



## Work Package 5

# Deliverable D5.3- Food contact recyclates

## Lead Partner: PRE

Author(s): Mathilde Taveau (PRE), Alexandra Pereira (PRE), Emma Väre (VTT), Manu Mulakkal (VTT), Mathilde Chachignon (VERI), Jasmin Pevec (RE)

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| Contact persons         | Mathilde Taveau (PRE)<br><a href="mailto:Mathilde.taveau@plasticsrecyclers.eu">Mathilde.taveau@plasticsrecyclers.eu</a>             |                     |                                   |
| Website                 | <a href="https://stopp-project.eu">https://stopp-project.eu</a>                                                                     |                     |                                   |
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| Deliverable responsible | PRE                                                                                                                                 | Contact person      | Mathilde Taveau                   |



| Deliverable Contributors                 |                     |              |                                       |                                       |
|------------------------------------------|---------------------|--------------|---------------------------------------|---------------------------------------|
|                                          | Name                | Organisation | Role/ Title                           | E-mail                                |
| <b>Deliverable leader</b>                | Mathilde Taveau     | PRE          | Public and Regulatory Affairs Manager | Mathilde.taveau@plasticsrecyclers.eu  |
| <b>Contributing Author(s)</b>            | Alexandra Pereira   | PRE          | Regulatory project manager            | Alexandra.pereira@plasticrecyclers.eu |
|                                          | Manu Mulakkal       | VTT          | Senior Scientist                      | Manu.mulakkal@vtt.fi                  |
|                                          | Emma Väre           | VTT          | research scientist                    | emma.vare@vtt.fi                      |
|                                          | Jasmin Pevec        | Remondis     | Polymer Scientist                     | jasmin.pevec@remondis.de              |
|                                          | Mathilde chachignon | Veolia       | Senior scientist                      | Mathilde.chachignon@veolia.com        |
|                                          | Patricia Mivelaz    | Veolia       | Research scientist                    | Patricia.mivelaz@veolia.com           |
| <b>Reviewer(s)</b>                       | Mathilde Taveau     | PRE          | Public and Regulatory Affairs Manager | Mathilde.taveau@plasticsrecyclers.eu  |
|                                          |                     |              |                                       |                                       |
|                                          |                     |              |                                       |                                       |
| <b>Final review and quality approval</b> | Milad Mosallaei     | VTT          | Project coordinator                   | milad.mosallaei@vtt.fi                |

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# TABLE OF CONTENTS

|   |                                                                                 |    |
|---|---------------------------------------------------------------------------------|----|
| 1 | INTRODUCTION .....                                                              | 13 |
| 2 | FOOD CONTACT LEGISLATION .....                                                  | 13 |
|   | REGULATION (EU) No 10/2011.....                                                 | 13 |
|   | REGULATION (EU) No 2022/1616.....                                               | 14 |
| 3 | FEEDSTOCK.....                                                                  | 15 |
|   | TYPE, MODE OF COLLECTION AND ORIGIN OF INPUT MATERIALS .....                    | 15 |
|   | 3.1.1 Feedstock for task 5.2 .....                                              | 15 |
|   | 3.1.1.1 Feedstock 1: separately collected household waste from Finland.....     | 15 |
|   | 3.1.1.2 Feedstock 2: German PP caps from DRS.....                               | 17 |
|   | 3.1.1.3 Feedstock 3: Separately collected household packaging from Germany..... | 17 |
|   | 3.1.2 Feedstock for task 5.3 .....                                              | 18 |
| 4 | RECYCLING PROCESS .....                                                         | 20 |
|   | PRE-PROCESSING.....                                                             | 21 |
|   | 4.1.1 Grinding.....                                                             | 21 |
|   | 4.1.2 Washing.....                                                              | 22 |
|   | DECONTAMINATION .....                                                           | 23 |
|   | 4.1.3 Air elutriation.....                                                      | 23 |
|   | 4.1.4 Extrusion .....                                                           | 24 |
|   | 4.1.5 Super-cleaning oven .....                                                 | 27 |
|   | 4.1.6 Optimisation of the decontamination unit.....                             | 27 |
| 5 | METHODS.....                                                                    | 30 |
|   | PROTOCOLS (SUSPECT SCREENING AND VOCs ANALYSIS).....                            | 30 |
|   | 5.1.1 Sample pre-treatment.....                                                 | 30 |
|   | 5.1.1.1 Micronization (flakes only).....                                        | 30 |



|                                  |                                                       |    |
|----------------------------------|-------------------------------------------------------|----|
| 5.1.1.2                          | Quartering.....                                       | 31 |
| 5.1.1.3                          | Cryogrinding.....                                     | 31 |
| 5.1.2                            | Protocol for suspect screening analysis.....          | 32 |
| 5.1.2.1                          | Sample pre-treatment .....                            | 32 |
| 5.1.2.2                          | Sample extraction .....                               | 33 |
| 5.1.2.3                          | Analysis .....                                        | 34 |
| 5.1.2.4                          | Data Interpretation .....                             | 35 |
| VOCs ANALYSIS.....               |                                                       | 36 |
| 5.1.3                            | Sample pre-treatment .....                            | 37 |
| 5.1.4                            | Analysis.....                                         | 38 |
| 5.1.5                            | Calibration and quantification.....                   | 39 |
| DECONTAMINATION EFFICIENCY ..... |                                                       | 42 |
| 5.1.6                            | Initial set-up (Task 5.2 Feedstock).....              | 42 |
| 5.1.6.1                          | Suspect screening.....                                | 43 |
| 5.1.6.2                          | VOCs .....                                            | 44 |
| 5.1.7                            | Improved set-up (Task 5.3 Feedstock) .....            | 45 |
| 5.1.7.1                          | Suspect screening.....                                | 45 |
| 5.1.7.2                          | VOCs .....                                            | 47 |
| 5.1.7.3                          | TGA study.....                                        | 49 |
| 6                                | VISCOSITY PROFILES.....                               | 50 |
| 7                                | CHEMICAL CONTAMINANT LEVELS AND RISK ASSESSMENT ..... | 52 |
| 7.1.                             | SAMPLING.....                                         | 52 |
| 7.2.                             | ANALYSIS.....                                         | 52 |
| 7.3.                             | METHODOLOGY FOR RISK ASSESSMENT .....                 | 53 |
| 7.1.1                            | Migration modelling .....                             | 53 |
| 7.1.2                            | Establishment of the migration limits .....           | 54 |
| 7.1.3                            | Substance origin .....                                | 55 |
| 7.4.                             | RESULTS .....                                         | 56 |
| 8.                               | CONCLUSION & RECOMMENDATIONS .....                    | 52 |
| 9.                               | REFERENCES .....                                      | 77 |





# FIGURES

|                                                                                                                                                                                                              |    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 1: Separated PP waste examples. Left: food packaging, Middle: non-food packaging, Right: unidentified (labeled non-food).....                                                                         | 16 |
| Figure 2: German PP caps from DRS.....                                                                                                                                                                       | 17 |
| Figure 3: Task 5.3 Feedstock. End of Life PP reuse cups.....                                                                                                                                                 | 19 |
| Figure 4: Recycling process flow diagram. Decontamination steps highlighted .....                                                                                                                            | 21 |
| Figure 5. Pilot-scale grinding setup at VTT, used for size reduction. ....                                                                                                                                   | 21 |
| Figure 7. Snapshot of sorted Finnish PP flakes. A, unwashed fraction, B, sink float separated and washed fraction.....                                                                                       | 23 |
| Figure 8. Air elutriation setup. A: schematic of the process. B: Actual equipment, Blue line demonstrates air flow, yellow bottom of the barrel (heavies) and red placement of the light fraction trap. .... | 24 |
| Figure 9: VTT VAREX flow diagram .....                                                                                                                                                                       | 25 |
| Figure 10: Close-ups of melt-filters (task 5.2 feedstock). A PP caps Germany, B separated Finland, C separated Germany.....                                                                                  | 26 |
| Figure 11: Contaminants trapped in filter from Task 5.3 feedstocks.....                                                                                                                                      | 26 |
| Figure 12: The super-cleaning oven. Earlier design to final set-up.....                                                                                                                                      | 27 |
| Figure 13. Knife grinder used for the sample prep (RETSCH, SM-2000) .....                                                                                                                                    | 31 |
| Figure 14: Quartering step .....                                                                                                                                                                             | 31 |
| Figure 15. Cryogrinding apparatus (RETSCH Cryomill) .....                                                                                                                                                    | 32 |
| Figure 16. Samples before extraction.....                                                                                                                                                                    | 33 |
| Figure 17: Samples during extraction.....                                                                                                                                                                    | 34 |
| Figure 18: Extracts of samples after extraction.....                                                                                                                                                         | 34 |
| Figure 19: GCXGC-TOF MS (LECO).....                                                                                                                                                                          | 35 |
| Figure 20.: Compound distribution by category .....                                                                                                                                                          | 36 |



|                                                                                                                                                                             |    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 21.: Thermodesorption tube with sample.....                                                                                                                          | 38 |
| Figure 22.: Thermodesorption tube with sample .....                                                                                                                         | 38 |
| Figure 23.: Calibration range of Limonene (campaign 1, calibration range : 0.2 – 10 ppm) .....                                                                              | 40 |
| Figure 24.: Concentration of Limonene in Sample 3.....                                                                                                                      | 41 |
| Figure 25: Recycling Process flow (Path B).....                                                                                                                             | 42 |
| Figure 26: Number of detected compounds in samples.....                                                                                                                     | 43 |
| Figure 27.: Number of detected compounds in samples by categories.....                                                                                                      | 44 |
| Figure 28: Process flow for super cleaning oven trials.....                                                                                                                 | 45 |
| Figure 29: Number of detected compounds in input feedstock by category .....                                                                                                | 46 |
| Figure 30: Number of detected compounds output of Super cleaning oven trials by category.....                                                                               | 46 |
| Figure 31: Residual mass of supercleaned flakes after TGA.....                                                                                                              | 49 |
| Figure 32: Viscosity profiles of task 5.2 Feedstock.....                                                                                                                    | 50 |
| Figure 33: Viscosity profiles of task 5.3 Feedstock.....                                                                                                                    | 51 |
| Figure 34. Number of substances legislated in either Regulation (EU) 10/2011 or Regulation (EC) 1334/2008, and also the sum of legislated substances in either or both..... | 57 |
| Figure 35. Origin of substances by percentage of detected substances per recycled source. Legend: All Plastics: sum of “plastics” and “plastics FCMS” categories. ....      | 58 |



# TABLES

|                                                                                                                                                                                                                                                                           |    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 1: Optimisation trials .....                                                                                                                                                                                                                                        | 29 |
| Table 2: Cryogrinding conditions .....                                                                                                                                                                                                                                    | 32 |
| Table 3: Sample pre-treatment for suspect screening analysis .....                                                                                                                                                                                                        | 33 |
| Table 4: List of VOCs.....                                                                                                                                                                                                                                                | 36 |
| Table 5: Sample pre-treatment for VOCs.....                                                                                                                                                                                                                               | 37 |
| Table 6: Calibration curve for Limonene (campaign 1) .....                                                                                                                                                                                                                | 39 |
| Table 7: Ranges of compounds (campaign 1 and 2) .....                                                                                                                                                                                                                     | 40 |
| Table 8: VOCs Concentrations in samples (ppm) .....                                                                                                                                                                                                                       | 44 |
| Table 9: VOCs Concentrations in input feedstock (ppm) .....                                                                                                                                                                                                               | 47 |
| Table 10: VOCs concentrations in output of Super cleaning oven trials.....                                                                                                                                                                                                | 48 |
| Table 11. Exposure conditions used for modelling and respective targeted applications.....                                                                                                                                                                                | 54 |
| Table 12: Overview of detected substances, concentrations, HQ from first modelling step, origins and detailed comments. Legend: PI = plastic input; RP = recycled plastic. For non-detects, the concentration in the pellets was considered as the LOQ (0.1 mg/kg). ..... | 59 |
| Table 13. Results from the second modelling step .....                                                                                                                                                                                                                    | 59 |



# Project summary

At STOPP, we're pioneering a transformative initiative to revolutionize the way we approach food packaging by working with all the stakeholders in the value chain to promote the "5 Rs": Refuse, Reduce, Redesign, Reuse, and Recycle

Our main aim is to drastically reduce the environmental impact caused by plastic waste in food packaging, aligning closely with the EU's Packaging and Packaging Waste Directive. Our collaborative efforts encompass every facet of the food packaging value chain.

We're set on creating circular strategies that not only appeal to plastic production and processing but also drive awareness through a multi-actor network. Our strategic actions include analysing plastic waste impact, monitoring current usage, designing sustainable business models, boosting recycling efforts, and understanding consumer attitudes through an in-depth study.

## Executive summary

This deliverable assesses the potential of recycled polypropylene (PP) to be used in food contact applications within Work Package 5 of the STOPP project. The work focuses on selected post-consumer and reuse-based PP feedstocks, including separately collected household packaging and end-of-life PP beverage cups from a closed-loop reuse system. These materials were processed through mechanical recycling and decontamination steps, including grinding, washing where relevant, air elutriation, extrusion, degassing and treatment in a super-cleaning oven.

The objective was to generate technical evidence on how these recycling steps affect the presence of residual substances in PP recyclates and whether the resulting materials could be considered for future food contact applications. To support this assessment, the deliverable combines suspect screening analysis with targeted analysis of volatile organic compounds (VOCs). This approach makes it possible to identify, quantify and compare substances present in the input materials, intermediate fractions and final recyclates, including contaminants from previous use, degradation products, residues linked to collection and sorting, and non-intentionally added substances (NIAS).



The results are interpreted in light of the EU food contact regulatory framework, particularly Regulation (EU) No 10/2011 and Regulation (EU) 2022/1616. These regulations underline that recycled plastics intended for food contact must not only be effectively decontaminated, but also assessed against food safety principles, authorised substance requirements, migration considerations and process control expectations.

Overall, the deliverable shows that recycled PP has potential for food contact applications, but that this potential depends on strict control of input materials, effective process design, robust decontamination performance and case-by-case risk assessment. The work does not constitute an authorisation dossier, but it provides practical learnings and analytical evidence to support further optimisation of recycling processes and future assessments of food-contact recycled PP.



