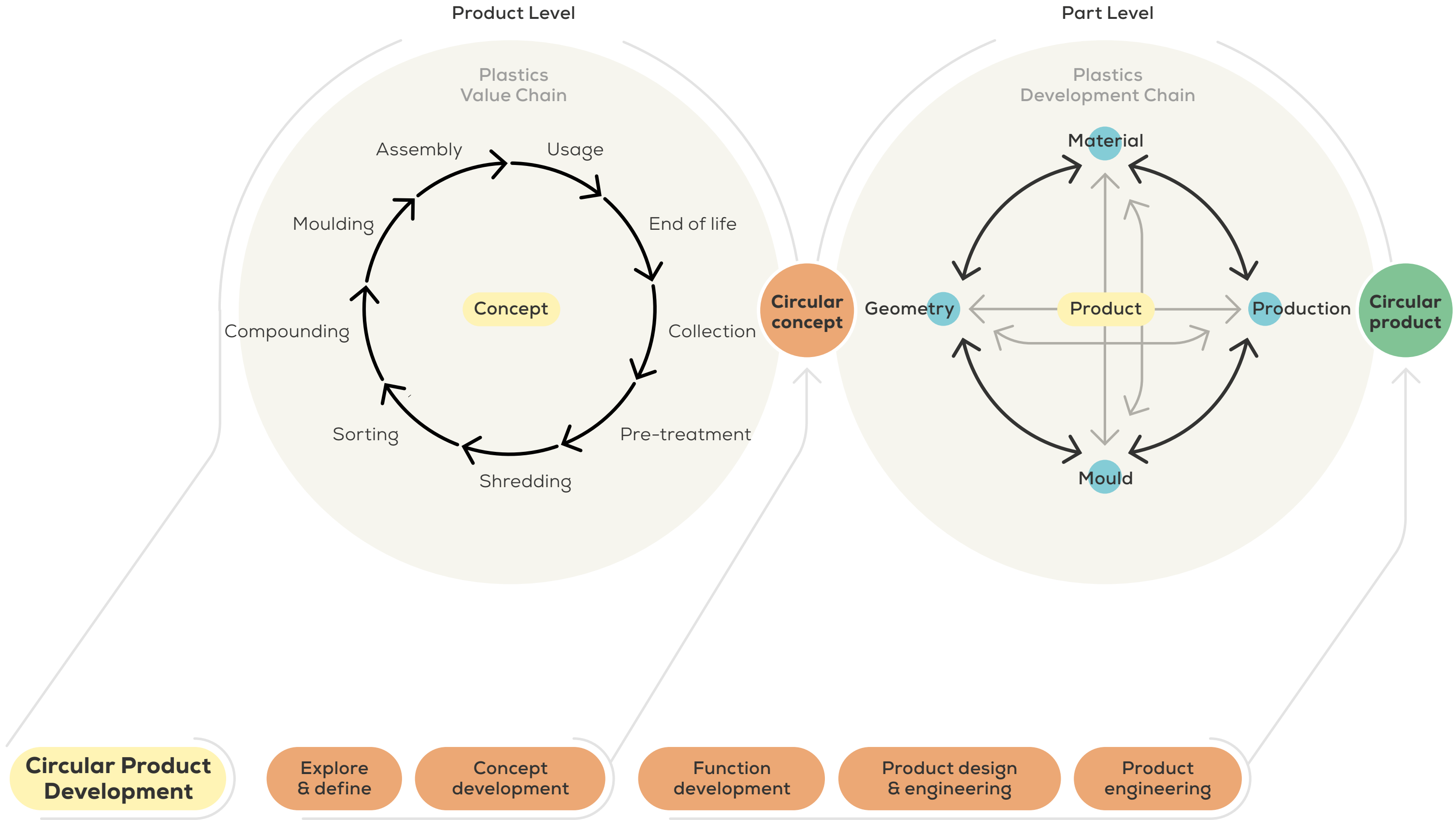
Whether to choose a design phase based on *'for'* or *'from'* principles depends on what you want to achieve. However in both approaches you will look at your product on two levels (fig. 2.6):

- **Product level** - the total assembly performing key functionalities and aesthetics

- **Part level** - the individual parts fulfilling a specific sub-function and made from a specific material

No matter where you decide to put your focus, you will always look at the production aspects; what techniques are used to produce the product and how they relate to the circular solutions. A Design *for* Recycling project focusses on designing the total product and creates a product architecture that facilitates optimal recycling later on. Before starting up the usual development activities, you need to map how your product can enter the recycling stream best (fig. 2.2 – Recycling steps).

Fig. 2.6 Product and Part levels



To make this happen all parts used in your product should be designed for easy separation avoiding glue fixtures and use of toxic materials. Once you know the demands and whilst developing the product architecture you can choose to incorporate recycled plastics for your parts. The choice to do so depends on your sustainability ambitions, the available budget and the opportunity to incorporate the activities (and time) needed to find appropriate materials.

A Design *from* Recycling project often focusses on (re)designing parts of a product fit for using recycled plastics. To make things easier you could choose to start with changing the materials of an *existing* product and replace (some of) its parts with recycled plastics. This is a good way to develop know-how and learn what options are suitable. It will also give you good insights on what the impact of using recycled plastics will be for your product and production. We call this a Drop-in Method. This method intends to create hands-on learnings without making big investments for development and tooling. The other option is to design a completely *new* product from scratch using as much recycled plastics as possible.

Be aware that the 'Drop-in Method' should not be confused with a 'Drop-in material'. A 'Drop-in Material' refers in the industry to a one-on-one replacement of a material which should not affect the production process. Applying the Drop-in Method means that you test a recycled plastic in an existing process to learn what happens to the material, the part, the mould and the production process. Once you have proven the material performance and have received comparable results from this testing you can start using the recycled material in (mass)production.

A Design *from* Recycling approach can also help you to convince your organisation of the value of circular products. The approach delivers step-by-step results. Results that will help build the confidence needed to implement circular development in a profitable way.

THE DROP-IN METHOD CREATES HANDS-ON LEARNINGS WITHOUT BIG INVESTMENTS FOR TOOLING

DESIGN **FOR** RECYCLING

By applying a Design *for* Recycling approach we aim to make a product suitable for the complete value chain, including all steps of the recycling process. These products will be designed in a way that all materials used can be retained in the highest possible qualities to maximise their reuse.

Many guidelines have been developed in the recent years to support companies in realizing Design *for* Recycling and enable design for plastic recycling. Different countries and sectors have even developed specific guidelines that can be useful for your project. Almost all guidelines are developed for the packaging sector, as this sector has the highest demand for plastics and generates most of our plastic waste today.

In the overview shown (fig. 2.7) you can find a selection of European organisations that can provide you with country or sector specific guidelines that might be helpful.

Fig. 2.7 Selected guidelines to design for plastics recycling

Organisation	Country	Sector
CITEO	France	Packaging
COTREP	France	Packaging
Ecosystem	France	EEE
Danish Plastics Federation	Denmark	Packaging
Der Grüne Punkt (DSD)	Germany	Packaging
Cyclos-HTP	Germany	Packaging
IK (Industrievereinigung Kunststoffverpackungen e.V)	Germany	Packaging
Zentrale Stelle	Germany	Packaging
KIDV	Netherlands	Packaging
Recoup	UK	Packaging
WRAP	UK	Packaging
OPRL	UK	Packaging
FH Campus Wien	Austria	Packaging
Circular Analytics TH GmbH	Austria	Packaging
CEFLEX	Europe	Packaging
RecyClass	Europe	Packaging
PETCORE Europe	Europe	Packaging (PET)
EXPRA	Europe	Packaging
EPBP	Europe	Packaging (PET bottles)
EFBW and UNESDA	Europe	Packaging
APR	US	Packaging
Suez.circpack®	Global	Packaging
Borealis	Global	Packaging

In our guidelines in chapter 3 we have incorporated the most relevant aspects of existing guidelines so you can apply them in designing plastic housings and parts for electrical and electronic devices. The new learnings from the PolyCE project are added and together they offer you an up to date and complete set of guidelines covering the value chain of plastics.

DESIGN **FROM** RECYCLING

DESIGN *FROM* RECYCLING; ACTIONS FOR GATE B

In this chapter we introduce some design strategies that can help increase the uptake of recycled plastics in the product design process. To do so we distinguish three key challenges:

1. Challenges with recycled plastics
2. Challenges during the development process
3. Challenges to implement recycled plastics in production

First, we look into the main challenges designers face to improve the circularity of plastics. Secondly, we touch upon the specific challenges that can arise in each step of the development process. And thirdly, we further introduce you to our Drop-in Method, developed to help you implement recycled plastics in your product.

1. CHALLENGES WITH RECYCLED PLASTICS

Virgin polymer materials are often engineered for very specific and demanding applications to meet a complex set of requirements or properties. To fulfil these, a large variety of different thermoplastics such as Styrenics (PS, HIPS, ABS, SAN), Polyolefins (HDPE, LDPE, PP), and different engineering thermoplastics (PC, POM, PUR, PA) are being used. A broad variety of additives (both organic & inorganic) are often added before processing. They are used to change material properties such as colour, melting point, flammability, density, or to meet legal, design or cost purposes.

Some of the following additives are now regulated, but might have been added in plastics in the past:

- pigments (e.g. TiO_2, ZnO, Cr_2O_3, Fe_2O_3, Cd)
- flame retardants (often brominated organics combined with Sb_2O_3 or polychlorinated biphenyls (PCBs))
- stabilizers
- plasticizers (e.g. compounds of Ba, Cd, Pb, Sn and Zn, or PCBs).

Let us have a look at an example from the food packaging industry to illustrate what challenge you might run into:

Materials for food packaging always need to meet 'food contact' regulations. However, these regulations constitute a barrier to increase the use of recycled plastics. The only established exception is PET used for bottles. When developing new packaging from 'r-plastic' it is in theory possible to get food contact approval from the EFSA (European Food Safety Authority). The approval is, for instance, required for your recycling processes.

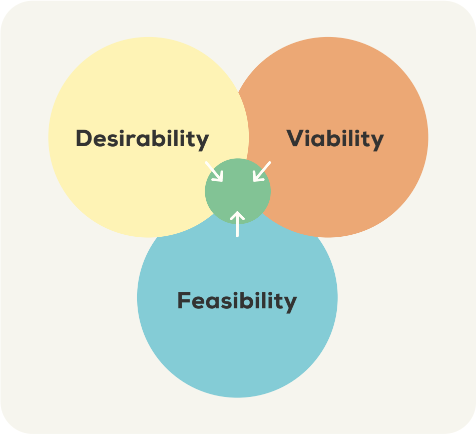
However, the application procedure to approve new recycling processes and r-plastics is a challenge. There are several reasons for that. For instance, at this moment there are no clear guidelines available on how to apply for r-plastic approval. And also, as recycled plastics are not yet widely used, there is a lack of reference cases from the past to help you base decisions upon.

Only recently, since May 2019, a new set of E.F.S.A. decisions were made on the use of recycled plastics. None of these have yet turned into approvals by the European Commission. In practice this means that all food packaging materials, other than PET for bottles, are to be recycled via an open loop at best.

Currently, as a designer or engineer you probably follow a corporate product development and material strategy. These strategies vary by company and therefore your challenge is to find the solution that matches your company's development context. To get a grip on your solutions it is helpful to assess your concepts using the integral product development criteria for desirability, profitability and feasibility (fig. 2.8). They will help to choose which ideas and recycled plastics are most useful for your product.

Looking at daily practice, all Design for Recycling options created must be justified on its short or mid-term commercial benefits. For example, a feasible r-plastic material can have a

Fig. 2.8 Key aspects to validate concepts



different purchase price than its virgin version. When the products' business case is viable (e.g. due to higher sales margins) it can turn out to be a good option. Today, only a few companies have been able to integrate all sustainability aspects systematically in their product strategy and development. Some of them through a Cradle-to-Cradle certification, but often without specific profitability requirements. Before choosing which r-plastic to use, it is important to understand the relevant cost and revenue aspects of it.

Another aspect to consider is what risks using r-plastics will bring. Replacing commonly used virgin materials by r-plastics can increase the project risks. Simply because the quality of r-plastic materials have not been proven over time and are to be investigated in the project. Choosing the right recycled material to use must be carefully decided on technical, legal and cost considerations and this is covered in the feasibility – viability check of the earlier mentioned Integral Product Development (IPD) model (fig. 2.8).
Note that integrating recycled materials in new products should not negatively impact any of the IPD assessment criteria (desirability – feasibility - viability), it should remain equal or enhance them.

A general rule to work by is the following:

- if the integration of a recycled plastic improves one of the IPD assessment criteria, not negatively impacting the other two, the material is up for serious consideration.

- if the material has a negative impact on cost, make sure to validate the business case of your product. Selling the product for a higher price could for instance cover the increase in cost and make it a viable solution.

Since recycled plastics are often new to designers and manufacturers (OEM), achieving the desired result is a path full of uncertainties. The lack of knowledge, experience and the increase in risks are major barriers for companies to use more recycled plastics. To help you clarify some of the main technical and economic attributes for virgin and recycled plastics look at the comparison table (fig. (2.9).

The goal of replacing virgin polymers with recycled polymers in a new product should result in *the following development criteria when compared to the current non-circular product:*

- maintain **profitability** of the product, e.g. lower material costs or higher profit margins (higher market appreciation) to compensate for higher material costs.

- not harming the **desirability** (smell, aesthetics, usability)

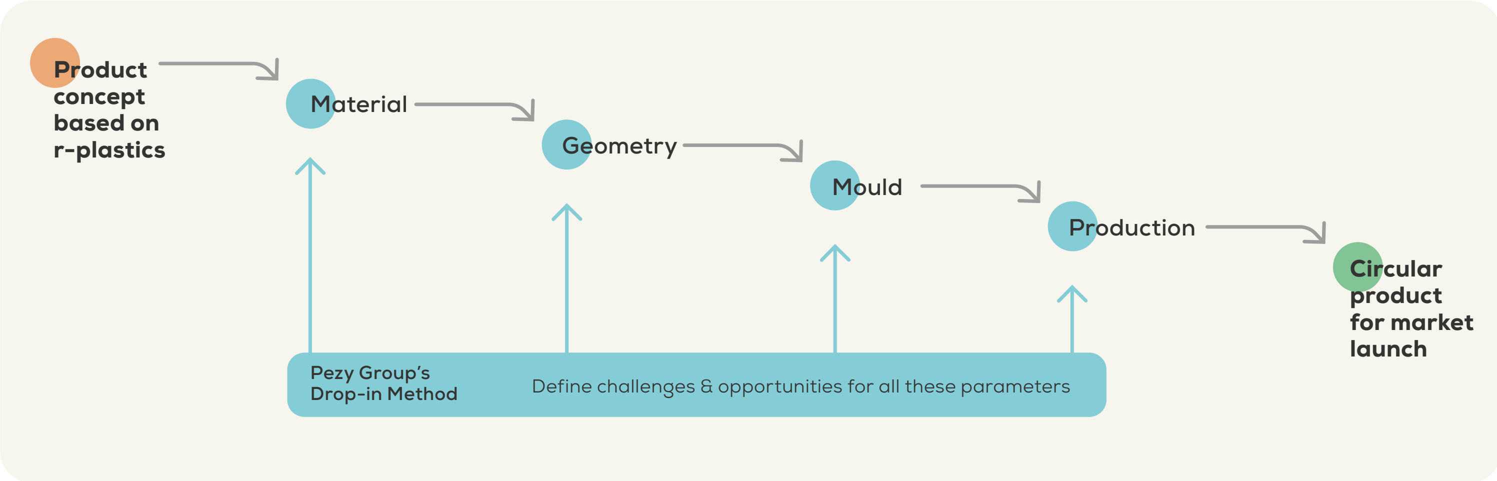
- comply with **feasibility** requirements (e.g. functions, robustness, UV resistance, water tightness etc).

Fig. 2.9 Virgin versus recycled plastics

		Virgin plastics	Recycled plastics
Technical	Quality	Constant	Quality variation based on used source
Technical	Availability	High	Limited PCR (PP, HIPS, ABS, PET)
Technical	Surface	Good surface finishing quality	High gloss surface are difficult to reach
Technical	Colour	Flexibility in colouring	Transparent natural colour barely available, mainly black and grey colours
Technical	Olfactory performance	Good	Can be smelly, depending on the source
Economic	Supply chain	Limited number of suppliers and availability of second source	Complex supply chain
Economic	Support	Strong technical support through the application chain	Low level of technical support
Economic	Price	Highly vulnerable to oil price	Less vulnerable to oil price, high quality grades are priced as virgin material

INTEGRATING RECYCLED MATERIALS COMES WITH BALANCING DESIRABILITY, FEASIBILITY AND VIABILITY

Fig. 2.10 Key product parameters



2. CHALLENGES DURING THE DEVELOPMENT PROCESS

When designing a plastic product there are four different product parameters that define the properties of the material in its behaviour and looks:

- Material quality (plastic grade)
- Geometry
- Mould
- Production process

The succeeding order as described above defines the actual/logical process a designer follows to create a good product. It is called the development waterfall (fig. 2.10).

These four product parameters have a direct relation to each other, which means that changing one of them will very likely have an impact on one other and on the result.

Every plastic grade has its own specific properties which have an impact on the mechanical and/or aesthetic behaviour of the material. The properties of a recycled plastic (r-PP, r-ABS etc) is not the same as the virgin plastic versions (in PP, ABS etc). Shifting your product material from virgin plastics to recycled plastics means that at least one of the four product parameters will change and effect the end result.

It can very well be that the real or even perceived performance of the recycled plastics is related to all aspects of the product parameters. We have summarised specific challenges for each parameter shown here in figure 2.11.

Fig. 2.11 Parameter challenges

	Challenges
Material	• Portfolio needed from supplier • Lack of material & application know-how at suppliers • Limited colour options • Quantity availability over time
Geometry	• No part specification (upper or lower limits of mechanical properties are unknown • CP or CPk values are unknown (i.e. tolerances uncertain) • No mouldflow data (i.e. less predictable than with virgin)
Mould	**Risk of mould damage by** • Contamination in general • Blocked hot runner • Surface contamination due to outgassing • Extra wear on texturing and high gloss • Blocking on air venting (extra cleaning required)
Production	• Variations in processing conditions • Limited acceptance by moulders related to risks using r-plastic • Full size process release needed • Lot-to-lot stability unknown or unproven

3. THE DROP-IN METHOD, AN APPROACH TO IMPLEMENT R-PLASTICS

If you want to integrate recycled plastics in your new product and at the same time reach the required properties, you need to understand the impact and properties of the recycled material to use. In general, designers have to deal with two key uncertainties at the start:

1. How to correctly translate the requirements and functions into the product to be developed

2. Get a grip on unknown r-plastic properties

By 'dropping in' recycled plastics into the moulds of an existing product, designers can learn a lot about the performance of the recycled material. The parts you have made from recycled plastics can be compared with the existing parts made from virgin plastics. This approach allows you to get acquainted with the possibilities of the recycled plastics for future purposes. Recycled plastics are often referred to as PCR (Post-consumer Recycled) or PIR (Post-industrial Recycled) materials.

Learning about the possibilities of PCR and PIR plastics by using and comparing them with virgin product parts is done step-by-step. First, simple shapes can be used to determine certain critical properties. Once more confidence is established, you can try more complex shapes. This step-by-step approach helps:

- to determine if the performance is comparable to virgin materials
- to understand what needs to be adjusted
- to figure out whether the material or geometry can be fine-tuned.