# Acronyms and abbreviations

| Acronym             | Definition                                                                        |
|---------------------|-----------------------------------------------------------------------------------|
| <b>DCM</b>          | Dichloromethane                                                                   |
| <b>DRS</b>          | Deposit Return System                                                             |
| <b>EC</b>           | European Commission                                                               |
| <b>EFSA</b>         | European Food Safety Authority                                                    |
| <b>EoL</b>          | End of Life                                                                       |
| <b>EtOH</b>         | Ethanol                                                                           |
| <b>EU</b>           | European Union                                                                    |
| <b>FCM</b>          | Food Contact Material                                                             |
| <b>GC-MS</b>        | Gas Chromatography–Mass Spectrometry                                              |
| <b>GC×GC-TOF MS</b> | Comprehensive Two-Dimensional Gas Chromatography–Time-of-Flight Mass Spectrometry |
| <b>HDPE</b>         | High-Density Polyethylene                                                         |
| <b>HQ</b>           | Hazard Quotient                                                                   |
| <b>IML</b>          | In-Mould Label                                                                    |
| <b>IR</b>           | Infrared                                                                          |
| <b>LOQ</b>          | Limit of Quantification                                                           |
| <b>NIAS</b>         | Non-Intentionally Added Substances                                                |
| <b>NIR</b>          | Near Infrared                                                                     |
| <b>PET</b>          | Polyethylene Terephthalate                                                        |
| <b>PP</b>           | Polypropylene                                                                     |
| <b>ppm</b>          | Parts per million                                                                 |
| <b>UV/VIS</b>       | Ultraviolet–Visible                                                               |
| <b>VOC</b>          | Volatile Organic Compound                                                         |
| <b>WP</b>           | Work Package                                                                      |



# 1 Introduction

This deliverable 5.3 presents the work carried out under Work Package 5 of the STOPP project to assess the potential use of recycled polypropylene (PP) in food contact applications. As plastic food packaging moves towards more circular models, demonstrating the safety of recycled materials is essential. This is particularly important for PP, which is widely used in food packaging but remains more challenging to recycle back into food contact applications than other polymers such as PET.

The work therefore contributes to understanding the conditions under which recycled PP could potentially be used in food contact materials. It highlights the importance of input material control, process design, decontamination efficiency, analytical monitoring and risk assessment. While the deliverable does not constitute a novel technology application dossier, it provides technical evidence and practical learnings that can support further optimisation of recycling processes and future assessments of food-contact recycled PP.

## 2 Food contact legislation

### Regulation (EU) No 10/2011

Regulation (EU) No 10/2011 is the main EU legislation setting specific rules for plastic materials and articles intended to come into contact with food. In simple terms, its purpose is to make sure that plastic packaging, containers, utensils and other plastic articles do not transfer substances to food in amounts that could endanger human health. It does this by defining which substances can be intentionally used in the manufacture of food contact plastics, under which conditions they can be used, and how compliance must be demonstrated.

The Regulation supports the broader food contact materials framework by setting detailed requirements for plastics. It establishes an EU list of authorised substances, including monomers, additives and certain processing aids, and introduces restrictions such as specific migration limits and overall migration limits. These



limits are used to control the amount of substances that may move from the plastic into food. The Regulation therefore provides a clear reference point for assessing whether a plastic material is suitable for food contact use.

For recycled plastics, Regulation (EU) No 10/2011 remains important because the final recycled material must still comply with the same safety principles as virgin food contact plastics. Even if the recycling process is effective, the recyclate may contain degradation products, residues from previous use, contaminants from collection and sorting, or non-intentionally added substances (NIAS). These substances must be considered when evaluating whether the recycled material can be safely used in food contact applications. The section below on Regulation (EU) No 2022/1616 provides more information on the latter.

This is particularly relevant for the risk assessment work carried out in this deliverable. The analytical work performed on PP recyclates aims to identify and quantify substances that may remain in the material after collection, sorting, washing, extrusion and super-cleaning. The results are then interpreted in light of food contact safety requirements, including whether detected substances are known, authorised, restricted, or potentially relevant from a toxicological perspective. In this context, Regulation (EU) No 10/2011 provides the regulatory basis for linking chemical analysis with safety assessment.

## Regulation (EU) No 2022/1616

[Regulation \(EU\) No 2022/1616](#) is the specific EU legislation for recycled plastic materials and articles intended to come into contact with food. Its purpose is to make sure that recycled plastics used in food packaging are safe for consumers. It recognises that plastic waste may contain substances from previous use, misuse, collection, sorting or recycling operations, and that these substances may remain in the recyclate as non-intentionally added substances.

The Regulation therefore sets rules for recycling technologies, quality control, traceability, and the placing on the market of recycled plastic food contact materials. One of its core objectives is to ensure that only recycled plastic produced through suitable and controlled processes can be used in food contact applications.



Regulation (EU) 2022/1616 also establishes the role of risk assessment in the authorisation of recycling processes. EFSA assesses whether recycling processes are able to remove contaminants to a level that is safe for the intended food contact use, while the European Commission and Member States decide on authorisation and maintain the EU system for approved processes and facilities. This creates a regulatory framework in which scientific evidence, process control and compliance documentation are all needed to justify the use of recycled plastics in food contact materials.

This Regulation is particularly important for the work carried out in this deliverable because the study focuses on whether recycled PP can be considered for food contact applications after decontamination. The analytical work on suspect substances and VOCs, together with the evaluation of the recycling and super-cleaning steps, directly supports the type of evidence required under Regulation (EU) 2022/1616.

In this context, Regulation (EU) 2022/1616 provides the key regulatory link between decontamination performance and the possible future use of recycled PP in food contact materials. It shows why the assessment must consider the origin of the input material, the effectiveness and control of each recycling step, the nature and concentration of detected substances, and the intended application of the final recycle. The results generated in this deliverable are therefore relevant for a potential novel technology application under Regulation (EU) No 2022/1616 for recycled PP.

## 3 Feedstock

### Type, mode of collection and origin of input materials

#### 3.1.1 Feedstock for task 5.2

##### 3.1.1.1 Feedstock 1: separately collected household waste from Finland

| Information                 | Specification                                                                                                                            |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Material in scope           | Post-consumer waste PP                                                                                                                   |
| Origin                      | Primary food contact material produced following Regulation (EU) No 10/2011. Hand separated from stream.<br>Material originates from EU. |
| Source                      | Non-Hazardous Municipal Waste, plastic packaging collection stream under the producer responsibility scheme.                             |
| Collection                  | Separate collection.                                                                                                                     |
| Specification plastic input | Maximum 5 % of materials and articles used in contact with non-food materials or substances.                                             |

In Finland, plastic packaging is separately collected due to producer responsibility legislation. PP was separated from this collection stream at HSY and PJH by visual identification (material marking PP (05)) and a handheld NIR device (trinamix Model SYS-IR-R-P). From these batches of PP waste, food packaging was separated at VTT. Food packaging was separated by positively identifying packages as containers in which food is sold, mostly by labels and knowledge of Finnish food packaging's appearance.



Figure 1: Separated PP waste examples. Left: food packaging, Middle: non-food packaging, Right: unidentified (labeled non-food).

The HSY and PJH streams were combined after separation of PP food packaging to achieve a big enough batch size. The resulting feedstock is separately collected PP food packaging from Finland. Of the total PP feedstock, 10% was non-food packaging, 6% unidentified and 84% food packaging by mass.

### 3.1.1.2 Feedstock 2: German PP caps from DRS

| Information                        | Specification                                                                                                                                       |
|------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Material in scope</b>           | Post-consumer waste PP                                                                                                                              |
| <b>Origin</b>                      | Post-consumer PP caps originating from the single-use deposit return system for beverage packaging in the European Union                            |
| <b>Source</b>                      | Non-hazardous post-consumer packaging waste originating from the single-use deposit return stream.                                                  |
| <b>Collection</b>                  | Separately collected and mechanically separated from the PET fraction during the processing and preparation of single-use deposit return packaging. |
| <b>Specification plastic input</b> | 100% PP from food contact material                                                                                                                  |

The material consists of post-consumer PP caps originating from the single-use deposit return system for beverage packaging in the European Union. The PP caps were separately collected and mechanically separated from the PET fraction during the processing and preparation of the single-use deposit return packaging. The resulting PP fraction was subsequently used as the plastic input material for further processing.



Figure 2: German PP caps from DRS

### 3.1.1.3 Feedstock 3: Separately collected household packaging from Germany

| Information              | Specification                                                                                                                                                                                      |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Material in scope</b> | Post-consumer waste PP                                                                                                                                                                             |
| <b>Origin</b>            | Primary food contact material manufactured in accordance with Regulation (EU) No 10/2011. The material originated from the Yellow Bag collection stream and was received in the form of compressed |

|                            |                |                                                                                                                                                                                                |
|----------------------------|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                            |                | bales. The bales were manually sorted into food and non-food packaging fractions                                                                                                               |
| <b>Source</b>              |                | The material is non-hazardous municipal waste originating from the original post-consumer plastic packaging collection stream (Yellow Bag)                                                     |
| <b>Collection</b>          |                | Separately collected post-consumer plastic packaging waste from the Yellow Bag collection stream, received as compressed bales and manually sorted into food and non-food packaging fractions. |
| <b>Specification input</b> | <b>plastic</b> | A maximum of 5 % of the materials and articles used are intended to come into contact with non-food materials or substances.                                                                   |

In Germany, plastic packaging is separately collected through the household packaging collection system. The material originated from the Yellow Bag collection stream and was received in the form of compressed bales. The bales were opened and manually sorted by hand into food and non-food packaging fractions. The sorting was carried out based on the identification of the respective packaging articles, allowing the food and non-food fractions to be separated prior to further processing.

### 3.1.2 Feedstock for task 5.3

The feedstock for Task 5.3 consisted of end-of-life polypropylene (PP) beverage cups collected from a closed-loop reuse system operating at stadium events in Germany. The cups were removed from the reuse loop and designated as end-of-life primarily based on visual criteria, including discoloration, persistent food staining, and lipstick marks, as well as physical damage such as cracks, fractures, or breakage. A notable characteristic of the collected cups was the extensive use of branding, applied through various decoration technologies. This represented the primary distinction between the different cup types. Based on the branding method, the samples were categorised into four groups: transparent cups (unbranded), digital printed cups, in-mould label (IML) cups, and cups decorated using other printing techniques, which were collectively classified as "other printed".



Figure 3: Task 5.3 Feedstock. End of Life PP reuse cups

| Information                 | Specification                                     |
|-----------------------------|---------------------------------------------------|
| Material in scope           | End of life Polypropylene <b>Transparent cups</b> |
| Origin                      | Primary food contact (drinks) of EU (DE) origin   |
| Source                      | Stadium events                                    |
| Collection                  | Closed loop; reusable cups                        |
| Specification plastic input | 100% PP from food contact material                |

| Information                 | Specification                                        |
|-----------------------------|------------------------------------------------------|
| Material in scope           | End of life Polypropylene <b>Direct Printed cups</b> |
| Origin                      | Primary food contact (drinks) of EU (DE) origin      |
| Source                      | Stadium events                                       |
| Collection                  | Closed loop; reusable cups                           |
| Specification plastic input | 100% PP from food contact material                   |

| Information                 | Specification                                        |
|-----------------------------|------------------------------------------------------|
| Material in scope           | End of life Polypropylene <b>in mould label</b> cups |
| Origin                      | Primary food contact (drinks) of EU (DE) origin      |
| Source                      | Stadium events                                       |
| Collection                  | Closed loop; reusable cups                           |
| Specification plastic input | 100% PP from food contact material                   |

| Information                 | Specification                                       |
|-----------------------------|-----------------------------------------------------|
| Material in scope           | End of life Polypropylene <b>Other printed</b> cups |
| Origin                      | Primary food contact (drinks) of EU (DE) origin     |
| Source                      | Stadium events                                      |
| Collection                  | Closed loop; reusable cups                          |
| Specification plastic input | 100% PP from food contact material                  |

## 4 Recycling process

Figure 4 showcases the processing steps involved in the recycling process developed in STOPP project to enable food-contact grade PP recyclates from the feedstocks described in above sections (task 5.2 and 5.3). The decontamination system is highlighted in the figure, and two paths could be identified based on whether super cleaning oven treatment is applied at the flake level or pellet level after extrusion. Both approaches were trialled with path B utilised at the developmental stages to optimise super cleaning oven design and processing

parameters. The following subsections will detail the involved processing steps in greater detail.

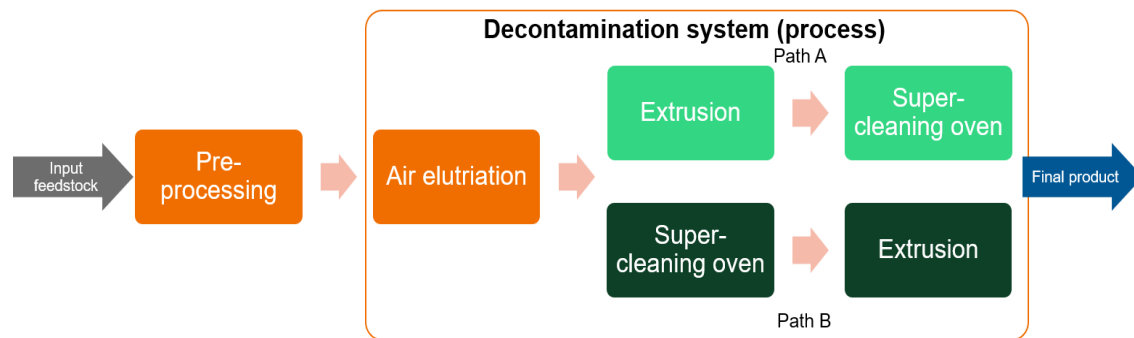


Figure 4: Recycling process flow diagram. Decontamination steps highlighted

## Pre-processing

### 4.1.1 Grinding

The Finnish food packaging material described in chapter 3.1.1.1 was ground at VTT. Grinding was performed in dry conditions with a cutting grinder having an 8 mm screen size for particles. Some packages were pre-cut with scissors to fit the opening of the grinder. The feedstock for task 5.3 (3.1.2) was also ground using the same equipment into flakes using 8 mm screen.



Figure 5: Pilot-scale grinding setup at VTT, used for size reduction.

At REMONDIS, the incoming material was delivered in the form of compressed bales. The bales were first opened to release the contained material, which was subsequently subjected to a preliminary shredding process (see Fig. 6). Following this size reduction step, metallic components were removed using appropriate separation technologies. The pre-treated material was then processed using near-



infrared (NIR) sorting. After NIR sorting, the material underwent a sink-float separation process. Subsequently, the material was processed in a wet cutting mill, where it was ground to a target particle size of approximately 12–15 mm. The PP caps from the single-use deposit return system are received as loose bulk material and are subsequently processed and dispatched in the same bulk form.



Figure 6: Grinding Process

## 4.1.2 Washing

For Finnish and German household-collected material, the washing process involved a separation of the sinking fraction from ground flakes (see Figure 7) and a 10-minute wash for each batch with 80 °C water, dishwasher tablets as surfactant (LV Konetiskitabletti All-in-one, 40 pcs / 150 liters of water) and 1 % caustic soda (NaOH). The batches were rinsed three times after washing and air-dried. No washing was performed on 5.3 feedstocks after grinding (PP drinks cup) as the feedstock had undergone a cleaning cycle as part of its re-use cycle.