This approach is not only the beginning of the development process for new products made from recycled plastics but can be the start of in-house competence and capacity building. New knowledge about the performance of recycled materials will shape your knowledge database, which can be very valuable input for future projects. The Drop-in Method was developed by Pezy Group during the Horizon 2020 PolyCE project. In co-creation with universities, research institutes and product developers from the industry, we connected research and hands-on experience to build a tool based on these three key 'pillars' (fig. 2.12) being:

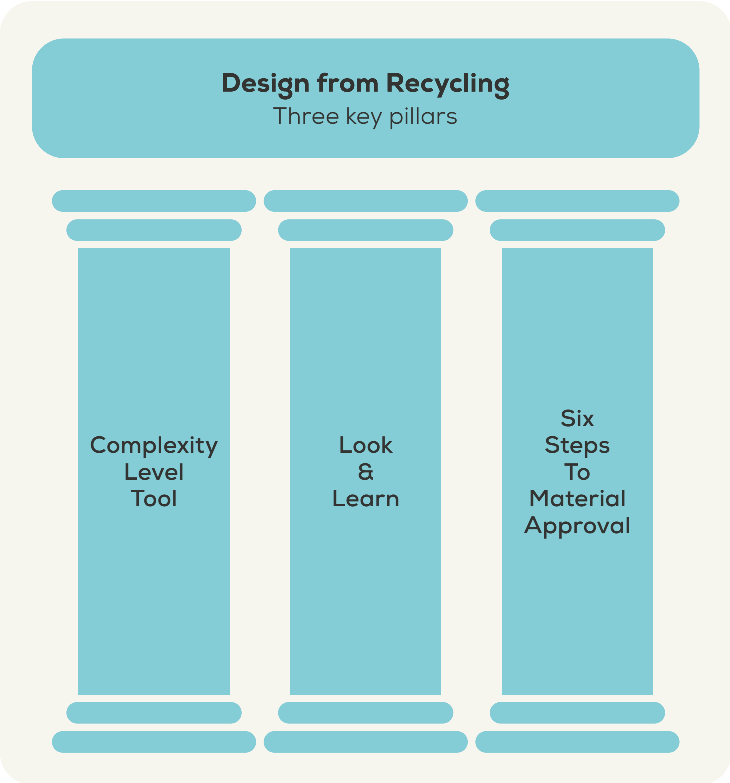
- Drop-in Complexity level tool
- Six Steps to Material Approval
- Look & Learn principle

The Drop-in Method always starts with applying the Complexity level tool (which we will describe more in detail later) and is followed by the Six Steps to material approval.

In the Six Steps we guide you through the complete process from material selection to mass production of parts made from recycled plastics.

In The Look & Learn step we build demonstrators. They provide first physical proof of mechanical and aesthetic

Fig. 2.12 Key pillars of Design from Recycling



properties and bring process insights. Let us have a closer look at what happens in the key pillars.

COMPLEXITY LEVELS, THE TOOL

Once you or your company makes the strategic choice to use recycled plastics in new products, it is important to define a starting point. Companies often have a wide range of products within their portfolio and each product consist of different plastic parts. All these parts need to fulfil their own specific requirements (e.g. mechanical, aesthetic and legal) and they define the complexity level for the integration of recycled plastics. Building up material application knowledge from scratch will come with hurdles. For this reason it is advisable to start with parts that have relatively low technical and aesthetic requirements and are therefore easier to manufacture from recycled materials.

Fig. 2.13 Complexity levels

Level one	materials available, economically feasible, state of the art
Level two	materials limited available, to be compounded according requirements, needs extra development time & cost
Level three	few materials available, long term develoment, limited design freedom
Level four	not (yet) available or high risk application

By evaluating your product portfolio and classifying the product parts from 'low hanging fruit & feasible' to 'the cream of the crop & not feasible yet', your roadmap and a first starting point can be defined (fig. 2.13).

In addition to looking at product parts, the following aspects should be considered:

- the availability (quantity and quality) of recycled materials
- design freedom
- aesthetic properties
- mechanical requirements
- legal aspects and complexity, etc.

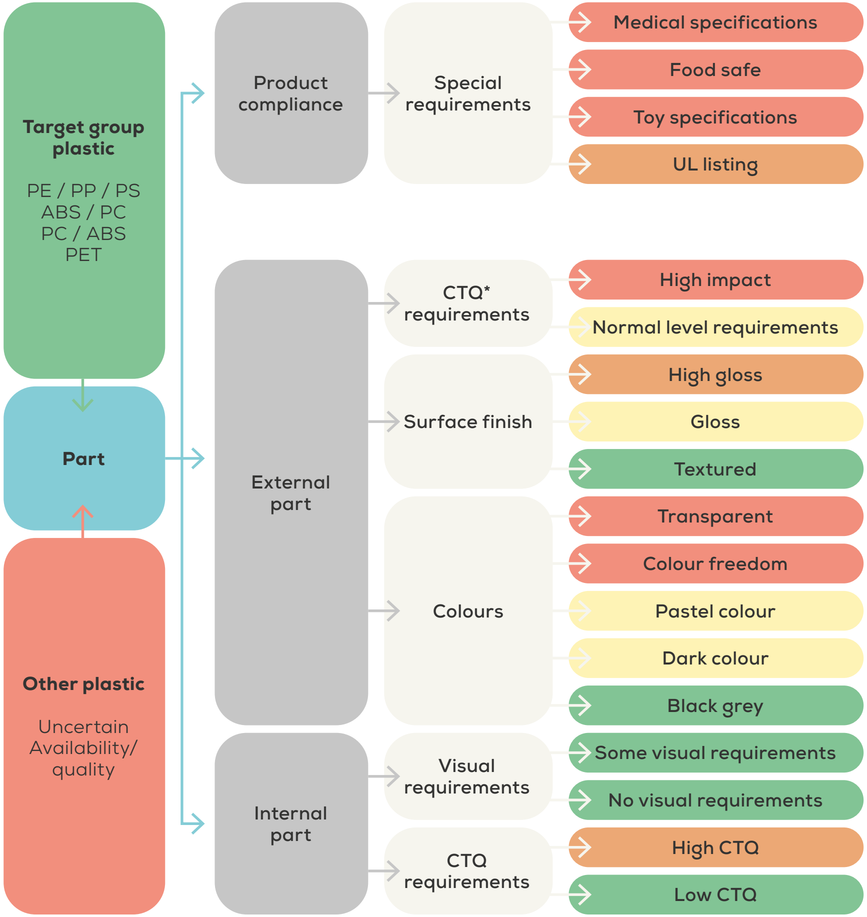
These aspects can be assessed through the Complexity Level tool using a decision tree format. An example of such a decision tree is shown in figure 2.14.

Such a decision tree helps you to identify the complexity to translate a certain product part from a virgin to a recycled grade. The example illustrated (fig. 2.14) starts with assessing the *polymer type*.

The complexity level tool is a flowchart to indicate the feasibility of turning a specific part into recycled plastics based on the visual and technical requirements and the applicable regulations. This informs the roadmap with short term (low hanging fruit) and longer term (cream of the crop) projects.

*CTQ = Critical To Quality

Fig. 2.14 Complexity level tool



Start with selecting a polymer from existing recycled plastics (PE, PP, PS, ABS, PC/ABS, PC or PET). The second column identifies if it is an external or an internal part with special requirements or specific applications. Usually it is easier to substitute internal parts with recycled materials as they often have 'low' aesthetic requirements. The third and fourth columns show examples of detailed requirements that could be critical to achieving good quality. The colours green, orange and red show to what extent certain properties are easy, challenging or impossible to fulfil at this moment.

Please note that specific material applications, like medical products, food packaging, and toys are not (yet) suitable for recycled materials.

DETAILED INFORMATION FROM SUPPLIERS IS CRUCIAL TO PERFORM FIRST TESTS WITH R-PLASTICS

SIX STEPS TO APPROVE A MATERIAL

After you have chosen the part to make with recycled plastics, the development process starts (fig. 2.15). Based on the previously used virgin plastic type and its specific requirements, you need to identify suitable suppliers for your recycled plastic. It is crucial that suppliers provide detailed information and samples of the materials which you can test on a small scale. The mechanical and aesthetic properties of the recycled plastics need to be tested first. These test results will give an indication *where* and to *what* extent the recycled material deviates from your initially used virgin plastic. When you select potential materials, focus on the most promising one(s). After this step you are ready to do a pilot moulding.

The following steps you will take should focus on the details for the specific application. The design might require some changes along the way to match the requirements with the recycled plastic properties. The product architecture and part design may possibly need to change to help to reduce complexity and increase the room for more recycled material use.

Uncertainties such as cost, availability, colour stability, lot-to-lot stability and process capability need to be reduced to a minimum to prove that the recycled material fits the business case and the technical needs of the product. Only after taking these steps it is possible to move towards large mould trials, product assembly and finally to mass production.

THE LOOK & LEARN PRINCIPLE

The third pillar of the Drop-in Method is all about removing specific uncertainties within each of the six steps. By creating demonstrators you can prove both aesthetic and mechanical properties as well as the material behaviour in processing. We call these samples ‘demonstrators’ as they demonstrate real information which can support you in making decisions on the PCR materials you are investigating. By using existing moulds (which do not add costs for tooling) you

Fig. 2.15 Six steps to material approval

Product concept

- **1. Material selection** — Source available R-plastics that are closest to the requirements
- **2. Property testing** — Determine critical to quality requirements (CTQ's) to create first indications on aesthetical, mechanical and processing behaviour
- **3. Pilot moulding** — Determine producability of the material by using a well known testing mould
- **4. Large moulding trial** — Learn to what extent the selected material(s) are suitable to fulfil the processing requirements over time
- **5. Product assembly** — Find proof for lot-to-lot stability and if the parts can be produced to fit the total application
- **6. Mass production** — Audit supplier and release product in new material

Final product

can learn more about the possibilities of recycled plastics. Parts moulded into recycled plastics can be compared with existing product parts made from virgin plastics. Example: Much knowledge usually exists for virgin parts and they are therefore a good reference to check aspects of the version made from recycled plastics.

A good start is to create simple shapes to get an idea on processing aspects and determine mechanical and processing properties. You could for example start with making tensile bars[11] (fig. 2.16) or perform a spiral flow[12] test. These parts and tests are very useful to find out more about the mechanical performance of the recycled plastic. To discover aesthetic

11. Tensile bars have a standardized sample cross-section, that has two shoulders and a gauge (section) in between. A tensile test applies tensile (pulling) force on a tensile bar and measures the response to the stress. By doing this, tensile tests determine how strong a material is and how much it can elongate.

12. Spiral flow test; the determination of the flow properties of a thermoplastic resin by measuring the length and weight of resin flowing along the path of a spiral cavity.

material qualities it is best to use simple curved shapes with textures. Produce samples in available colours from your suppliers and these will give you a good indication of what quality level can be reached.