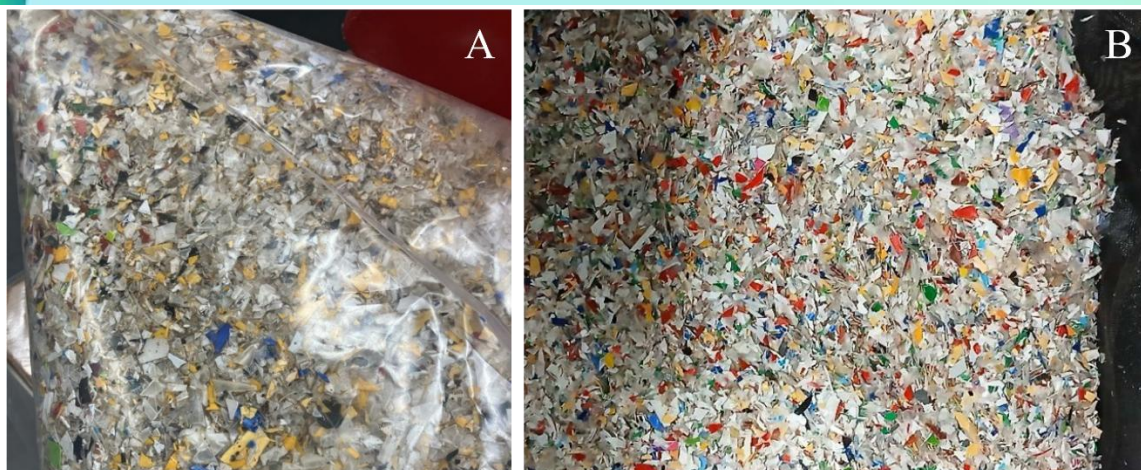


Figure 6. Snapshot of sorted Finnish PP flakes. A, unwashed fraction, B, sink float separated and washed fraction.

## Decontamination

The decontamination system utilised in this work comprises of the following sub-systems: Air elutriation unit, Super-cleaning oven and twin-screw extruder. Depending on the input feedstock, all or some of these units would be included in the decontamination process. The super-cleaning operation could be applied at flake level (path B) or at pellet level after extrusion (path A). Some trials were performed with super-cleaning applied at flake level before extrusion and the final trials were performed with super cleaning applied after extrusion at pellet level.

### 4.1.3 Air elutriation

The air elutriation setup at VTT was modified from a gas flow coating equipment by building a trap for the light fraction and installing air flow measurement to the exhaust (see Figure 8). This setup was calibrated according to RecyClass air elutriation – calibration –guidelines (Elutriation Calibration Procedure for HDPE Color developed by PFE and APR). With the VTT equipment, the targeted 99% removal of the lights couldn't be reached without significant material loss, the achieved removal in the calibration was ~90%.

This allowed for the separation of the lightest fraction (films, paper) from the batches. Any dust leftover from the grinding was also removed at this phase by the airflow and filters.

The elutriation was performed on each of the 5.2 feedstocks in small batches to accommodate the limited volume accepted by the equipment. Air flow and processing time were fixed based on the calibration.

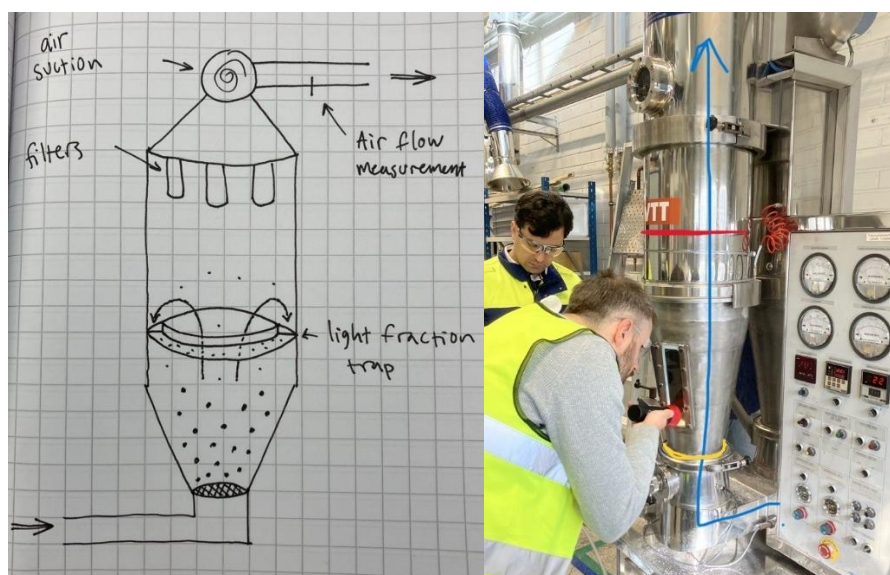


Figure 7. Air elutriation setup. A: schematic of the process. B: Actual equipment, Blue line demonstrates air flow, yellow bottom of the barrel (heavies) and red placement of the light fraction trap.

## 4.1.4 Extrusion

Extrusion processing of all material was done at VTT with the VTT Varex (Figure 8) equipment, which has a cascading extrusion structure (tandem extrusion) with multiple sensors for in-line process monitoring and control. In simple terms, a single screw extruder (NGR E:Gran) is connected to a twin-screw extruder (Leistritz ZSE27 MAXX) via a melt filter unit (Gneuss KF45 rotary screen filter). For these STOPP trials, only the twin-screw extruder was utilised instead of the cascade configuration where feeding of flakes was done directly to the twin screw extruder. This decision was done based on the nature of the feedstock (deemed clean enough due to pre-processing steps of washing and cleaning) as it did not necessitate the additional melt filtration provided by the upstream single screw extruder. Twin screw extruder melts and further mixes the melt and allow for VOC removal as it travels to the exit die. A 200µm screen size filter was utilised just before the exit die to ensure the final product is free from particulate contaminants. The VOC removal in this unit can be achieved by means of extrusion degassing and also from stream stripping where deionised water was injected in controlled dosage (as a mass %). The resulting steam and VOCs are removed through degassing port closer to the exit die.

Processing of all material was done at 230 °C with an approximate throughput of 10kg/h.

## In-line instrumented tandem extrusion line

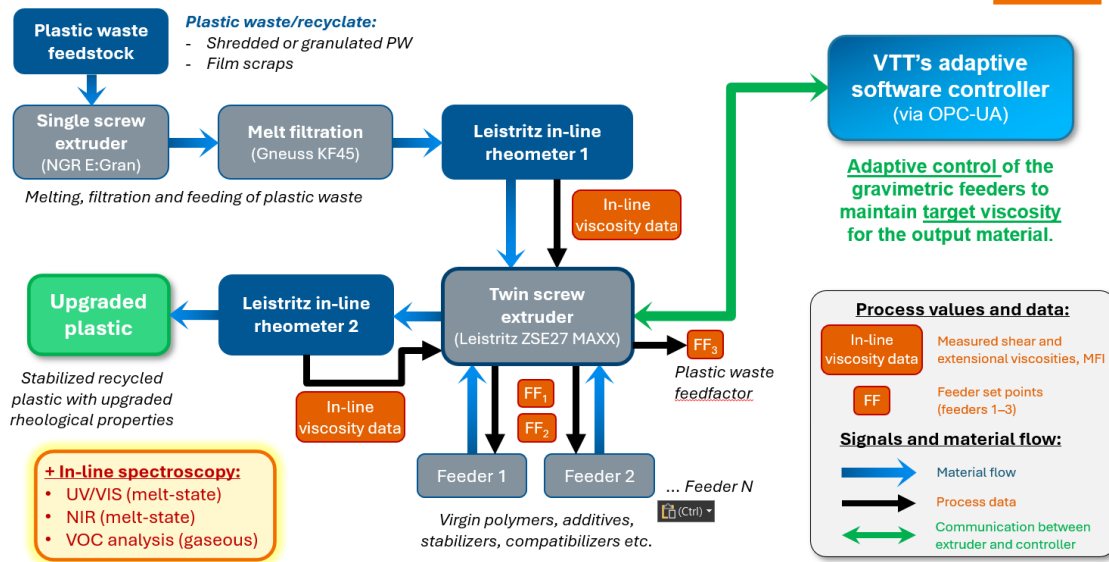


Figure 8: VTT VAREX flow diagram

The VAREX has in-line instrumentation to monitor the quality of the material. In-line rheometers (Leistritz) provide viscosity data from the input feed (when used in tandem configuration) as well as output from twin screw extruder (all configurations). These provide essential tools to monitor and actively control the quality (viscosity) of recycled product as necessary during extrusion. Colour of the melt is monitored with in-line UV/VIS spectroscopy (ColVisTec) and chemical composition is monitored with in-line NIR spectroscopy (ColVisTec).

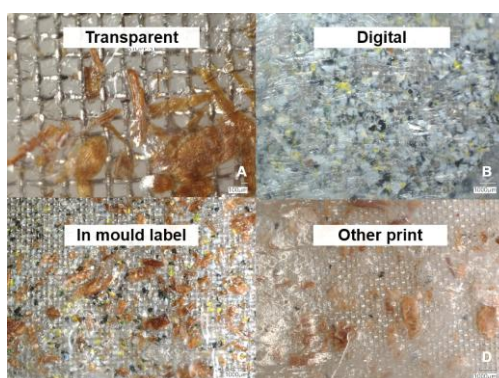
Decontamination at this stage is twofold; melt-filtration removing non-melting particles out of the material and steam + vacuum efficiently removing VOCs. The residue in the filters (located behind the exit die) reveal leftover contamination in the feedstocks. Figure 10 and Figure 11 shows the melt filters after extrusion. Among 5.2 feedstocks shown in Figure 10, the PP caps seem very clean when it comes to material contamination, only little pieces of un-melted plastics were left on the filter. The Finnish separately collected material seems to have mostly polymeric contamination, presumably PET film that was adhered to PP packaging and didn't



Figure 9: Close-ups of melt-filters (task 5.2 feedstock). A PP caps Germany, B separated Finland, C separated Germany

sink in the sink-float. The German separately collected material has more metallic foil pieces as well as other mixed contaminants.

As for 5.3 feedstock (Figure 11) the contaminants trapped behind the filter were relatively less as justified by their means of collection that limits potential cross-contamination. In transparent cups, hard flake like residue in amber colour could be seen and is likely a result of thermos-oxidative degradation of PP during the process. Glassy residue left behind the mesh could be PP gels as they do not melt at typical processing temperatures and are left behind at the melt filter. In Digital cups, pieces of the labels could also be seen behind the mesh trapped in glassy residues. Similarly, for in-mould labels cups, amber flakes and decorative labels could be seen. In other printed cups, a pink hue has been imparted to the glassy residue with similar amber flakes. It is interesting that the decoration on the cup had no red or pink shades in it. As mentioned previously, detailed information of the decorative labels and processes (label material, adhesion promoters and ink formulations) were not available to fully elucidate the observations from melt filter



except the obvious that they didn't melt at process temperature for PP and could consist of a different material or grade. It is possible that some of these ( $< 200\mu\text{m}$ )

Figure 10: Contaminants trapped in filter from Task 5.3 feedstocks

might have escaped into the melt and reached the final product (pellets) and the effects of these contaminants in food contact safety will be crucial.

## 4.1.5 Super-cleaning oven

The super-cleaning oven setup (Figure 12) consists of a vacuum oven with a container where plastics (pellets or flakes) are being exposed to IR (infrared) light and are mixed for uniform distribution of IR energy. The IR source and its wavelength was chosen to specifically heat up the plastics treated in the oven (PP). The theory is that IR light penetrates the pellets and mobilizes VOCs which move to the plastic surface and from there, get removed by the vacuum. The mixing ensures that the plastic temperature doesn't rise too high and the plastic doesn't melt. Unlike traditional vacuum ovens, IR energy source ensures that only the plastics are heated and not its surroundings resulting in minimum heat loss and greater efficiencies.

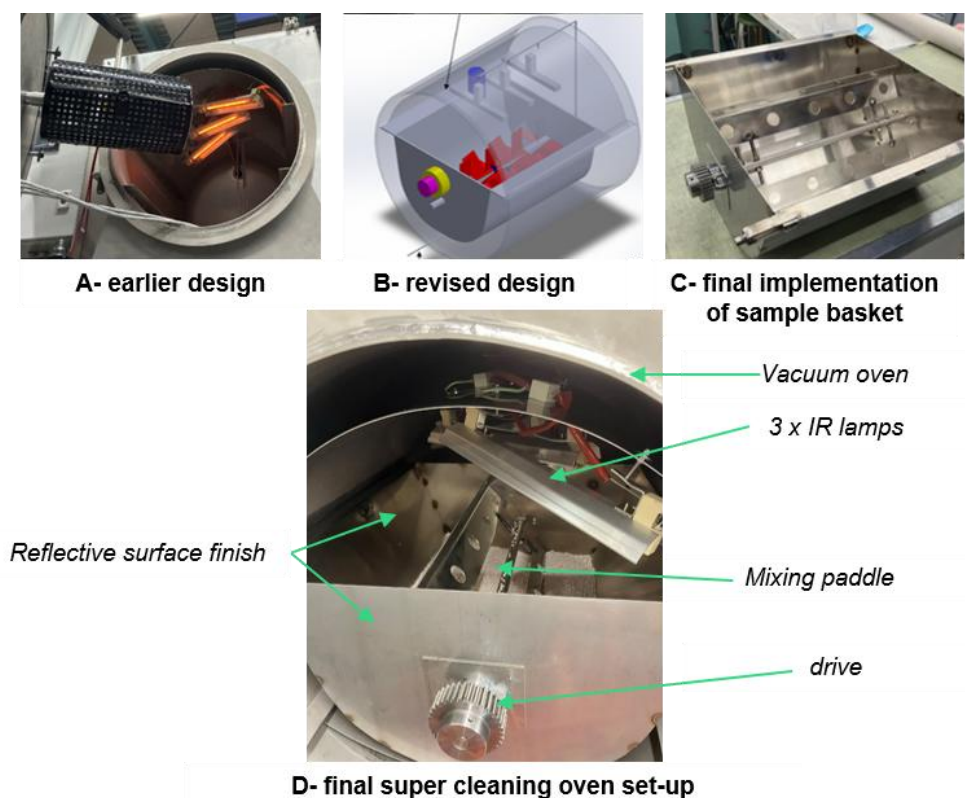


Figure 11: The super-cleaning oven. Earlier design to final set-up

## 4.1.6 Optimisation of the decontamination unit



Effective removal of VOCs (decontamination) using super cleaning oven depends on the temperature, vacuum and the duration of IR treatment. When vacuum is applied, the partial pressure decreases and the increased temperature softens the plastic matrix which enhances the mobility of VOCs within the plastic which then migrate from the surface and out of the polymers. When these desired parameters are maintained for sufficiently long durations, this results in a diffusion gradient which promotes VOC migration from the bulk to the surface and out of the materials. As such, these parameters had to be optimised for effective decontamination. Furthermore, IR heat is absorbed by (and heated) materials differently and the inside of the super clean oven must be designed such that the polymers are heated faster (and to a higher temperature) than the surrounding (container basket, oven walls). Several design iterations of the ovens were performed to achieve optimised heating in this regard. The samples treated utilising initial oven design Figure 12(A) and first set of oven parameters (60 minutes of 100% IR exposure at 95V (100%) lamp power) were subjected to screening and VOC analysis. Task 5.2 materials were utilised for this initial study. These results are presented in detail in section 5.1.6. These resulted implied minimal effect of super cleaning on the decontamination of the samples and it was decided to update the oven design and perform a parametric study to better understand the oven parameters to improve the ovens performance.

A series of trials were performed to particularly understand the influence of treatment duration, temperature and vacuum without melting the polymers. The oven design was updated to achieve good sealing (vacuum) by sheathing exposed cables and applying gaskets on interfaces. Sample carrying baskets and oven internals were made of exposed metals to reflect IR light rather than absorb and heat up faster than the plastic samples being treated. To control the temperature, several illumination sequences were programmed across the three IR lamps and applied to the same sample (Digital printed flakes). These could be characterised as a % light on in 1 min for comparative purposes. The following trial series were executed. As a control, the samples were treated with a normal vacuum oven at a temperature that is closer to the onset of melting and well above the heat deflection temperature of PP. These control parameters were chosen to maximise decontamination utilising traditional means of degassing and contrast with IR heated decontamination unit developed here.

Table 1: Optimisation trials

| No | Trial parameters                                                                                        | Exposure time (min) |
|----|---------------------------------------------------------------------------------------------------------|---------------------|
| 1  | <b>Vacuum oven</b> : 145 °C, 10 mbar for <b>300</b> minutes                                             | 300                 |
| 2  | <b>IR</b> oven for <b>30</b> min: Program 11 (4 s ON, 4s OFF; IR ON for 44% of the time. 100% power)    | 13.2                |
| 3  | <b>IR</b> oven for <b>80</b> min: Program 01 (4 s ON sequential; IR ON for 80% of the time. 100% power) | 64                  |
| 4  | <b>IR</b> oven for <b>240</b> min: Program 11 (4 s ON, 4s OFF; IR ON for 44% of the time. 100% power)   | 105.6               |

These samples were subjected to screening and VOC analysis and the results are discussed in section 5.1.7.



## 5 Methods

### Protocols (Suspect screening and VOCs analysis)

Several methods will be used to analyse NIAS (Non-Intentional Added Substances) in samples (pellets and flakes):

- Suspect screening analysis
- Target analysis of volatile organic compounds (VOCs)

Work on sample preparation and analysis procedures has been conducted to adapt the protocols to the project's samples. These protocols are detailed in the sections below.

#### 5.1.1 Sample pre-treatment

Before applying the analysis protocols for Suspect screening and VOCs target analysis, a sample preparation is applied on samples. Pellets and flakes are analysed within the framework of the project STOPP.

##### 5.1.1.1 Micronization (flakes only)

A micronization step is essential to reduce the size of the flakes, which initially measure approximately 1 cm. This step is particularly important as the protocol specifies the extraction of 3g of flakes. Reducing the volume of the aliquot through grinding is necessary; if the aliquot volume is too large, it would require an excessively large volume of solvent for the extraction process. Additionally, smaller flakes allow for a more representative aliquot (due to the heterogeneity of the flakes). The grinding should be performed to achieve a consistent particle size of approximately 4 mm, ensuring an efficient and manageable extraction procedure.



Figure 12. Knife grinder used for the sample prep (RETSCH, SM-2000)

### 5.1.1.2 Quartering

The quartering step in the analysis of NIAS in plastic samples is crucial for ensuring representative sampling. This process involves dividing the sample into four equal parts, then selecting two opposite quarters to combine for analysis. This method reduces bias and ensures that the analyzed sample is representative of the entire batch, leading to more accurate and reliable results. Depending on the initial mass of the sample, the quartering process is repeated between 2 to 6 times to achieve the desired sample size for analysis.



Figure 13: Quartering step

### 5.1.1.3 Cryogrinding

Following the quartering process, samples undergo cryogrinding using liquid nitrogen at  $-180^{\circ}\text{C}$ . The specific conditions for this step are detailed in the table below, yielding a fine powder with a particle size of approximately  $20\text{ }\mu\text{m}$ .

Table 2: Cryogrinding conditions

| Step      | Precooling | Grinding | Cooling | Cycle |
|-----------|------------|----------|---------|-------|
| Time      | 10 min     | 1 min 30 | 1 min   | 2     |
| Frequency | 5 Hz       | 30 Hz    | 5 Hz    |       |



Figure 14. Cryogrinding apparatus (RETSCH Cryomill)

## 5.1.2 Protocol for suspect screening analysis

Suspect screening is an analytical technique used in mass spectrometry to identify known compounds (suspects) in a sample. This approach allows for the retrospective analysis of data to detect the presence of these compounds, providing a broader understanding of the sample's composition. Veolia has developed an analysis that allows for the screening of 8000 compounds in samples.

### 5.1.2.1 Sample pre-treatment

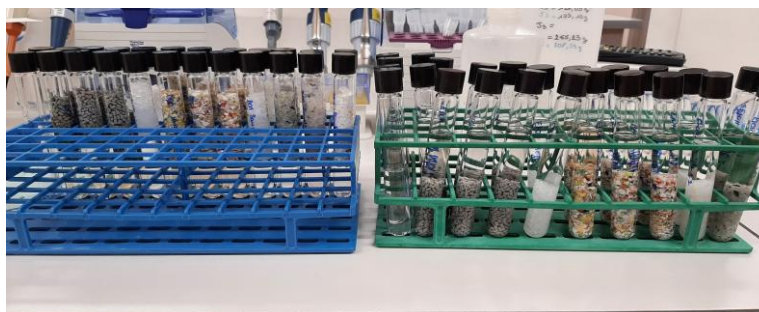
Pre-treatment steps were applied to the samples before sample preparation (see definitions below). Initially, the flakes were subjected to micronization to reduce their size. This was followed by the quartering method to ensure a representative

sample. Prior to extraction, the sample underwent a grinding procedure to ensure it is in optimal form for analysis.

*Table 3: Sample pre-treatment for suspect screening analysis*

| Pre-treatment steps     | Flakes | Pellets |
|-------------------------|--------|---------|
| Micronization (4 mm)    | Yes    | No      |
| Quartering              | Yes    | Yes     |
| Grinding (<200 $\mu$ m) | No     | No      |

## 5.1.2.2 Sample extraction



*Figure 15. Samples before extraction*

For the sample extraction, a solvent-to-sample ratio of 1 mL per 1 g was initially considered. However, due to the larger-than-expected size of the flakes, this ratio was adjusted to 9.9 mL of solvent for every 3 g of sample. To maximize the extraction of a wide range of molecules, two different types of solvents were used in the extraction process. This dual-solvent approach is expected to enhance the efficiency and comprehensiveness of the extraction, ensuring a more thorough analysis of the sample.

The extraction was conducted as follows:

Extraction 1: 3 g of sample + 9.9 mL of DCM, 3 days at 40°C

Extraction 2: 3 g of sample + 9.9 mL of EtOH (95%), 7 days at 60°C

After the extractions, the samples were collected by taking an aliquot of 500  $\mu\text{L}$  from the extracted solution, to which 10  $\mu\text{L}$  of Phenanthrene D10 (at a concentration of 100 mg/L) was added as an internal standard.

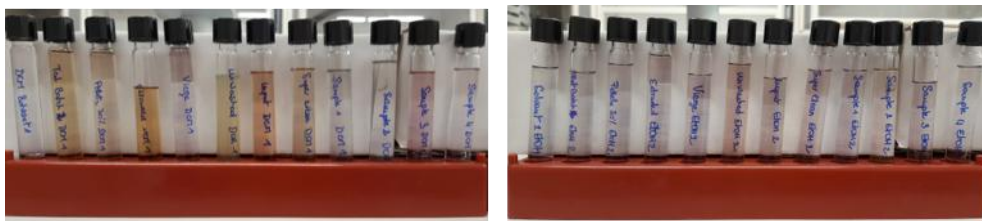


Figure 17: Extracts of samples after extraction

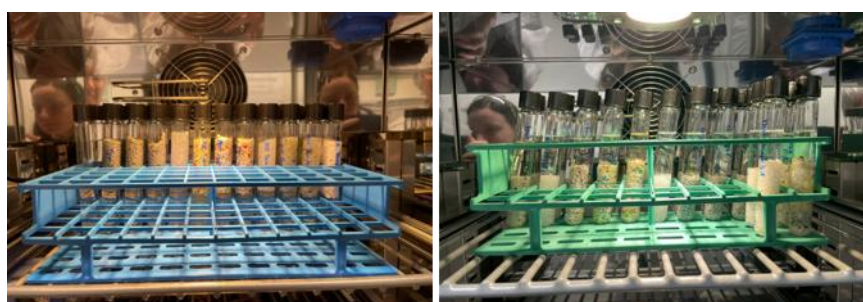


Figure 16: Samples during extraction

### 5.1.2.3 Analysis

The analysis consisted of a direct injection of the extracts (1  $\mu\text{L}$ ) followed by a GC $\times$ GC-TOFMS analysis. The equipment used for suspect screening analysis is a GCXGC-TOF MS (LECO).



Figure 18: GCXGC-TOF MS (LECO)

## 5.1.2.4 Data Interpretation

The analytical technique used for this study enables the detection and identification of a broad spectrum of organic compounds (molecular weights between approximately 50 and 1000 g/mol).

After the laboratory analyses, a significant amount of data processing work is carried out using the software associated with the analyser, as well as in-house programs developed by Veolia. A signal (area) is obtained for each detected compound.

During data processing, the results are systematically compared with those obtained for blank solvent extraction (control sample). Indeed, even for a "control sample", numerous peaks are visible. They do not necessarily correspond to micropollutants but rather to molecules released by the equipment used during sampling, sample preparation or by the analytical system. For this reason, peaks that are present in both the control and the samples are considered irrelevant and are removed during the data processing.

VERI has established a database containing nearly 8000 compounds that could potentially be found in environmental matrices and classified in 5 categories (see below).

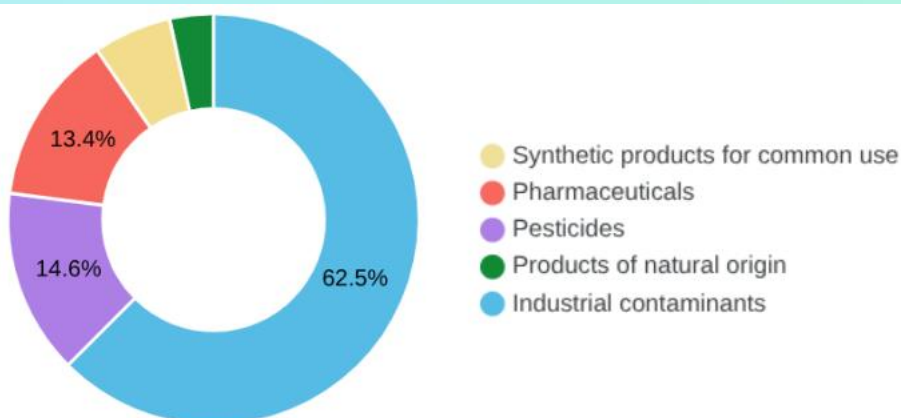


Figure 19.: Compound distribution by category

Based on the technical information available in the VERI database and the experimental data from each analysis, there is 2 cases:

- Identification based on experimental data or data from literature. Proposal of a molecular name.
- No confirmation of identification possible from experimental data. No molecular name (category “Not identified”).

Note: Ions, metals, and molecules with very low (very volatile compounds) or very high molecular weight (polymers) are not detected by this type of analysis. The techniques used do not allow the analysis of compounds requiring special analytical conditions (derivatisation, etc.) such as THMs or other disinfection by-products, glyphosate, AMPA or Perfluorinated compounds. Oestrogens and iodinated contrast agents are not detected either.

## VOCs analysis

Following the Suspect screening, a targeted analysis was conducted, focusing on 14 specific Volatile Organic Compounds (VOCs). The following table provides a comprehensive list of these 14 VOCs, which are the focus of this targeted analytical method.

Table 4: List of VOCs

| Name of VOCs               | CAS Number |
|----------------------------|------------|
| 2-Chloroaniline            | 95-51-2    |
| $\alpha$ -Isomethyl ionone | 127-51-5   |
| $\alpha$ -pinene           | 80-56-8    |

|                               |          |
|-------------------------------|----------|
| b-pinene                      | 127-91-3 |
| Benzaldehyde                  | 100-52-7 |
| Butylated hydroxytoluène      | 128-37-0 |
| camphene                      | 79-92-5  |
| Decamethyl cyclopentasiloxane | 541-02-6 |
| Diphenyl ether                | 101-84-8 |
| Eucalyptol                    | 470-82-6 |
| Isobornyl acetate             | 125-12-2 |
| Limonene                      | 138-86-3 |
| Methoxynaphthalene            | 93-04-9  |
| p-Isopropyltoluene            | 99-87-6  |

### 5.1.3 Sample pre-treatment

Pre-treatment steps were applied to the samples before sample preparation (see definitions below). Initially, the flakes were subjected to micronisation to reduce their size. This was followed by the quartering method to ensure a representative sample. As samples were directly analysed by thermo-desorption, the sample underwent a grinding procedure to ensure it is in optimal form for analysis (particle size < 200 µm).

Table 5: Sample pre-treatment for VOCs

| Nature of sample     | Flakes | Pellets |
|----------------------|--------|---------|
| Micronization (4 mm) | Yes    | No      |
| Quartering           | Yes    | Yes     |
| Grinding (<200 µm)   | Yes    | Yes     |



## 5.1.4 Analysis

Thermal desorption analysis was performed on each sample. A desorption tube containing 5 mg of sample was prepared, with the sample positioned between two pieces of glass wool to ensure efficient desorption.

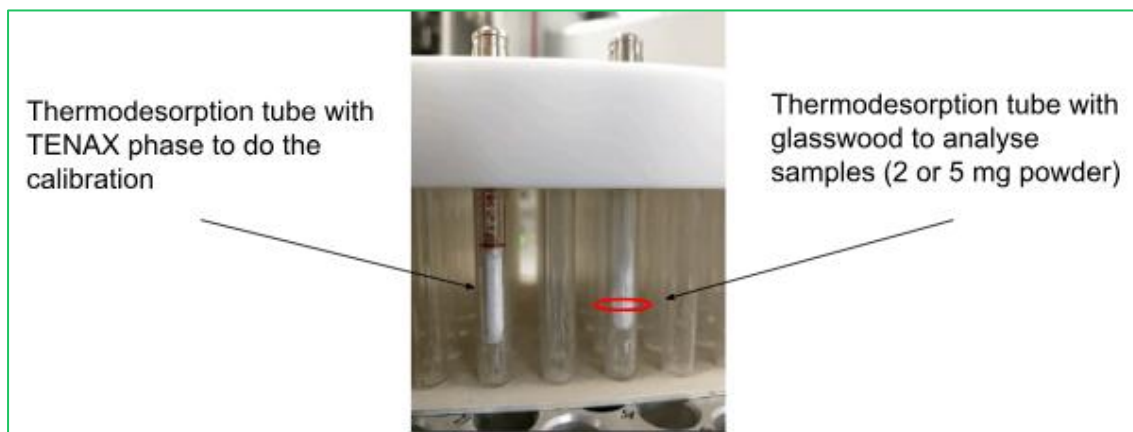


Figure 20.: Thermodesorption tube with sample

The equipment used for VOCs analysis is a GC-MS (Agilent).