Creating physical samples is a powerful and convincing way to show the potential of the recycled plastics. Once you are confident that the recycled material could work, try moulding more complex shapes (fig. 2.16). Find out how stable the material is in geometry and in processing longer production runs.

Following this principle means that you start building the in-house knowledge on recycled plastics materials that is needed for successful implementation.

So to summarize, creating demonstrators offers you different insights:

- It helps determine the feasibility and desirability of the recycled materials for your purpose
- You build up knowledge to compare virgin plastics and recycled plastics and find out to what extent they match. This knowledge will also help to build a more complete database on recycled plastic specifications.
- It is a crucial way to help you build in-house knowledge on the complete process. Knowledge you need to build to remove the knowledge gap that existed.

Fig. 2.16 Examples of tensil bars and large surface test moulding

DESIGN GUIDELINES

DESIGN GUIDELINES

The guidelines can be used to help you map relevant aspects for your project. Whether a guideline is relevant depends on where you are situated in the design process. We have devided the guidelines into two levels:

- **if you want to develop new product concepts, start at the product level**
- **if you want to further develop a determined product concept, start at the part level**

PRODUCT LEVEL

You focus on all design and feasibility aspects of the recycling processes. Determine their requirements to formulate the base for your new product concept and architecture.

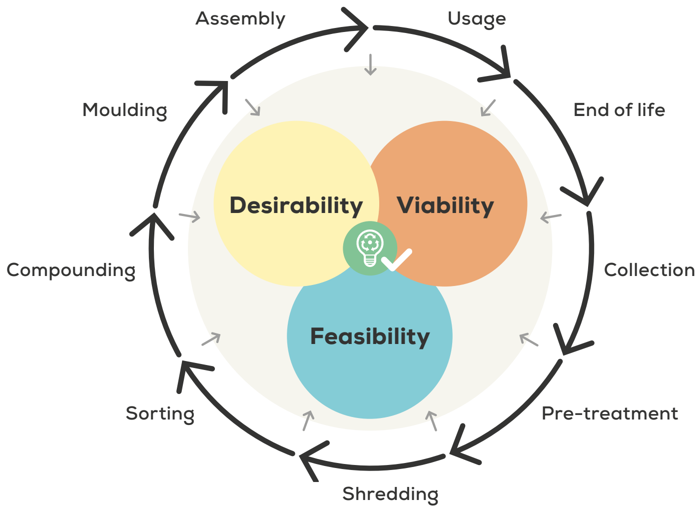
Essential: this approach requires in-depth knowledge of both product development and recycling processes.

PART LEVEL

You focus on maximising the use of recycled plastics and the specific material properties to validate.

Essential: this approach requires in-depth knowledge of recycled materials and material properties.

Fig. 3.1 Balance product development and recycling needs



Whether you start from product or part level, the goal is to maximise the reuse of materials. The guidelines are made to help you achieve this goal and we have aligned them with the current systems for e-waste plastic recovery. This alignment helps to ensure that your product materials will maintain the highest quality possible when entering recycling processes. In applying the guidelines both Design *for* Recycling and Design *from* Recycling topics are addressed:

Design *for* Recycling

- Avoidance of hazardous substances
- How to enable easy access and removal of hazardous or polluting components
- How to use recyclable materials which will be recycled by WEEE recyclers
- How to use material combinations and connections that allow easy liberation

Design *from* Recycling

- How to use recycled materials

When working with the guidelines in this chapter you will see that we have organised them in two sections:

1. **From start to concept**
   → Building a product architecture

2. **From concept to production**
   → Design & Engineering parts

FROM START TO CONCEPT
BUILDING A PRODUCT ARCHITECTURE

ENABLE EASY ACCESS AND REMOVAL OF HAZARDOUS OR POLLUTING COMPONENTS

Guideline 1

Use click/snap solutions to fix **batteries** in a product. Avoid permanent fixing such as glued, welded and enclosed solutions.

Batteries can cause problems in the recycling process if they are not manually removed before they go into the shredder. If not removed, they pollute the material streams and can explode during the recycling process. Batteries are also seen as dangerous by consumers, and therefore it is important to make them easily removable.

When using Li-ion batteries, use hard cells. Soft Li-ion batteries are easily damaged and volatile which is a safety and fire risk.

Guideline 2

To fix **valuable components** (PCBs, cables, wires and motors) in a product, use metal screws, click fingers, press fit, shrink foil, self-screwed/tapering or connectors. Avoid permanent fixing such as 2K (in mould decoration), PSA tapes, glue, melting (different plastics, enclosures) and welding.

Valuable components can pose a health and safety risk since a large part of all e-waste still ends up in third world countries where it is recycled on the street under very primitive conditions. These components are often extracted by methods such as burning cables to extract the copper and pouring acids on PCBs to get out the valuable metals. This releases many kinds of toxic fumes and poses a great health risk to humans and an environmental risk since the local surroundings often suffer from these activities.

To account for these risks, designers are advised not to glue valuable components together but to choose for click/snap-solutions to enable easy removal. If the valuable components are easier to take out it contributes to less negative health and environmental impacts. Most importantly it has a positive impact on 'controlled' recycling as valuable materials can be easily separated: less of it gets lost in other material streams and more can be recycled into new materials.

➔

Guideline 3

Use a module for hazardous components in the product structure to **enable taking out one non-recyclable module** instead of searching for several different hazardous parts.

To use one module where all the hazardous components are located makes the recycling process easier and more efficient. It is easier for the recycling workers to find one module in the manual dismantling step instead of taking time to find several components. It saves time and effort in the process which reduces costs significantly. E.g. use an external power supply instead of an internal power supply. The external power supply is likely to contain BFR, but can be separated physically at the start of recycling. This will prevent it from polluting the material stream.

Guideline 4

Use **detachment possibilities** for polluting components/materials (dust bags, lamps, cord sets, cord winders, paper, cardboard, textiles, wood, foams, glass and ceramics).

Providing detachment possibilities for hazardous and polluting components is vital as they otherwise easily end up polluting the material streams. The easier it is to take out these materials, the easier it is to keep the material streams pure. In case it is not possible to create easy detachment possibilities, clear markings on the product indicating how to destruct will be helpful at the first stage of the recycling process (when the product is to break open). Breaking open usually happens when the product falls onto the recycling belt in the first dismantling step. If the product does not break open at that moment, the markings/indications showing were to manually apply force will help easier removal of a polluting component.

Guideline 5

Use **drains** for operating liquids and gasses and enable easy removal of components such as oil tanks, compressors and hoses.

Drains are important to provide to avoid polluting the material streams in the recycling process, since drains make it possible to take out operating liquids and gasses and prevent them from polluting the material streams or the surrounding air. Therefore it is important to consider the removal of these components in the design, and make sure they are easy to find and take out. In case the request for drains is not possible to fulfil, markings for destructive action can help at the first stage of the recycling process where the product breaks open. This usually happens when the product falls onto the recycling belt in the first dismantling step. If it does not break open there, a marking or indication on where to manually apply force to enable taking out a polluting component is helpful.

USE RECYCLABLE MATERIALS WHICH WILL BE RECYCLED BY WEEE RECYCLERS

Guideline 6

Avoid the use of coatings on plastics such as painting, lacquering, since it can result in changed density of the plastic.

Avoid coatings if possible since all forms of coatings pollute the material streams or makes the recycling process difficult. Coatings change the density of the plastics, which makes it possible to end up in the wrong material stream. The coating material itself also pollutes the streams. Printing of numbers or lines for level-indication (which are small compared to the product as a whole) are not a problem, in fact that is better than using a sticker for the same purpose. Other options are screen-printing, in-mould texturing, laser engraving.

When a coating is needed, a density difference < 1% of the materials weight is ok. Always avoid multilayer lacquering.

Guideline 7

Avoid use of foam.

When foam is necessary, use thermoplastic foam. Do not use elastomers or thermosets for foam.

Guideline 8

Minimize the use of magnets.

Magnets will end up in the ferrous material stream, polluting it.

Guideline 9

Minimize the use of thermoplastic elastomers.

Thermoplastic elastomers are not recycled. Therefore they have to be separated. Particles that are not separated can be seen as a pollutant.

Guideline 10

Avoid thermosets and composites.

When thermosets are necessary, use thermosets outside the density range of 0.85 – 1.25 g/cm3 (range of the common recycled plastics).

Background: Thermosets cannot be recycled, and will be burned.

Guideline 11

Do not use plating, galvanizing, vacuum-metallization as coating on plastics, since it can result in density change of the plastic.

These techniques are a problem, as they connect plastic and metal.

USE MATERIAL COMBINATIONS AND CONNECTIONS THAT ALLOW LIBERATION

Guideline 12

Avoid moulding different material types together by 2K or xK processes (different plastic materials injected into the same mould, or overmoulding, or in mould labelling) such as moulding a thermoplastic elastomer onto PP (e.g. toothbrush). If the material types are the same and only differ in colour and additives it is ok to use, for example moulding red PP containing antioxidants on black PP containing talc.

Avoid moulding different material types together since the end result will not be recyclable. It is very difficult to separate materials that have been joined by 2K or xK processes. Therefore these joined materials will end up as waste or (depending on density) they will pollute other plastic streams. In-mould assembly or assembly injection moulding which uses 2K or xK and which does not result in a chemical bonding of materials, allows for separation of materials during shredding. In this case, no materials will be lost.

Guideline 13

Avoid connections that enclose a material permanently. Avoid methods such as: moulding inserts into plastic, rivets, staples, press-fit, bolts, bolt and nut, brazing, welding and clinching.

To avoid using connections that enclose a material permanently helps to avoid polluting the material streams. Enclosing a material permanently makes it harder to separate the different materials. The processes mentioned are typical for tightly enclosing one material into another and are therefore recommended to be avoided.

USE RECYCLED MATERIALS

Guideline 14

For injection mould plastic parts, **consider using more textured surfaces.** Avoid uniform high gloss surfaces.

Possible traces of elastomer and glass in r-plastics reduce the quality of (large) high gloss surfaces.

FROM CONCEPT TO PRODUCTION
DESIGN & ENGINEERING PARTS

DO NOT USE HAZARDOUS SUBSTANCES

Guideline 15

Avoid the use of substances that are listed for future restriction in the 'SIN list'.