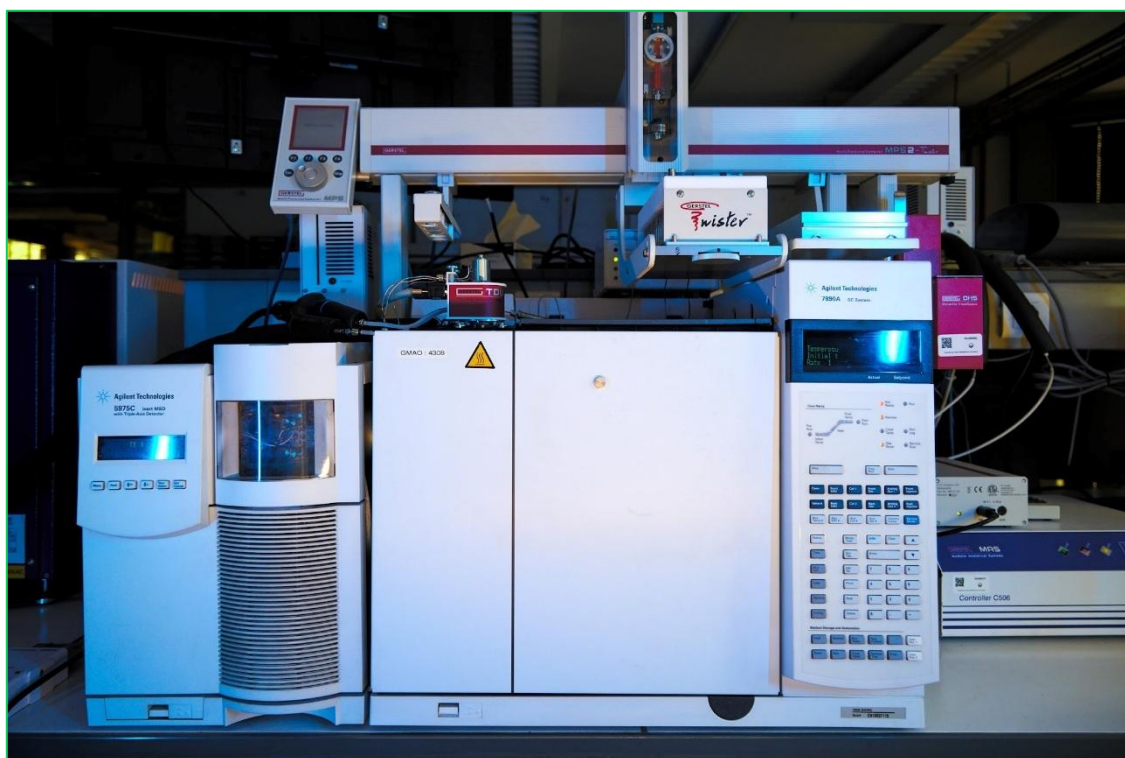


Figure 21.: Thermodesorption tube with sample



## 5.1.5 Calibration and quantification

For each compound, calibration curves were performed over a range of 0.02 ppm to 10 ppm (9 calibration points) using an internal standard (Naphthalene-d8).

- For the first campaign, the internal standard area was unstable due to a problem with the autosampler, which affected the injection of the internal standard. Consequently, calibration curves were made without an internal standard.
- For the second campaign, the internal standard was used for each calibration curve.

For calibration curve validation, criteria on the difference between the spiked concentration and the experimental value were defined as follows:

- $\pm 70\%$  tolerance for the low concentration point
- $\pm 20\%$  tolerance for the middle and high concentration points

Calibration points that did not meet these criteria were excluded from the final calibration curve. Consequently, the quantification limit varied depending on the compound and the number of valid calibration points retained.

An example of a typical calibration curve for Limonene is shown below. The table below reports "Theoretical concentration" (spiked concentration) and recalculated concentration. The low concentration points (0.02, 0.04, and 0.1 ppm) were below a reliable quantification limit and showed poor recovery (between -1500% and -160%). These points were therefore excluded from the calibration curve. For Limonene (Campaign 1), the calibration range was therefore 0.2-10 ppm (cf Figure 23).

Table 6: Calibration curve for Limonene (campaign 1)

| Theoretical concentration | Recalculated concentration | Recovery | Calibration curve |
|---------------------------|----------------------------|----------|-------------------|
| 0,02 ppm                  | X                          | X        | X                 |
| 0,04 ppm                  | X                          | X        | X                 |
| 0,10 ppm                  | X                          | X        | X                 |

|          |          |      |   |
|----------|----------|------|---|
| 0,20 ppm | 0,32 ppm | 60%  | ☑ |
| 0,40 ppm | 0,23 ppm | -43% | ☑ |
| 1,0 ppm  | 0,96 ppm | -4%  | ☑ |
| 2,0 ppm  | 2,09 ppm | 4%   | ☑ |
| 4,0 ppm  | X        | X    | ✗ |
| 10 ppm   | 9,98 ppm | 0%   | ☑ |

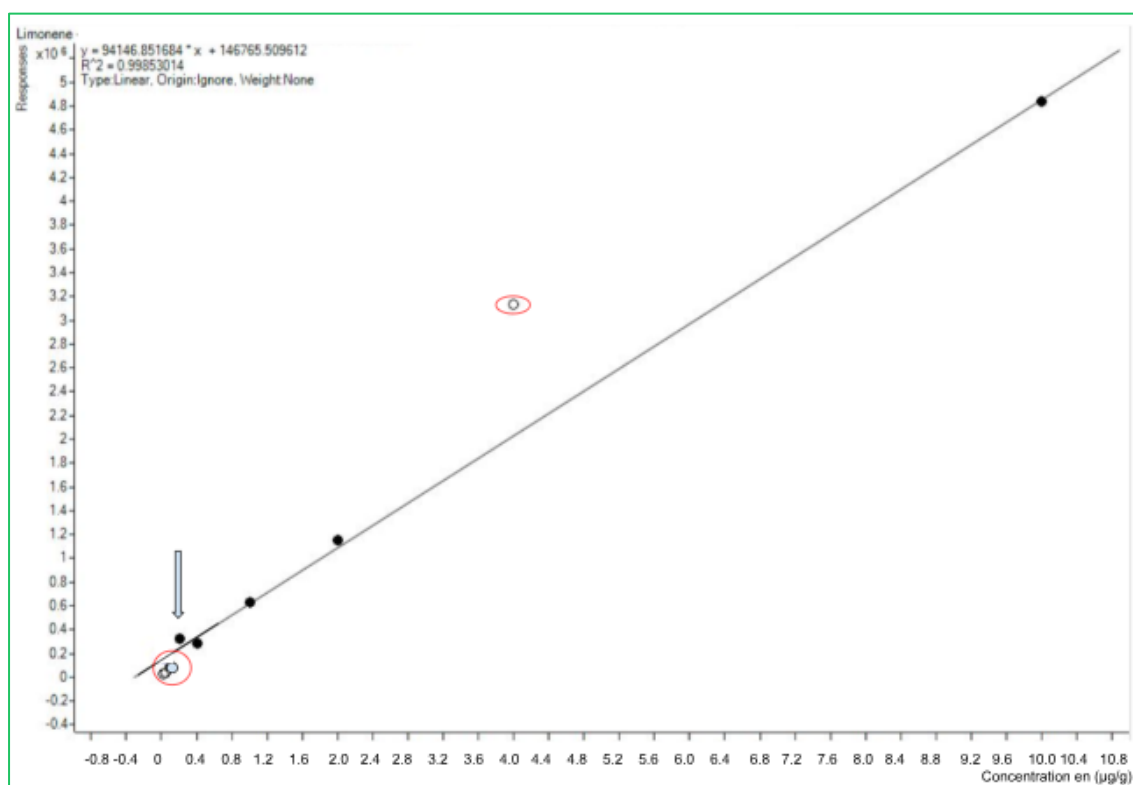


Figure 22: Calibration range of Limonene (campaign 1, calibration range : 0.2 – 10 ppm)

For all compounds, quantification was performed using calibration curves. The quantification limits for each compound are presented in the table below, reflecting the variability in calibration point acceptance across compounds.

Table 7: Ranges of compounds (campaign 1 and 2)

| Name of VOCs | CAS Number | Concentration range, campaign 1 (ppm) | Concentration range, campaign 2 (ppm) |
|--------------|------------|---------------------------------------|---------------------------------------|
|--------------|------------|---------------------------------------|---------------------------------------|

|                               |          |            |            |
|-------------------------------|----------|------------|------------|
| 2-Chloroaniline               | 95-51-2  | /          | 0.02 - 4.0 |
| a-Isomethyl ionone            | 127-51-5 | 0.10 - 10  | 0.02 - 4.0 |
| a-pinene                      | 80-56-8  | 0.40 - 4.0 | 0.02 - 4.0 |
| b-pinene                      | 127-91-3 | 0.40 - 10  | 0.02 - 4.0 |
| Benzaldehyde                  | 100-52-7 | 2.0 - 10   | 0.10 - 4.0 |
| Butylated hydroxytoluène      | 128-37-0 | 0.10 - 10  | 0.02 - 4.0 |
| camphene                      | 79-92-5  | 0.40 - 10  | 0.02 - 4.0 |
| Decamethyl cyclopentasiloxane | 541-02-6 | 0.40 - 4.0 | 1.0 - 4.0  |
| Diphenyl ether                | 101-84-8 | 0.10 - 10  | 0.02 - 4.0 |
| Eucalyptol                    | 470-82-6 | 0.40 - 10  | 0.10 - 4.0 |
| Isobornyl acetate             | 125-12-2 | 1.0 - 10   | 0.04 - 4.0 |
| Limonene                      | 138-86-3 | 0.20 - 10  | 0.02 - 4.0 |
| Methoxynaphthalene            | 93-04-9  | 0.10 - 10  | 0.02 - 4.0 |
| p-Isopropyltoluene            | 99-87-6  | 1.0 - 4.0  | 0.02 - 4.0 |

Example of quantification: Limonene, sample 3 (campaign 2): As shown in the figure below, the corrected area of 0.58 corresponds to 0.22 µg/g on the Limonene curve.

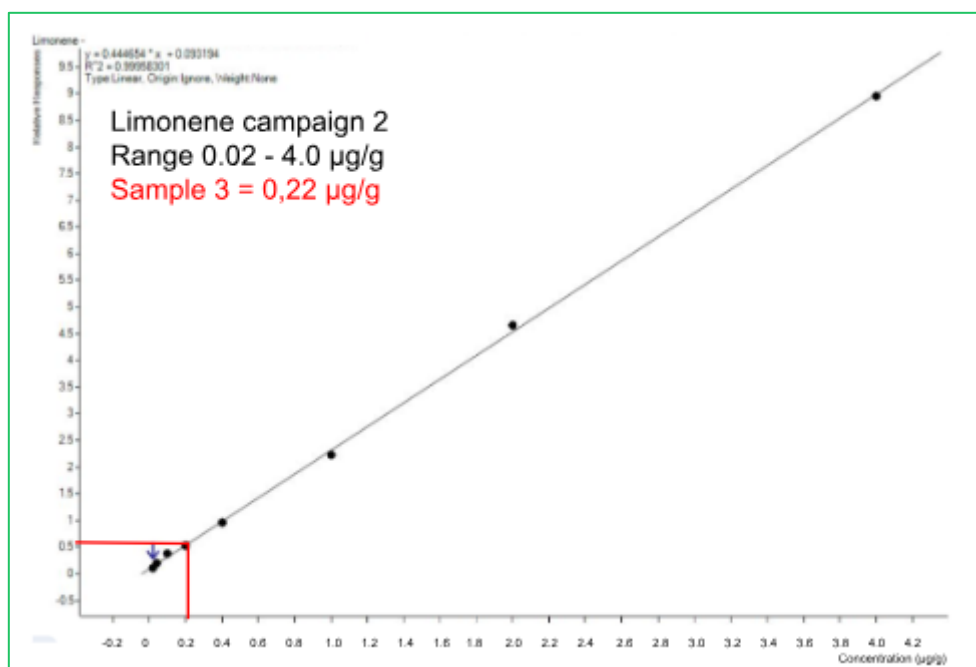


Figure 23.: Concentration of Limonene in Sample 3

# Decontamination efficiency

Decontamination efficiency is a critical performance parameter in food-contact recycling processes, as it demonstrates the ability of a recycling technology/process to remove contaminants from post-consumer plastic waste to levels that do not pose a risk to human health. Typically, this is achieved by means of challenge tests, where surrogate contaminants are intentionally introduced and their removal quantified in each of the process steps. Owing to the developmental nature of the recycling process developed in STOPP project, decontamination efficiency of each of the process steps could be evaluated indirectly by comparing suspect screening and VOC analysis.

## 5.1.6 Initial set-up (Task 5.2 Feedstock)

The initial decontamination efficiency of the recycling process was evaluated using hand sorted PP material from Finland (Feedstock 1) as the input feedstock. A process flow as shown in Figure 24 was evaluated. It must be noted that super cleaning was applied before extrusion in this process flow. Samples were taken at the input to each of the process steps (sub-operations). The primary process output of interest is the 100% recycled feedstock 1 pellets. Additionally, a dilution of this material with virgin PP (30% recycled content) was prepared to understand the effect of dilution on decontaminant levels. Virgin PP pellets were also prepared via extrusion and subjected to screening and VOC analysis as a benchmark. It must be noted that steam stripping was not utilised in these extrusions and decontamination effect of the extrusion comes solely from degassing of the melt.

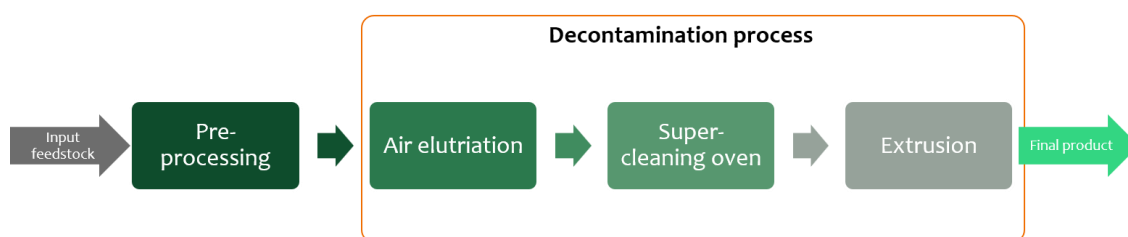


Figure 24: Recycling Process flow (Path B)

## 5.1.6.1 Suspect screening

After analysis, samples can be compared based on the number of detected compounds along the decontamination unit.

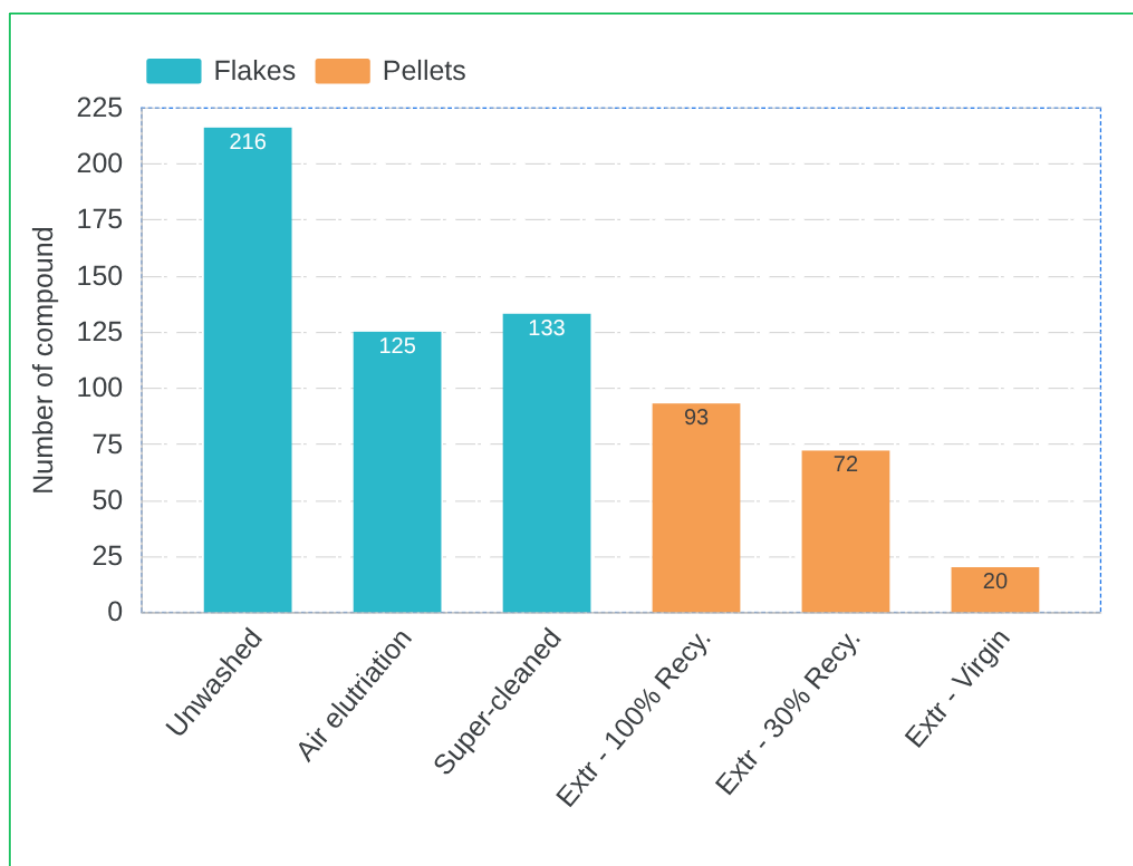


Figure 25: Number of detected compounds in samples

It can be seen from Figure 25 and Figure 26 that the input (unwashed) to the recycling process had a total of 216 compounds detected within it. Downstream process of washing and wind sifting had resulted in significant reduction as expected as these processes are designed to remove lighter contaminants such as dust, dirt, films and paper from the flakes. However, the number of detected compounds had increased slightly after super cleaning operation. This implies that the processing parameters of the oven and its design is inadequate to effectively remove any contaminants. This conclusion led the complete redesign and additional oven trials. As expected, extrusion process resulted in a important reduction in the total number of detected compounds and dilution with 70% virgin PP resulted in dilution of the contaminants below the detection limits leading to reduced number of compounds detected. As a reference, a total of 20 compounds were detected in virgin PP.

Because detected compounds are organized by categories in the VERI database, similar graphs can be produced for sample comparison with complementary categorical information Figure 26.

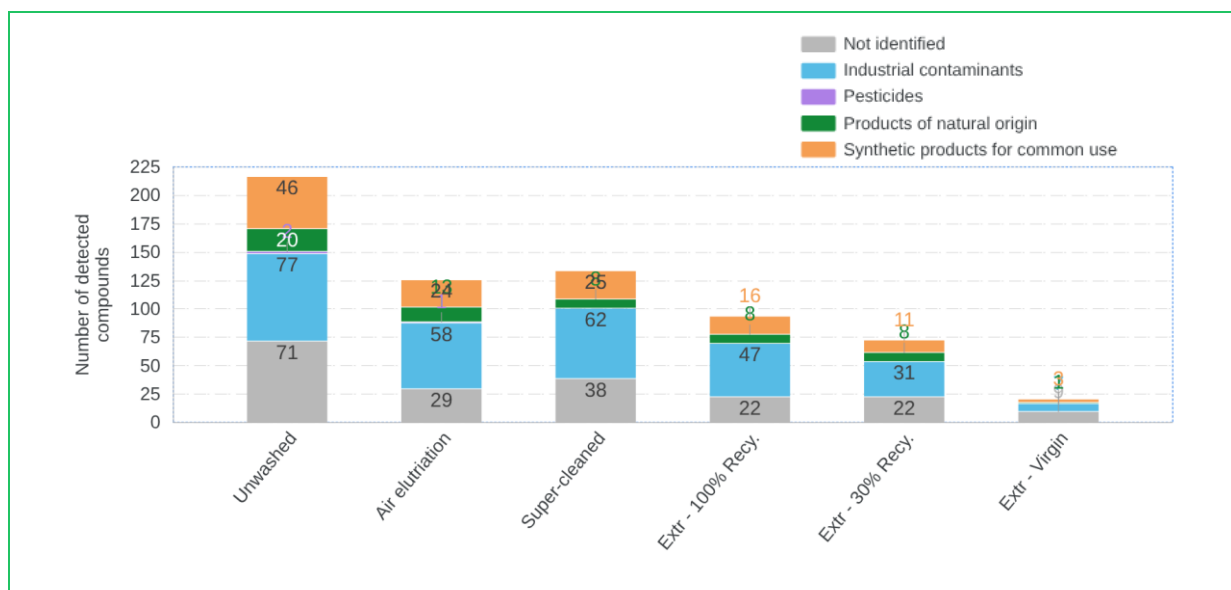


Figure 26.: Number of detected compounds in samples by categories

## 5.1.6.2 VOCs

Table 8: VOCs Concentrations in samples (ppm)

| Compound                      | Unwashed       | Air Elutriation | Super-cleaned  | Extr - 100% Recy. | Extr - 30% Recy. | Extruded - Virgin |
|-------------------------------|----------------|-----------------|----------------|-------------------|------------------|-------------------|
| a-Isomethylionone             | <b>0,3 ppm</b> | <0,1 ppm        | <0,1 ppm       | <0,1 ppm          | <0,1 ppm         | <0,1 ppm          |
| a-Pinene                      | <0,4 ppm       | <0,4 ppm        | <0,4 ppm       | <0,4 ppm          | <0,4 ppm         | <0,4 ppm          |
| b-Pinene                      | <b>6,5 ppm</b> | <0,4 ppm        | <0,4 ppm       | <0,4 ppm          | <0,4 ppm         | <0,4 ppm          |
| Benzaldehyde                  | <2 ppm         | <2 ppm          | <2 ppm         | <2 ppm            | <2 ppm           | <2 ppm            |
| Butylated hydroxytoluene      | <b>1,9 ppm</b> | <0,1 ppm        | <b>0,2 ppm</b> | <0,1 ppm          | <0,1 ppm         | <0,1 ppm          |
| Camphene                      | <0,4 ppm       | <0,4 ppm        | <0,4 ppm       | <0,4 ppm          | <0,4 ppm         | <0,4 ppm          |
| Decamethyl cyclopentasiloxane | <b>0,7 ppm</b> | <0,4 ppm        | <0,4 ppm       | <0,4 ppm          | <0,4 ppm         | <0,4 ppm          |
| Diphenyl ether                | <0,1 ppm       | <0,1 ppm        | <0,1 ppm       | <0,1 ppm          | <0,1 ppm         | <0,1 ppm          |
| Eucalyptol                    | <b>0,6 ppm</b> | <0,4 ppm        | <0,4 ppm       | <0,4 ppm          | <0,4 ppm         | <0,4 ppm          |
| Isobornyl acetate             | <1 ppm         | <1 ppm          | <b>1,0 ppm</b> | <1 ppm            | <1 ppm           | <1 ppm            |
| Limonene                      | <b>5,3 ppm</b> | <0,2 ppm        | <0,2 ppm       | <0,2 ppm          | <0,2 ppm         | <0,2 ppm          |
| Methoxynaphthalene            | <0,1 ppm       | <0,1 ppm        | <0,1 ppm       | <0,1 ppm          | <0,1 ppm         | <0,1 ppm          |
| p-Isopropyltoluene            | <1ppm          | <1ppm           | <1ppm          | <1ppm             | <1ppm            | <1ppm             |

## 5.1.7 Improved set-up (Task 5.3 Feedstock)

Task 5.3 materials were utilised for further developing and optimising the super cleaning oven as it was identified as the weakest operation in the recycling process. Figure 27 shows the typical processing flow diagram where pre-processing operation consisted of only griding as the feedstock (cups) were supplied washed. Input contaminant levels of all feedstocks were characterised using suspect screening and VOC analysis. Digital printed sample was chosen for the oven trials to optimise the oven parameters for cleaning.

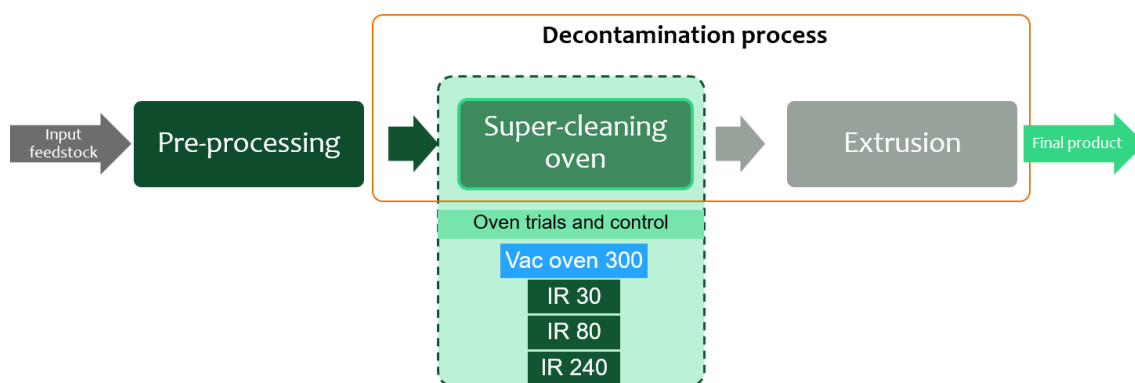


Figure 27: Process flow for super cleaning oven trials

### 5.1.7.1 Suspect screening

After analysis, cups samples can be compared based on the number of detected compounds.

Figure 28 shows the total number of detected compounds in the input material (flakes of PP cups) with the lowest compounds detected for transparent cups as expected. Highest number of detected compounds were for in mould label cups.

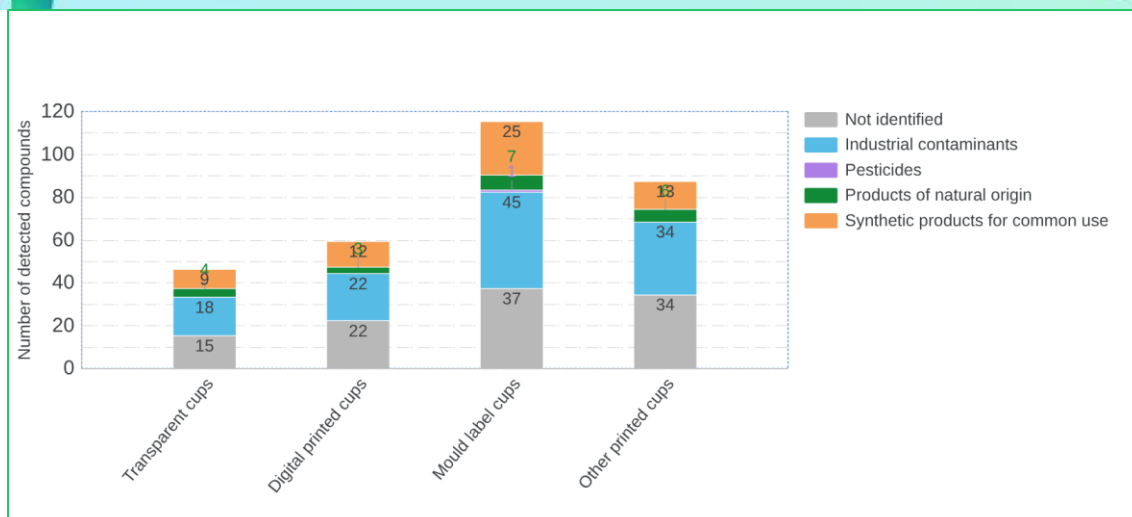


Figure 28: Number of detected compounds in input feedstock by category

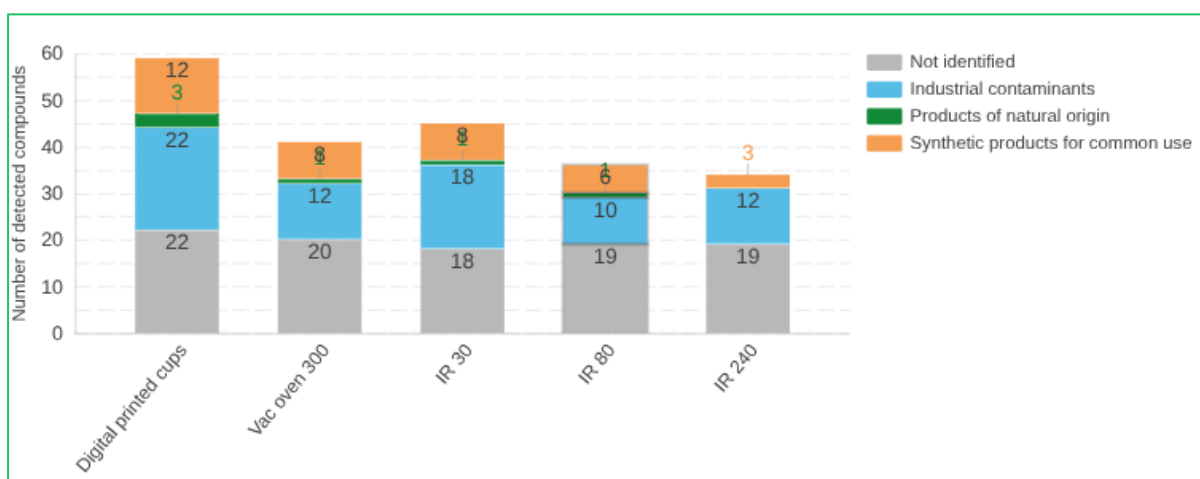


Figure 29: Number of detected compounds output of Super cleaning oven trials by category

Figure 29 shows the detected compounds for Digital printed samples (flakes) after being subjected to different super cleaning oven processing parameters as part of the optimisation trials. It can be seen that there is a reduction in the total number of detected compounds as a result of oven parameters implying that the revised oven design and processing parameters has been successful. Super cleaning oven treatment IR 30 (30 minutes) were slightly greater than the control of normal vacuum oven treatment for 300 minutes at 145 °C. IR 80 and IR 240 resulted in lower number of detected compounds in the sample. IR 240 was selected as the optimum profile for the super cleaning future samples aspart of recycling process. This is because IR 80 profile had irradiation ON for 80% of the treatment time resulting in bulk temperatures to raise faster compared to IR 240 where irradiation



was on for 40% of the time over a longer period. It must be noted that even though these parameters resulted in lower detected compounds on super cleaned flakes, further optimisation will be required for pellets as they absorb IR energy differently to that of flakes by virtue of their geometry (surface area). Diffusion pathways for the VOCs could also be different between pellets and flakes so same oven parameters are unlikely to provide matching results across flakes and pellets. However, the relative trends are likely to be same.