'These substances are mainly used in plastics as surfactants, solvents, stabilizers, plasticizers, anti-corrosions, pigments and coatings. Do not use in concentrations above 1000ppm, (0,1% per article) per substance.

Background: The 'SIN list' is a list of substances that are not restricted yet, but are being pushed to go on the SVHC list (see also Guideline 17) in the future. SIN list substances are a good indication of substances to be restricted/banned in the future and therefore it is important to already now stop using them. If these substances are used in materials today it is very likely that these material streams cannot meet the requirements to be recycled and reused in new products in the future. www.sinlist.chemsec.org

Guideline 16

Do not use halogenated polymers (e.g. PVC, PTFE).

PVC degrades at the typical processing temperatures ABS, PC, PC/ABS, PP, PA, HIPS. The generated hydrochloride acid corrodes normal extruders and moulds.

Guideline 17

Avoid the use of Substances of Very High Concern (SVHC) according to REACH and substances classified carcinogenic (Carc. 1A or 1B), mutagenic (Muta 1A or 1), reprotoxic (Repr. 1A or 1B) by CLP Regulation in housing/housing parts.

This will impede these substances to be contained in the plastic recyclates.

Guideline 18

Avoid use of any BFR's (Brominated Flame Retardants; PBDEs, TBBPA, PBBs, HBCDs, etc.) in the product. Make it 100% BFR-free.

Several BFRs are already restricted and it is likely that more will become banned. If these substances are used in materials today it is very likely that these material streams cannot meet the requirements to be recycled and reused in new products in the future. It is important that not a worse alternative is selected.

USE RECYCLABLE MATERIALS WHICH WILL BE RECYCLED BY WEEE RECYCLERS

Guideline 19

Use only common plastics in the product such as ABS, MABS, PE, PP, PA, PC, PC/ABS, HIPS.

Common plastics can easily be recycled and should always to be used as a first choice. If another material is needed ensure the reasons are motivated and supported. There are established recycling streams for these plastics, which means that they very likely will be recycled. Other materials currently occur in too small volumes in the waste stream to make it economically viable to recycle them.

Background: When other than these common plastics are used, choose plastics outside the density range of 0.85 - 1.25 g/cm3.

Guideline 20

Avoid glass fibre filled plastics.

Glass fibres pollute material streams, reducing mechanical properties and cause wear.

Background: Instead of using glass fibres to increase the modulus, use carbon fibre or mineral filled plastics, e.g. a PP-talc mineral can be recycled.

Guideline 21

Minimize the use of thermoplastic elastomers.

When elastomers are necessary, minimize the use of elastomers and choose for an SEBS based TPE.

Background: Most of the elastomers are filtered out during the separation steps. The fraction of elastomers that is not filtered out is likely to end up in the PS stream. When a SEBS based TPE is used as elastomer and will end up in the PS stream, it may act as an impact modifier and therefore is doing the least harm.

Guideline 22

Avoid polymer blends.

Mono material streams should be the goal. Blends like POM/ABS, PA/ABS, PC/PBT, PPE/PS, PET/PBT pollute material streams. (except for PC/ABS, as this can be recycled well)

Guideline 23

Minimize additives in plastic materials.

Additives reduce the purity of the plastic streams. Check the need for additives.

Guideline 24

Avoid use of thermoset-rubbers.

Thermoset rubbers cannot be recycled, therefore avoid the use of thermoset-rubbers. In case you do need to use a thermoset-rubber, make it easy separable to avoid polluting other streams.

ENABLE EASY ACCESS AND REMOVAL OF HAZARDOUS OR POLLUTING COMPONENTS

Guideline 25

Avoid magnetic components on PCBs.

PCB's have many valuable non-ferrous metals. If magnets are placed onto the PCB, the PCB might end up in the ferro stream. In that case the valuable non-ferrous metals are lost and will pollute the ferro stream.

USE RECYCLED MATERIALS

FROM CONCEPT TO PRODUCTION

Guideline 26

Use virgin plastics for very demanding parts. E.g. transparent lightguides.

Recycled plastics are different than virgin plastics. They cannot meet every demanding requirement.

Guideline 27

For injection mould plastic parts, **consider more venting ports** or wider ones.

Recycled polymers can have higher emissions due to pollution or degrading polymers during production.

Guideline 28

Choose geometries for injection moulded parts that allow easy flow paths. Avoid tight and narrow geometries.

The high shear rates caused by narrow geometries will stress and degrade the polymers.

Guideline 29

For injection mould plastic parts, **do no use long injection paths** (length from gate to end of product to completely fill the product).

Recycled polymers are more sensitive to shear and temperature. A possible solution could be to use multiple injection points. Consider increasing the wall thickness.

USE MATERIAL COMBINATIONS AND CONNECTIONS THAT ALLOW LIBERATION

Guideline 30

Avoid fixing ferrous metals to non-ferrous metals in either parts or fasteners. For example, do not use a screw (ferrous metal) to attach a part to aluminium (non-ferrous).

If ferrous and non-ferrous materials are joined and the product goes into shredding it is very likely that either the ferro or the non-ferrous stream will be polluted. The materials are shredded to small pieces and either the screw will go with the host component to the non-ferrous stream or the non-ferrous part will follow the screw into the ferrous stream. This pollutes the material streams.

Guideline 31

Do not permanently fix Aluminium, Copper (including Brass), Stainless steel or Steel together in the following combinations:

- If the main material in a component is **Al (cast)**, do not attach a part of Stainless steel or Steel onto it.
- If the main material in a component is **Al (wrought)**, do not attach a part of Al (cast), Copper, Stainless steel or Steel onto it.
- If the main material in a component is **Stainless steel**, do not attach a part of Copper onto it.
- If the main material in a component is **Steel**, do not attach a part of Copper or Stainless steel onto it.
- If the main material is **Copper**, do not permanently fix a part of Iron, Lead, Antimony or Bismuth to it.

These combinations are based on thermodynamical properties of the materials, indicating which materials are feasible to combine and which ones are not. Depending on the main material in a component, smaller amounts of other materials will end up polluting that stream. Some materials are easy to separate while some are very problematic. A good and easily separable material combination will result in streams that are less polluted as well as less waste, since many streams containing a pollutant that is hard to extract will simply end up as a waste fraction.

CASES

In this chapter we present a selection of case studies from the Horizon 2020 PolyCE project. All cases followed the Design from Recycling approach described in the previous chapters.

Whilst working on the cases, knowledge from all involved partners came together to cover the complete value chain of (recycled) plastics. In these cases, demonstrators were created to showcase the possibilities and challenges for effective reuse of PCR plastics from WEEE in large-scale production. Our aim was not to compromise on product quality and where possible implement the Design for Recycling guidelines.

PEZY GROUP

PEZY GROUP: A NEW PRODUCT

Being a full-service product development agency with specialists in design, engineering, electronics and industrialization, Pezy Group first recognized the potential of a circular economy in 2009. In that year we became the first design agency in The Netherlands with a Cradle-to-Cradle accreditation. Since then, we have gained a lot of experience in the application of sustainable plastics, like bio- and recycled plastics, in consumer products. With the experience we developed since then, we have learned how to evade certain pitfalls when shifting from commonly used and fully specified virgin plastics, towards recycled plastics with partly unknown specifications.

GOAL AND MAIN CHALLENGES: A NEW PRODUCT

In creating a circular product for Wireless Value we developed a design mainly made from recycled materials. The product parts we had to make from virgin materials are designed to be recycled keeping the original material quality level as high as possible.
An important requirement to meet was to create a circular electrical device without taking any concessions on both the functional and aesthetical demands. The assignment was to discover how we could maximize a circular design within these two requirements. The Wireless Value portfolio contains a variety of housings created for different markets and purposes. The total product portfolio included housings with different shapes, colours and materials.

This offered the opportunity to develop a modular platform of products with which it is possible to put together various product architectures using several 'functional blocks'. This principle could facilitate the needs of various products yet made use of a standard set of housing parts.

Our approach helped to minimize the number of housings needed. We developed the plastic housing using PCR plastics (Post-consumer Recycled) coming from a WEEE (Waste of Electrical and Electronic Equipment) stream and made it fully recyclable according to the design guidelines created by the PolyCE project.

RESULTS

The result is a product family of three housings, that together provide the new product platform for wireless measurement in all varieties needed. Two out of three housings were developed into final products.

The project created valuable insights in the challenges and possibilities across the complete development process. When following the design for recycling guidelines designers had to face several challenges.

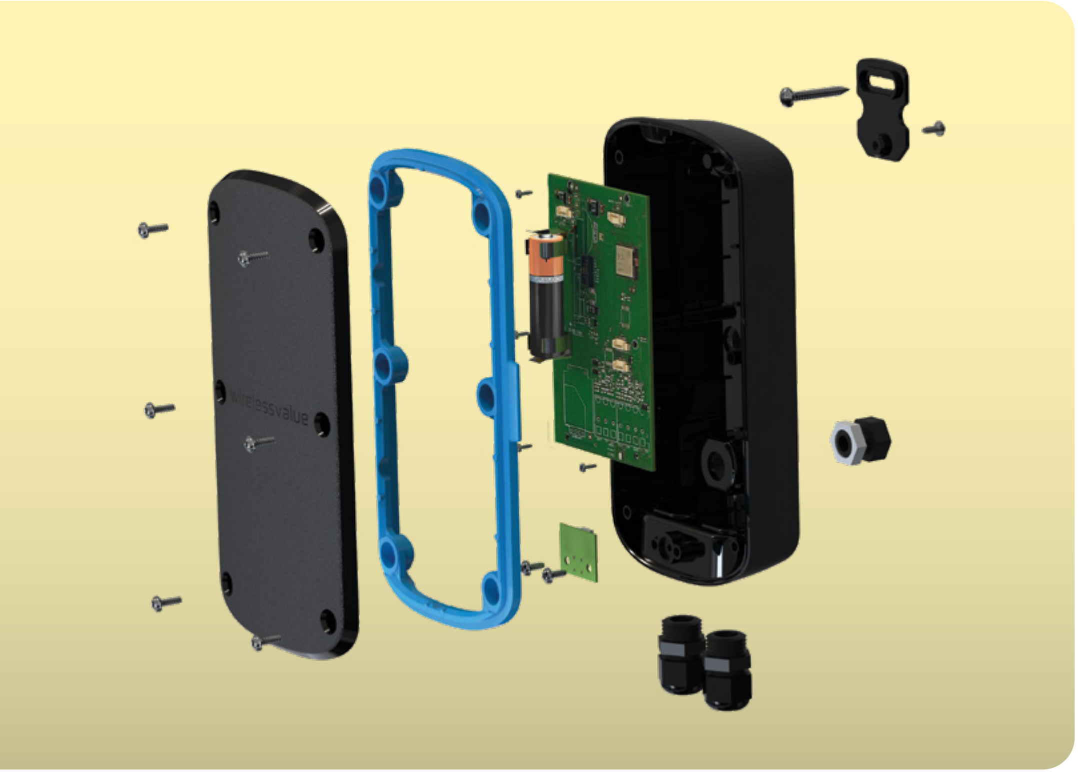
One of the challenges was to make the housing watertight. Parts to provide this sealing function are usually made from elastomers. Because elastomers are not available as a recycled material and are known for limitations in colour, we decided not to use them.