## 5.1.7.2 VOCs

VOC concentrations of the input samples are seen in Table 9. Transparent cups produced no detectable levels of the target VOCs. Three compounds were above the detectable limit for the remaining samples with Digital printed cups releasing most VOCs among the samples.

*Table 9: VOCs Concentrations in input feedstock (ppm)*

| Compound                      | Transparent Cups | Digital printed cups | In-Mould Label Cups | Other Printed Cups |
|-------------------------------|------------------|----------------------|---------------------|--------------------|
| a-Isomethylionone             | <0,1 ppm         | <0,1 ppm             | <0,1 ppm            | <0,1 ppm           |
| a-Pinene                      | <0,4 ppm         | <0,4 ppm             | <0,4 ppm            | <0,4 ppm           |
| b-Pinene                      | <0,4 ppm         | <b>1,5 ppm</b>       | <0,4 ppm            | <0,4 ppm           |
| Benzaldehyde                  | <2 ppm           | <2 ppm               | <2 ppm              | <2 ppm             |
| Butylated hydroxytoluene      | <0,1 ppm         | <b>6,3 ppm</b>       | <b>1,3 ppm</b>      | <b>0,5 ppm</b>     |
| Camphene                      | <0,4 ppm         | <0,4 ppm             | <b>1,3 ppm</b>      | <0,4 ppm           |
| Decamethyl cyclopentasiloxane | <0,4 ppm         | <b>0,7 ppm</b>       | <0,4 ppm            | <b>0,5 ppm</b>     |
| Diphenyl ether                | <0,1 ppm         | <0,1 ppm             | <0,1 ppm            | <0,1 ppm           |
| Eucalyptol                    | <0,4 ppm         | <0,4 ppm             | <0,4 ppm            | <b>0,6 ppm</b>     |
| Isobornyl acetate             | <1 ppm           | <1 ppm               | <1 ppm              | <1 ppm             |
| Limonene                      | <0,2 ppm         | <0,2 ppm             | <b>0,6 ppm</b>      | <0,2 ppm           |
| Methoxynaphthalene            | <0,1 ppm         | <0,1 ppm             | <0,1 ppm            | <0,1 ppm           |
| p-Isopropyltoluene            | <1ppm            | <1ppm                | <1ppm               | <1ppm              |

Table 9 shows the VOC concentration for Digital printed samples (flakes) after being subjected to different oven processing parameters as part of the optimisation trials. A reduction in detected compounds could be seen across most of the revised supercleaning parameters with IR 80 being the most effective in

removing VOC. This is expected as the increased temperature of the samples (by virtue of longer IR irradiation time) will result in greater removal of VOC. For Butylated hydroxytoluene, a commonly used antioxidant for PP, IR 30 setup produced more compared to even untreated samples. Other oven setups were lower than the untreated as expected. It is possible that the relatively short duration caused some compounds to migrate to the surface, increasing what could be dissolved in the solvent leading to a high total signal compared to the untreated sample. Conversely, the longer treatment setups may have helped remove these compounds from the surface, leading to a lower total signal during solvent dissolution.

Table 10: VOCs concentrations in output of Super cleaning oven trials

| Compound                         | Digital print -<br>Untreated | Vac Oven<br>300 | IR 30           | IR 80           | IR 240          |
|----------------------------------|------------------------------|-----------------|-----------------|-----------------|-----------------|
| 2-Chloroaniline                  | No Data                      | <0,02 ppm       | <0,02 ppm       | <b>0,03 ppm</b> | <0,02 ppm       |
| a-Isomethylionone                | <0,1 ppm                     | <0,02 ppm       | <0,02 ppm       | <0,02 ppm       | <0,02 ppm       |
| a-Pinene                         | <0,4 ppm                     | <0,02 ppm       | <b>0,07 ppm</b> | <0,02 ppm       | <0,02 ppm       |
| b-Pinene                         | <b>1,5 ppm</b>               | <0,02 ppm       | <0,02 ppm       | <b>0,1 ppm</b>  | <0,02 ppm       |
| Benzaldehyde                     | <2 ppm                       | <0,1 ppm        | <0,1 ppm        | <0,1 ppm        | <0,1 ppm        |
| Butylated<br>hydroxytoluene      | <b>6,3 ppm</b>               | <b>5,9 ppm</b>  | <b>9,1 ppm</b>  | <b>2,8 ppm</b>  | <b>2,5 ppm</b>  |
| Camphene                         | <0,4 ppm                     | <0,02 ppm       | <0,02 ppm       | <0,02 ppm       | <0,02 ppm       |
| Decamethyl<br>cyclopentasiloxane | <b>0,7 ppm</b>               | <1 ppm          | <1 ppm          | <1 ppm          | <1 ppm          |
| Diphenyl ether                   | <0,1 ppm                     | <b>0,03 ppm</b> | <b>0,03 ppm</b> | <0,02 ppm       | <0,02 ppm       |
| Eucalyptol                       | <0,4 ppm                     | <0,1 ppm        | <0,1 ppm        | <0,1 ppm        | <0,1 ppm        |
| Isobornyl acetate                | <1 ppm                       | <b>0,07 ppm</b> | <0,04 ppm       | <b>0,2 ppm</b>  | <0,04 ppm       |
| Limonene                         | <0,2 ppm                     | <b>0,2 ppm</b>  | <b>0,6 ppm</b>  | <b>0,2 ppm</b>  | <b>0,02 ppm</b> |
| Methoxynaphthalene               | <0,1 ppm                     | <0,02 ppm       | <0,02 ppm       | <0,02 ppm       | <0,02 ppm       |
| p-Isopropyltoluene               | <1 ppm                       | <0,02 ppm       | <0,02 ppm       | <0,02 ppm       | <0,02 ppm       |

### 5.1.7.3 TGA study

Thermogravimetric analyses were performed on the samples as a way to gauge the effectiveness of decontamination across the investigated oven parameters. It is envisaged that this method could serve as a qualitative test to rapidly develop oven parameters without waiting for full scale screening and analysis. The samples were subjected to TGA in Nitrogen atmosphere at 10 K/min from 40 °C up to 230 °C and held (isothermal) for 10 minutes and then cooled down to 40 °C. This range is similar to the processing window in the extruder for PP. The reasoning behind this methodology is that if the VOCs were removed from the sample through decontamination steps, then there would be less mass loss detected in TGA when subjected to same temperature profile. Consequently, the sample with least mass loss in TGA will be the most decontaminated. Figure 31 shows that the IR 80 and IR 240 flakes had less mass loss in TGA runs following their treatment compared to flakes without treatment as volatiles were removed prior in super cleaning oven.

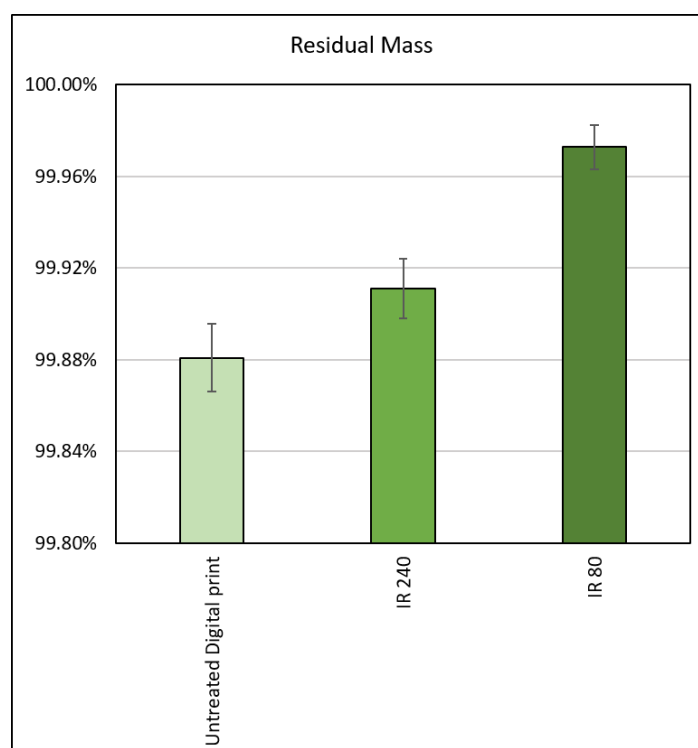


Figure 30: Residual mass of supercleaned flakes after TGA

## 6 Viscosity Profiles

The flow characteristics of the materials could be deduced from their viscosity profiles captured during extrusion. As VAREX was utilised in a single extruder configuration, viscosity profiles at the output (near the die) were captured. Shear viscosity and extensional viscosity are two different measures of how a polymer melt resists deformation (flow under force). The former describes resistance to flow when layers of fluid slide past each other (shear) while the latter describes the deformation when the material is stretched rather than sheared. Viscosity profiles of task 5.2 materials are shown in Figure 31. The samples are generally shear thinning across the rates reported. The PP\_HS\_GE\_B\_HAND (3.1.1.3 PP from post-consumer separate collection – food material hand sorted from Germany) material demonstrates a marginal increase in shear viscosity between 10 and 50  $\text{s}^{-1}$  implying shear thickening behaviour, but the viscosity drops at higher rates which is likely to be the optimal processing window for this material. The melt filter for this sample revealed metallic foils and other contaminants and it is possible that these contaminants could have influenced this behaviour.

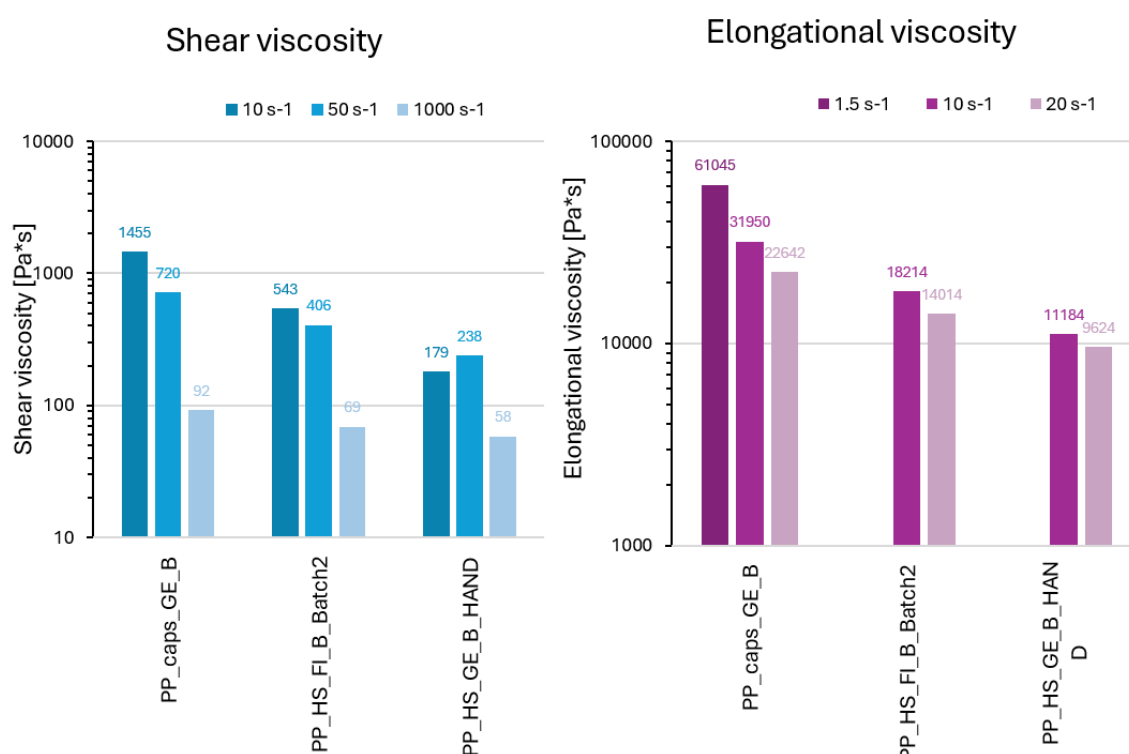


Figure 31: Viscosity profiles of task 5.2 Feedstock

Similarly, the viscosity profiles task 5.3 materials are shown in Figure 32. It can be noted that there is no value shown at very low shear rates ( $10 \text{ s}^{-1}$ ) and this is due to

the shear viscosity being too high (material doesn't flow) at this rate but then rapidly decrease with increasing shear rate. As expected, there is a noticeable increase in viscosity for the samples with decoration compared to transparent cup samples that are devoid of any decoration. However, the viscosity values across the recycled feedstock are in the range that is suitable for injection moulding applications.

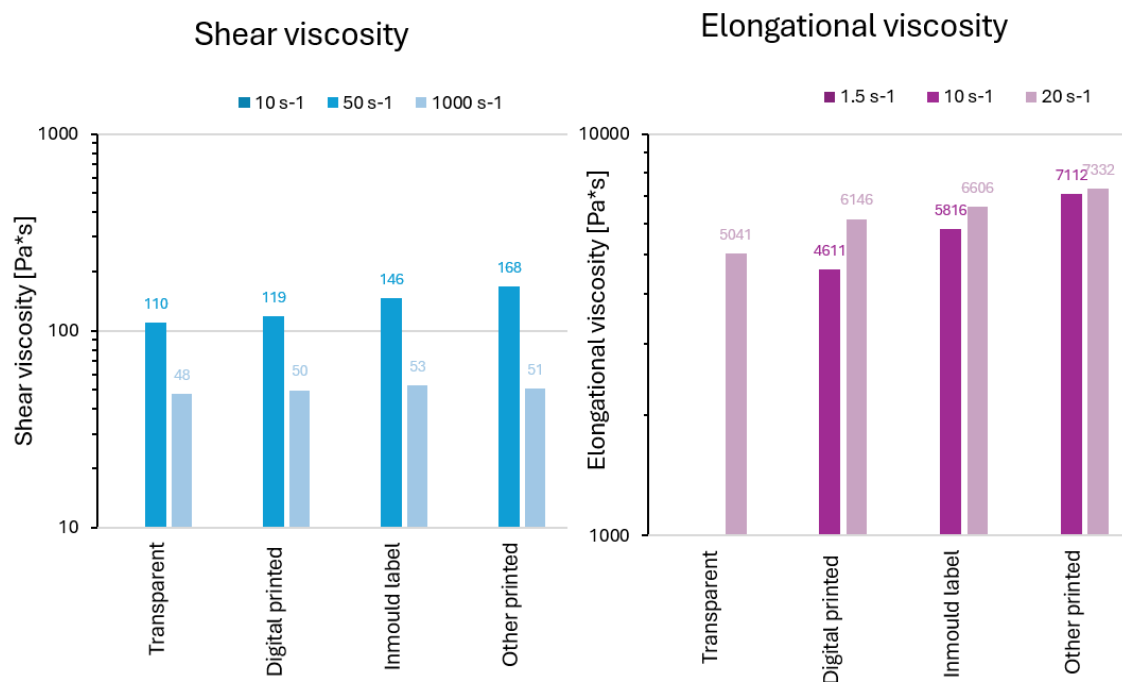


Figure 32: Viscosity profiles of task 5.3 Feedstock



# 7 Chemical contaminant levels and risk assessment

## 7.1. Sampling

Flakes (plastic input to the decontamination process) and pellets (output from the decontamination process, the so-called recycled plastic) were sampled from the following sources of the recycling process:

- Transparent cups
- Digital printed cups
- In-mould label cups
- Other printed cups
- PP\_caps\_GE\_B (PP bottle caps collected from Germany)
- PP\_HS\_FI\_B\_Batch2 (PP from post-consumer separate collection – food material hand sorted from Finland)
- PP\_HS\_GE\_B\_HAND (PP from post-consumer separate collection – food material hand sorted from Germany)

## 7.2. Analysis

All chemical analyses were performed by the laboratory J.S. Hamilton Poland Sp. z o.o, which has taken part in the proficiency tests organised by DRRR GmbH, complying with the Regulation (EU) No 2022/1616.