We explored the alternatives, but the outcome resulted into two options:

- accepting uncertainties in the sealing function
- an overall worse score on
- design for recycling.

As the product had to comply with sealing requirements, we had to use a virgin plastic TPV material. Like in the guidelines described, this material is likely to be filtered out.

All other parts are made from Post-consumer Recycled plastics and the level of their mechanical and aesthetic quality were proven to be comparable to virgin versions.



KEY LEARNINGS

1. **Once specifications of parts become clear, define the CTQ's.** Suitable plastic types must be chosen to match the CTQ's.

2. **Start sourcing for possible materials as early as possible.** Once materials are found, check CTQ performance through testing.

3. **Look for any specific hurdles that were not applicable when using virgin plastics:**
    - Material availability
    - Material quality consistency
    - Functional requirements

THE IMAGINATION FACTORY

THE IMAGINATION FACTORY

The Imagination Factory is a London based strategic design and creative engineering company. The team works with businesses of all shapes and sizes to help deliver solutions with a positive impact. As a certified Bcorp it is in The Imagination Factory's DNA to look for ways to design in harmony with the planet's resources so the PolyCE project was an exciting venture to be involved in. Together with FundWaste, the team set out to design a waste management sensor connected to the Internet of Things. FundWaste helps businesses generate revenue by recycling plastic and paper using a "waste to wealth" methodology. Working between the customer and the waste recyclers they deliver transparent pricing and use smart technology and artificial intelligence to support their waste to wealth infrastructure.

GOAL AND MAIN CHALLENGES: A NEW PRODUCT

With the Fundwaste demonstrator the goal was to design a product with post- consumer recycled (PCR) plastics using both Design for & from Recycling strategies. The product required a functional and visually appealing plastic housing.

RESULTS

Designing for & from Recycling strategies were implemented from the start of the development process. The guidelines developed during the PolyCE project were applied which helped to identify and overcome specific challenges. In the development of the Fundwaste sensor the key points to pay attention to were:

- Using build principles suitable for shredding at end of life
- Avoiding over-moulding and adhesives
- Avoiding paint finishes
- Maintaining wall thicknesses of 1mm and above
- Testing the properties of the recycled PC-ABS in a moulded demonstrator

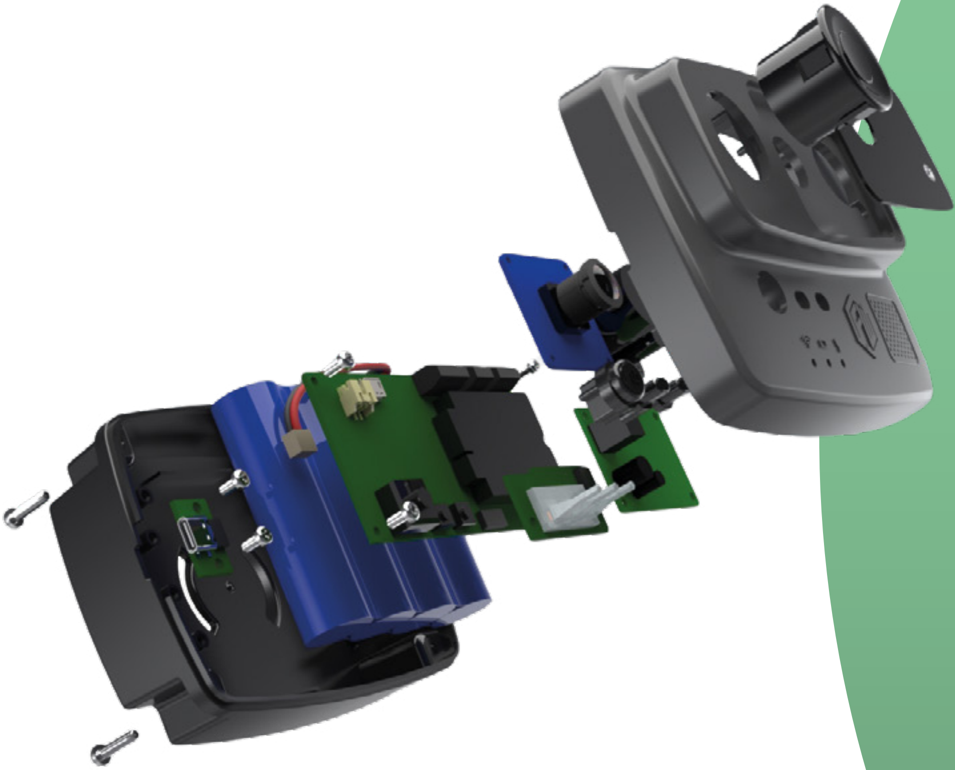
PRODUCT SETUP

The main components are the body (front and back cover) and a control knob. These three components were produced in the same material, black PC/ABS, complying to Design from/for Recycling guidelines. In addition, the product has internal electronic components and an IR-transparent lens cover. The housing is screwed together so it breaks up easily during the shredding step in the recycling process.

CHALLENGE

The Fundwaste demonstrator uses an infrared camera to monitor the waste source. To ensure reliability, the inner electronics are protected by a housing. To allow the IR-camera to still perform as desired, it is necessary to use a material which does not block the infrared spectra used by the camera. Typically, PMMA is used for such applications as it does not cause any disruption. Obtaining recycled PMMA from both post-consumer and post-industrial sources with the quality needed is currently not possible.

Therefore, only virgin material can be used. At the recycling stage the lens cover will easily break apart from the other parts as the design uses snaps to fix the lens cover to the main body. The best option for recycling would be to use compatible materials that do not significantly influence the quality of the main material stream. In this case the body is made from PCR PC/ABS and so the option for a PC lens cover was considered. However functional requirements did not allow the use of PC as it tends to block the IR spectra.



KEY LEARNINGS

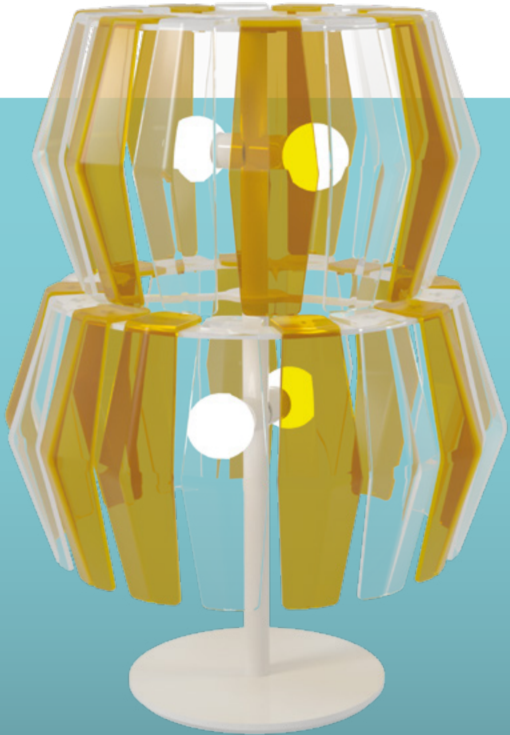
1. **Keep to bulk available recycled polymers. Selecting these materials will ensure supply in the future.**

2. **The recycled material portfolio is restricted.** Although bulk polymers are preferred, in some applications the need for other materials is required. Here the limited recycled material portfolio remains a hurdle. The same applies for colour freedom.

3. **The circular design process is close to the known design process.** Being aware of the specific hurdles when designing with recycled materials shows it is nearly the same as a standard design process.

4. **Using PCR plastics provides a company like Fundwaste with a powerful message that aligns with their brand messaging and is currently achievable with some limitations on design freedom.**

ona®



ONA

Ona is a design agency with a strong link to architecture, design, art and culture. They create lighting designs and custom lamps for their clients. In addition to the design and quality of their products, Ona is specialized in developing and manufacturing those ideas, concepts and lighting products that their clients dream about, matching their architecture and interior design projects. The mission of Ona is to create projects from idea to development, manufacturing custom lamps, create the onsite presentation, installation and final touches. Ona offers full-service support throughout the whole process to guarantee the best possible result.

GOAL AND MAIN CHALLENGES : A NEW PRODUCT

Within the PolyCE project Ona set the goal to develop a high-end design fixture for LED lighting considering design for and from recycling strategies. In essence the goal was to start implementing Post-consumer Recycled (PCR) or Post-industrial Recycled (PIR) plastics in multiple future high-end lighting components. The appearance of the product needed to comply with Ona's design principle of creating products with a 'noble appearance'.

Currently Ona uses materials like metals, exotic woods and ceramics to represent a noble and durable character. Switching to recycled plastics formed a major challenge as plastics are commonly perceived as 'cheap and low end' in their markets.

Tackling this challenge with Ona's limited experience in using plastic in production called for an integral yet step-by-step approach to define solutions.

A usual step to take in implementing r-plastics in products is to start with the so called low hanging fruit: parts or housings which do not have very challenging requirements. The parts for Ona's products however required high gloss transparency and translucency. Quality and aesthetics form the core of their products.

CHALLENGES

Taking on the assignment Ona set out to solve several aspects, such as:

Modularity

Modularity in the product design allows for versatility in a variety of end-products. For this purpose, a single plastic part called the 'boomerang', was developed. The part can be used in many configurations, giving birth to a whole family of lighting fixtures without the need for additional tooling.

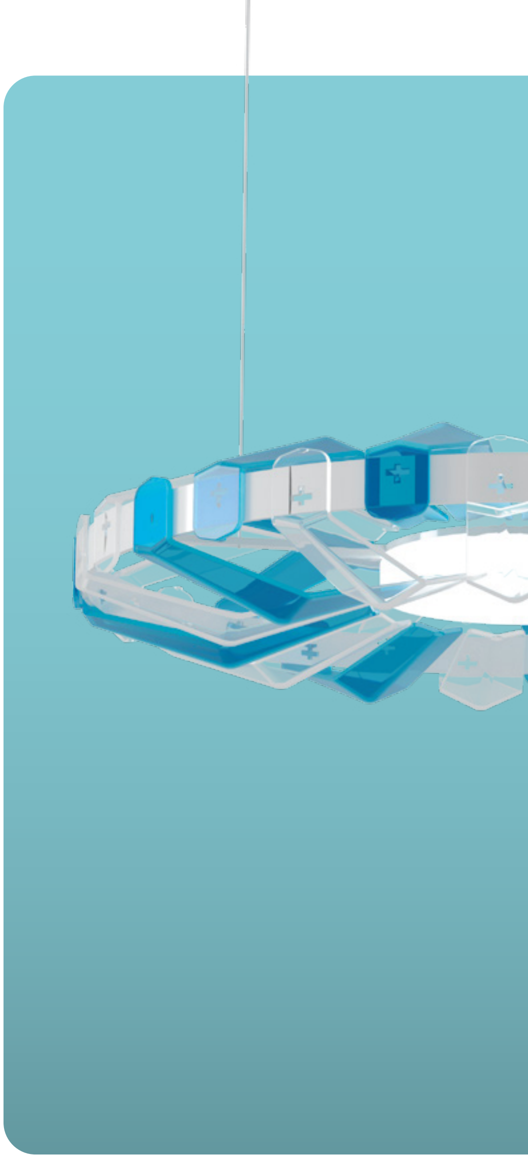
Its modular design also has the advantage that broken parts can easily be replaced. This prevents the renewal of entire product segments (e.g. lamp hoods) which would result in good parts going to waste. Using this product setup enabled Ona to extend the overall product life-time.

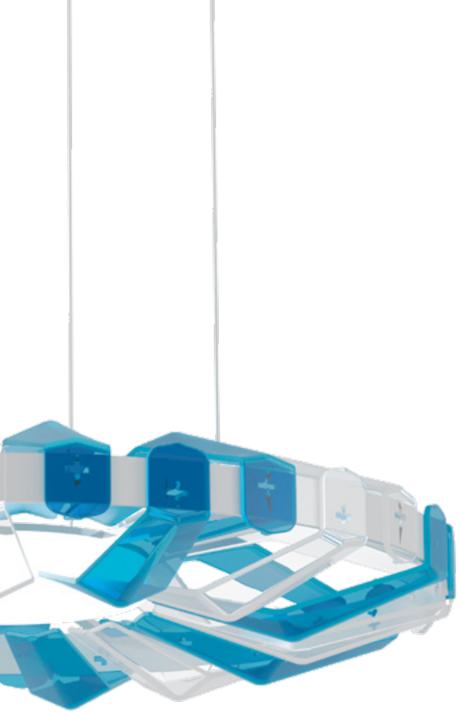
Transparency

In the concept stage, the goal was set to use plastics sourced from post-consumer waste. However, during the development stage it became clear that high quality transparent materials are nearly non-existent. Therefore, plastics from both post-industrial and post-consumer sources (even outside of WEEE streams) have been used. The required noble appearance could eventually be achieved by sourcing only the best recycled materials available from packaging and other waste sources.

Moulder experience

Knowledge of plastics moulding appeared to be crucial in the development process. One easily tends to blame the material (not performing as desired) when issues in production occur. And even more so when using recycled materials. However, knowing how to deal with materials in moulding and the willingness to execute tests can lead to surprising and satisfying results. The experience of the moulder that will handle the material is key. Initially the moulding trials with virgin PC did not result in producing parts successfully. However, partnering up with an experienced moulder led to satisfying results.





KEY LEARNINGS

1. **Transparent colour limitations** Obtaining colour freedom and transparency in recycled polymers is one of the big challenges of recyclers today. This means that finding high quality coloured and/or transparent grades for similar projects is challenging but not inevitable.

2. **PIR over virgin** When PCR plastics do not meet requirements, it is worth exploring PIR grades. A higher purity and colour freedom can be obtained from these sources. Compared to virgin, PIR plastics are still the better option.

3. **Processing experience** Moulding experience and the will to perform moulding tests are key to succeed. Involving the experience and knowledge of the moulder can make the difference in achieving the results you are looking for in your material.

4. **Modularity in design** Modularity is a great way to design a versatile product and offers the advantage to replace broken parts easily without replacing (and wasting) the entire product. Modularity also has the potential to better support recycling processes as parts usually break apart during shredding.

PHILIPS

Philips, the Dutch multinational in consumer and healthcare products, aims to make the world more healthy and sustainable offering meaningful innovation in healthcare, consumer lifestyle and lighting. Philips recognizes the potential of the circular economy and regards the use of recycled plastics as an important element in achieving this. As a leader in their field, Philips wants to set an example and stimulate the market for recycled plastics. In line with the EC strategy and their 'Green Deal' ambitions, Philips initiated an internal sustainability policy to force development teams to use recycled materials and specific recycled plastics. The Philips commitment in the EU pledge is to reach 7600 tons in 2025. This is a challenge for product development, knowing that many products contain a maximum of 500 grams of commodity plastics eligible to be replaced by r-plastics. Other product parts consist of metal components, thermoset plastics, food contact or medically approved plastics and electronics like LED's and PCB boards.

GOAL AND MAIN CHALLENGES: A DROP-IN METHOD

Within the PolyCE project Philips aimed to develop new insights and tangible demonstrator prototypes to test the limits and possibilities of recycled plastics. Applying the Design from Recycling approach and looking at the three key pillars for development: Drop-in complexity tool, Six step material approval and Look&Learn, led to several demonstrator cases that were worked out. These pillars formulate the base of the Drop-in Method as described in these guidelines. The demonstrators helped to explore the implementation possibilities and generate insights on how to solve the challenges in material validation, aesthetic standards, long term production stability and material availability.

RESULTS

In general, the demonstrators generated new and positive knowledge on r-plastics related to Philips production processes. The PolyCE project created valuable results and argumentation used in proposals and new initiatives with product management and marketing.

One proud result made possible with input from PolyCE partners was the commercial launch of the Senseo Eco in the EU market. In the future Philips aims to develop more sustainable product propositions including recycled WEEE plastics next to PIR, packaging waste, ELV plastics, chemically recycled plastics and maybe Ocean Waste Plastics.

DEMONSTRATOR CASES

1. PHILIPS FLOORCARE – VACUUM CLEANER

The floorcare demonstrator aims to implement and showcase the quality of recycled materials in both step-in and high-end vacuum cleaners.

By creating an overview of components and requirements of the existing product we determined 13 parts to perform moulding trials and produce part validations. Positive results were obtained using PCR ABS grades. The requirements per part differ, but the most important CTQ test concerned impact-, climate-, aesthetics- (high gloss black) and fatigue tests. The major difference with originally used virgin ABS was found in processing. Optimizing the processing

parameters to compensate mould shrinkage, flatness of round parts and lower melt temperatures required the most effort in this demonstrator. Trials were performed for the step-in model (high-gloss black non-lacquered plastic) and the high-end lacquered models by applying the knowledge gained during previous lacquering tests. This previous knowledge was gained by performing independent small-scale test trials, allowing to evaluate materials on key product requirements.

These requirements can include aesthetic, mechanical and even post-processing trials like printability and colour consistency. As Philips was already using recycled PP in this product, it was possible to make fully functional bagless vacuum cleaners from WEEE sourced recycled plastic in two different configurations: an unlacquered step-in model and a lacquered high-end model. As a result, the products are produced with more than 75% recycled plastics, an increase of 45% compared to the previous models.

Prior to the development of this demonstrator, early test mouldings already showed us that the quality of some recycled plastics today is very high. In some cases, the recycled material is even outperforming aesthetic expectations as was showcased in the demonstrator of the high gloss black vacuum cleaner.

2. PHILIPS SHAVING – MALE SHAVER

The inner frames of shavers are less demanding parts in terms of functionality and aesthetics. These frames are used in millions of Philips products produced in Europe and China. Altogether they form a plastic usage of 130 tons per year. Applying r-plastics successfully would mean a big step towards reaching the Philips goals on implementing recycled material. In this demonstrator they tested two materials;

- a black PCR PC/ABS
- a light grey PIR PC/ABS.

These parts have severe CTQ's on dimensional stability, water resistance (IP67), drop testing and chemical resistance. Production and full release test results where particularly positive for implementing the black PCR PC/

ABS supplied by MGG polymers (Müller-Guttenbrunn Group).

One issue that required additional testing was the chemical resistance of recycled PC/ABS, which is lower than the virgin grade. This material requirement resulted in the formation of small cracks caused by forces applied to the adapter plug inlet part during usage. As a result, this effected the water tightness and failing on a required product functionality.

To solve the slightly higher shrinkage rate, options that do not require mould changes were explored first. This means either adjusting the parts' process window or optimising moulding parameters. Both options did not solve the issue and new design rules had to be developed to decrease the force and tolerances of this module, consequently, requiring a slight mould adaptation. As a result of this project Philips is expecting to implement recycled PC/ABS inner frames and new design rules for male shavers in 2020-21.

3. SENSEO ECO

Philips challenged their coffee machine department to develop the most sustainable Senseo coffee machine by closing the loop. No compromises were allowed on the design and coffee taste, and an existing model was selected for optimisation. Based on this machine already selling in the market, the different possibilities to integrate recycled plastics in the product were evaluated. The complexity level tool described in the guidelines was used to map the opportunities and challenges. Executing moulding and product validations in Senseo and other espresso machines showed positive results for applications

of recycled ABS(PCR) and PC(PIR). To serve their markets Philips faced a big challenge: to provide a range of colours. Together with Sitraplas, the options were explored, and they developed beautiful colours in green, nougat brown, diffuse white, deep black and smoky translucent black recycled PC. MGG polymers, a specialized recycler, delivered the highgloss, deep piano black recycled ABS needed for the large housing parts.

The Senseo Eco demonstrator was an important case study for Philips to overcome challenges like material availability, heat stability and colour freedom. Simultaneously the environmental footprint was reduced, new useful aesthetics were created, and the product has helped to raise consumers awareness. The Senseo Eco exceeded the initial expectation. The final product could be produced with a recycled content of 75% and became an example of the many possibilities for integrating recycled plastics in new products. The results and insights delivered with this demonstrator project have been crucial for building the internal confidence needed to continue sustainable developments within Philips.

KEY LEARNINGS

In general, it's possible to conclude that both Post-Consumer Recycled ABS and PC/ABC sourced from WEEE streams, and Post-Industrial Recycled PC are implementable in new electronic equipment with minor design changes.

However, when high product requirements are applicable, further development on the material level could be needed. For example, within the Philips demonstrator cases, extra development was needed on the chemical resistance of recycled PC/ABS and ball pressure resistance for recycled ABS. In some cases, making slight design changes or new design rules can also compensate this. The PolyCE project opened many opportunities and fact-based development insights to match Marketing and Product management (customer) demand. Putting speed and continuous focus on the implementation of recycled plastics has been a big advantage of the PolyCE project and has proven to be important for its success.

1. **Further material development is needed** for properties like impact resistance, chemical resistance, materials shrinkage and plastic strength in relation to part design.

2. **IEC[13] ball pressure requirements for recycled ABS parts can lead to failure above 90°C.**

3. **Colour and gloss requirements of Philips are high, yet possible to reach with recycled ABS.**

4. **Mould pollution over time can add business case costs as more frequent cleaning is needed.**

5. **Positive trend in recycled plastics is that the odour perception is improving.**

6. **Philips is for now only open to switch to sustainable materials under cost-down scenarios.** This is logical as a Drop-in Method will not gain quality improvements and/or added functionality.

7. **More validation efforts & costs are needed when using recycled plastics.**

8. **Business risks like RoHS[13] and REACH[13] safety are always relevant and can be met by recyclers.** Philips encourages recyclers to perform more frequent batch testing and in-line statistical process control when possible.

9. **Financial compensation** in the form of tax benefits, recycled material refund at procurement stage or a virgin plastics tax could help generate positive business cases and change the playing field for companies using PCR plastics in high volume, low margin consumer goods.

10. **Market data shows not all consumers/ countries are asking to use more recycled plastics.**

11. **Quality of recycled plastics sourced from WEEE has been improving over recent years and the current black recycled ABS grades are close to virgin.** The next major step is colour freedom by compounding, colour sorting or chemical/physical recycling technology.

12. **UL[13] listing is needed for materials used in products intended for the US market.** The associated costs for the UL Yellow Card tests are usually too expensive for the volume recyclers produce. On top of this recyclers need to deliver more lots compared to registration for virgin plastics which increases the costs even more. Levelling the playing field in the future is needed.

13. **It takes time for business to shift from virgin to recycled plastics as each product and part needs to be validated.**

13. IEC: International Electrotechnical Commission
RoHS: Restriction of Hazardous Substances
REACH: Registration, Evaluation, Authorization and restriction of Chemicals
UL: Underwriters Laborotories

WHIRLPOOL

Whirpool, a global company, regionally focused, they are committed to taking care of their communities and the planet. Reducing the amount of water and energy that their products use, designing zero waste to landfill manufacturing plants, and using on-site solar and wind to help power facilities are all part of their responsibility to conserve the earth's resources. Having a strong purpose behind everything they do keeps their people, products, and services focused on improving lives at home.

GOAL AND MAIN CHALLENGES: A DROP-IN METHOD

The main goal for the demonstrators developed within the PolyCE project is the effective re-use of closed loop recycled plastics (PCR) from WEEE waste streams. Here, the individual parts or products need to meet the usual and expected levels of quality and performance. Within the project multiple series of material tests were performed to characterize the key physical-mechanical performances. In the case of positive results, lab-scale material testing and production-scale moulding trials were executed to create tangible proof. The focus of the project was put on components for washing machines made of recycled (PCR)PP filled with $CaCO_3$, and refrigerator components made of recycled (PCR) polystyrene. The PCR-plastics from these two products cover most of the total thermoplastics used (more than 35% of the total thermoplastics volume). The main development challenges referred to quality, performances (visual and physical) and legislative compliance of PCR plastics. None of these was allowed to compromise the whole product, its components or the consumers expectation.

RESULTS

WASHER TUB DEMONSTRATOR

Generally, when recycled, washing machines are collected and treated within the Large Domestic Appliance category. This category includes washers, dryers, dishwashers and cooking appliances. Trials were preformed on materials from two reorganized clusters to limit the material diversity and (plastic) contamination. The target material for these clusters is filled-PP. The first cluster covered the collection of plastics from the entire washing machine. The second cluster targeted the washer tubs, a single plastic part of a washing machine. At the end of the recycling process no significant difference was found in the quality or contamination of the sorted plastic flakes retrieved from both clusters. Because no significant difference was found and the material collection of the 'washers only' cluster (entire washing machine) is more economical, further work proceeded only with the material from this cluster. An improvement in material quality was noted when comparing the final material quality to the current pre-treatment protocols. The part at hand, a washing machine tub comes with high requirements for mechanical and chemical stress resistance and the material used needs to comply to RoHS and REACH legislation. The legislative, chemical, thermal, mechanical and other properties were tested for compliancy and showed, on a property level, that the recycled plastic is suitable for the intended application without the need to add additives to the material. Industrial moulding trials showed no difference in processability of the material. Assembly of the parts showed no issues regarding weldability, weld strength or dimensional tolerances. For now, the major question remaining is how the material behaves during accelerated life-time tests and if a reorganization of the collection procedure can be realized to ensure material availability outside the project.

REFRIGERATOR LINER DEMONSTRATOR

Freezers and refrigerators currently fall under Temperature Exchange Equipment (EU category 1) and are treated separately in recycling from other electronics appliances. This forms an advantage as the recycling stream is less heterogenous both on the product type and material level. Within the project tests were performed on three clusters: standard fridges, white drawers and transparent drawers. The materials derived from these clusters were tested with two possible applications in mind. The standard fridge cluster was intended to be reused for fridge liners and door liners. The materials derived from the fridge drawer clusters were to be used again in injection moulded fridge drawers. The flakes produced from the transparent drawer stream were intended to comply with current transparent PCR grade standards.

But in the process, it was found that it is still difficult to obtain this grade from a mechanical recycling process as impurities seemed inevitable in the shredding processes. As the right solutions where not found and extra costs involved could not be justified, the trials for the transparent and white drawer clusters had to be discontinued. In general, for all clusters, food contact requirements remained uncertain so only feasibility trials were set-up for the material recovered from the standard fridge cluster (rHIPS).

In these trials extrudability and thermoformability was tested on:

- two mixtures of virgin and recycled material; HIPS and rHIPS (respectively in 80/20 and 50/50, m%/m% ratio)
- 100% r-HIPS

After these tests, assembly trials were executed followed by in-house testing protocols. All the material property, processability and functionality tests showed positive results: the recycled material proved to be similar to virgin quality. To get the desired aesthetic result, future colour optimization needs to happen, but this could be done within the possibilities of today's process technology.

From a technical point of view the recycled material is suitable to replace the virgin grade used today. However, the trials needed to be discontinued as the material could (at this stage) not comply with the food grade regulations. This is a strong go/no-go requirement and remains the biggest obstacle for applying the material in this product segment. Investigations also taught us that current available rHIPS material from WEEE is not on the EC priority list to be evaluated and approved for food-grade applications.

KEY LEARNINGS

1. **Closed loop recycling and clustering showed to be beneficial for the quality of the recycled material and its applicability in the targeted product.** Material sources from similar applications have a high probability to fulfil necessary requirements for use in the same new products.

2. **Testing hazardous legacy substances, RoHS and REACH compliance on both flake and pellet level have been performed in cooperation with Erion.** Although some flakes did not comply, the substance gets diluted during the compounding process, ensuring compliancy on the pellet level.

3. If it would be possible to **re-arrange waste clusters and collection schemes to obtain closed loop recycled plastics**, the circular economy could get a giant boost with manufacturers like Whirlpool setting an example.

4. **Obtaining a food-contact approved treatment process is very difficult for mechanical recyclers of both WEEE and other waste sources.** A big effort has been made in what is needed to obtain food contact approval for rHIPS from WEEE. But this seems to be impossible at this moment due to unharmonized pieces of legislation. If legislation was harmonized soon and processes approved, it could create a giant boost in recycling and the uptake of recycled materials.

EPILOGUE & BIBLIO-GRAPHY

EPILOGUE

This document is the outcome of research performed within the the PolyCE project that has received funding from the EU's Horizon 2020 Research and Innovation Program under Grant Agreement number 730308. It is based on Deliverable 8.1.: "Guidelines on life cycle thinking integration and use of PCR plastics in new electronic products", which is the outcome of almost four years of close collaboration between the project partners and several external experts. To the best of our knowledge, this document contains the current state of research. However, since materials and processes are constantly evolving, it might need to be updated in the future. Future research could furthermore analyse requirements and opportunities for cluster-specific guidelines.

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GOOD DESIGN SOLVES PROBLEMS, GREAT DESIGN PREVENTS THEM

COLOPHON

This book has been created by the partners of the PolyCE EU project, which is a Horizon 2020 EU funded project, that has the ambition to enhance the uptake of recycled materials in new electrical and electronic appliances.

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PolyCE

"THESE GUIDELINES ARE A GREAT PRACTICAL TOOL TO HELP DESIGN PRODUCTS READY FOR A CIRCULAR ECONOMY, IMPROVE ENVIRONMENTAL FOOTPRINT AND REDUCE DEPENDENCY ON NATURAL RESOURCES"

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