Samples were cryogenically ground to ensure homogenization and optimized extraction efficiency prior to analysis. The following semi-quantitative non-targeted screening analyses were carried out in all samples (3 replicates each):

- Identification of semi-volatile compounds using GC-MS/FID (mass range: 30–800 Da, LOQ of 0.1 mg/kg, DB-5 column, detector in EI mode) after solvent extraction (24h/40°C, dichloromethane). Internal standard used: Mineral Oil Saturated Hydrocarbons (MOSH) and Mineral Oil Aromatic Hydrocarbons (MOAH).
- Identification of non-volatile compounds using LC-QTOF-MS (mass range: 50–1700 Da, LOQ of 0.1 mg/kg, water/methanol gradient with a C18 column,



detector in ESI+ mode) after solvent extraction (24h/ 60°C, acetonitrile).  
Internal standard: MOSH/MOAH.

All identified substances were compared with the NIST library and internal libraries. A match factor (GC-MS/FID) or score (LC-QTOF-MS) over 80% was considered acceptable.

## 7.3. Methodology for risk Assessment

### 7.1.1 Migration modelling

Risk assessment was performed assuming that a 100% rPP packaging is in direct contact with food. The worst-case concentrations of each substance in the pellets were used for modelling regardless of the type of sample. For substances detected in the flakes and not in the pellets, the LOQ (0.1 mg/kg) was used as the worst-case concentration [1].

Following Regulation (EU) 10/2011 and JRC recommendations [2] and, the substances were first modelled assuming 100% migration into the food (first modelling step), according to the following equation:

$$C_{food} = \frac{C_{polymer} \left( \frac{mg}{kg} \right) \times d_{polymer} \left( \frac{g}{cm^3} \right) * S_{packaging} (cm^2) * e_{packaging} (cm)}{M_{food} (g)}$$

Where:

$C_{food}$ : concentration of the substance into the food (mg/kg or ppm)

$C_{polymer}$ : concentration of the substance in the polymer (mg/kg or ppm)

$d_{polymer}$ : density of PP (g/cm<sup>3</sup>) – 0.92 g/cm<sup>3</sup>

$S_{packaging}$ : contact area of the food contact material (cm<sup>2</sup>) – 600 cm<sup>2</sup>,

$M_{food}$ : weight of the food in contact with the material (g) – 1000 g assuming a density of food 1 g/cm<sup>3</sup>,

$e_{packaging}$ : thickness of the food contact material (cm) – 0.05 cm – worst-case thickness expected in a PP packaging material.

Having this in mind, the Hazard Quotient (HQ) – meaning the exposure level divided by the restriction in food (migration limits) – was calculated. If the 100 % migration scenario HQ was superior to 1, a second migration modelling step was performed using the AKTS SML software (version 6.8) for the exposure scenarios mentioned Table 11.

For the second step, the following parameters were considered based on worst-case scenario:

- Good solubility of the migrant in the food simulant ( $KP/F = 1$ )
- Olive oil (simulant D2 in Annex III of Regulation (EU) 10/2011) as the food simulant
- Piringer model is followed. PP parameters:  $\tau$  (1577) and  $Ap^*$  (13.1)

*Table 11. Exposure conditions used for modelling and respective targeted applications*

| Targeted Applications                           | Time (d) | Temperature (°C) | S (cm <sup>2</sup> ) | Thickness (μm) | M (g) |
|-------------------------------------------------|----------|------------------|----------------------|----------------|-------|
| <b>Packaging intended for refrigeration</b>     | 10       | 40               | 600                  | 500            | 1000  |
| <b>Packaging intended for long term-storage</b> | 365      | 25               | 600                  | 500            | 1000  |

## 7.1.2 Establishment of the migration limits

The methodology used to establish migration limits for each substance is described below:

1. If a substance was listed without limits under Regulation (EC) 1334/2008 (on flavourings and certain food ingredients with flavouring properties for use in and on foods) or 10/2011 (plastic food contact materials), no further risk



evaluation was needed; if listed with a specific migration limit, that limit was applied.

2. If a substance was listed in Annex 2 or Annex 10 of the Swiss Ordinance on food contact materials, the specific migration limit was considered because these annexes provide limits for substances, including printing ink substances, that may not be specifically covered under EU food contact materials legislation.
3. For the remaining substances, the EFSA Threshold of Toxicological Concern (TTC) decision tree was used [3]. The genotoxicity potential was evaluated either through registration under the CLP Regulation or by using ToxTree. For substances with no genotoxicity concerns, the Cramer Class was used to derive migration limits. If further toxicological data were needed, substances were checked for registration under REACH and data was collected regarding toxicological data for general population oral exposure.

For substances for which the Cramer Class applied, the following considerations were applied:

- Class I:  $1.8 \text{ (mg/person/day)} / 1 \text{ kg food/person/day} = 1.8 \text{ (mg/kg food)}$
- Class II:  $0.540 \text{ (mg/person/day)} / 1 \text{ kg food/person/day} = 0.540 \text{ (mg/kg food)}$
- Class III:  $0.09 \text{ (mg/person/day)} / 1 \text{ kg food/person/day} = 0.09 \text{ (mg/kg food)}$
- For organophosphates, the limit of  $0.018 \text{ mg/person/day}$  was used =  $0.018 \text{ (mg/kg food)}$

The Cramer Class approach is applicable to the whole population (based on 60 kg body weight and 1 kg of food consumption).

In cases where more than one limit was applicable to a substance, the most conservative limit was used for the HQ calculation.

## 7.1.3 Substance origin

Substances were screened for their origin according to the EU legislation and registration under REACH. If the substance could not be found through this initial screening, the following databases (in order) were used: Cospatox, CPPdb, FCCmigex and PubChem. The substance origin was divided into the following categories:

- Plastics FCMs: substances falling in this category are listed or are a common NIAS of a listed substance in the EU or Switzerland legislations on plastic food contact materials.
- Plastics: substances with use in other types of plastic packaging (food and non-food contact) without a specific legislated reference in food contact materials legislation (EU or Switzerland).
- Food: as a residue from the food industry.
- Consumer products: residue from other consumer products that are not food such as cosmetics or other personal care items;
- Others: for all other origin types that could not be easily identifiable.

## 7.4. Results

A total of 145 individual substances were detected at least once in the samples. Figure 33 shows, by recycling source, the number of detected substances listed under Regulation (EU) 10/2011 and/or Regulation (EC) 1334/2008. Overall, the majority of detected substances (43–68%, depending on the source) were listed in one or both of these EU regulations. Transparent cups had the lowest number of detected substances (25) and the highest share of substances listed in Regulation (EU) 10/2011 (64%). For the remaining sources, 36–55% of detected substances were listed in Regulation (EU) 10/2011.

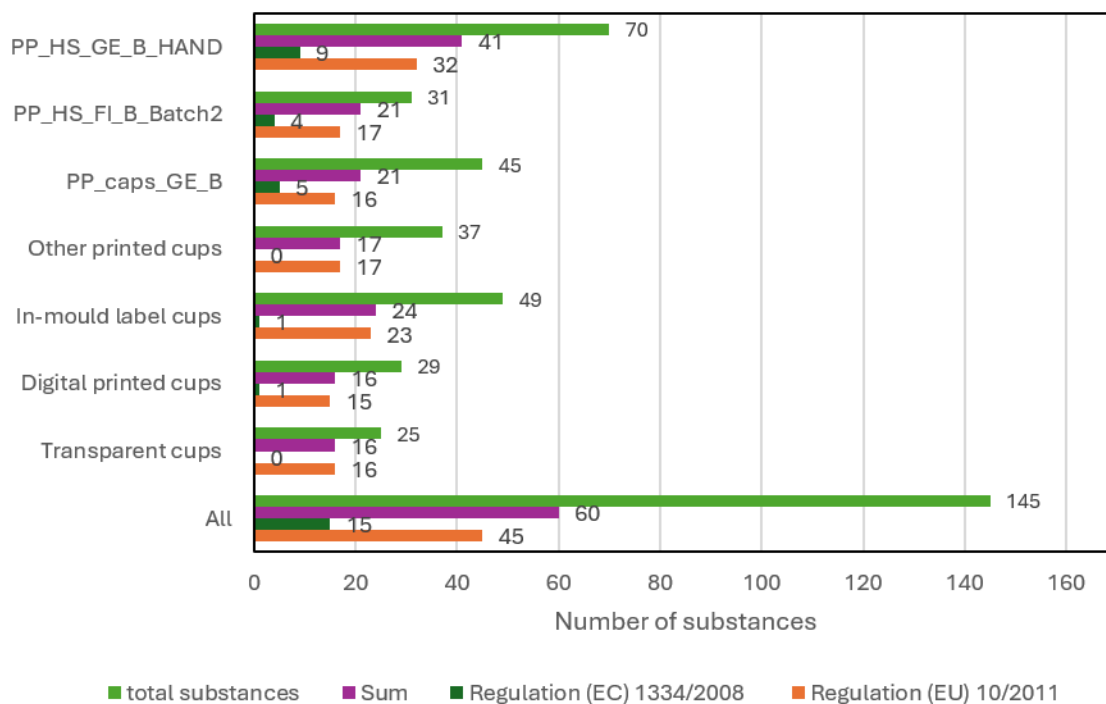


Figure 33. Number of substances legislated in either Regulation (EU) 10/2011 or Regulation (EC) 1334/2008, and also the sum of legislated substances in either or both.

Substances may originate from the virgin material itself, but also from degradation products or contaminants introduced during the material's service life. It is therefore relevant to assess their origin beyond their regulatory status, as shown in Figure 34. Across all detected substances, the majority (51–84%) could be attributed to the plastics packaging industry, covering both food and non-food contact packaging. Other attributed origins included the food industry (8–26%) and consumer products (3–14%).

The increase in substances linked to plastic packaging but not listed under Regulation (EU) 10/2011 highlights a regulatory gap for substances associated with decorative components, including related NIAS, which remain less regulated than under frameworks such as the Swiss Ordinance.

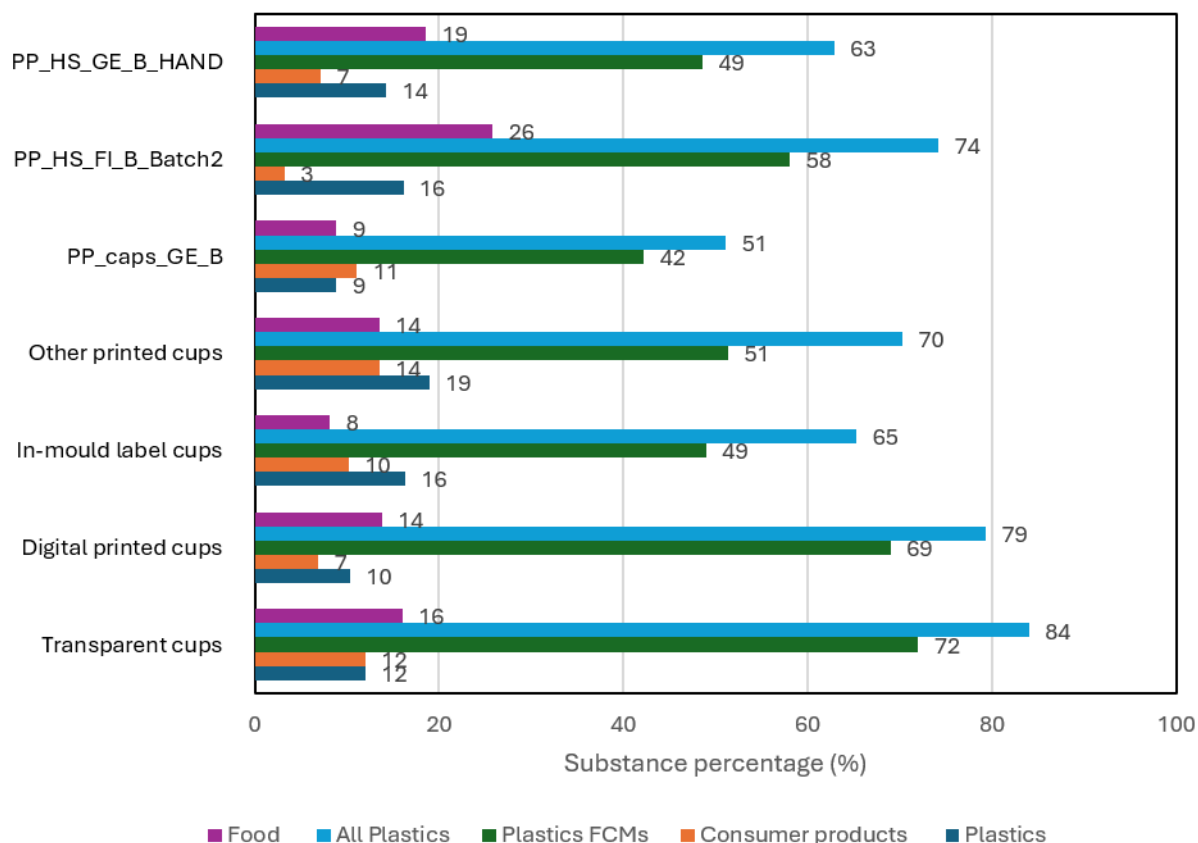


Figure 34. Origin of substances by percentage of detected substances per recycled source. Legend: All Plastics: sum of “plastics” and “plastics FCMs” categories.

An overview of the substances, their origin, concentration and risk assessment is given in Table 12. Only 19% were detected more than half the times considering both the flakes and pellets and more than 30% was only detected once in either. This is coherent with the complexity of the chemical fingerprint of recycled materials, which includes NIAS that can not be easily predictable as in a virgin material.



Table 12: Overview of detected substances, concentrations, HQ from first modelling step, origins and detailed comments. Legend: PI = plastic input; RP = recycled plastic. For non-detects, the concentration in the pellets was considered as the LOQ (0.1 mg/kg).

| Compound                                                  | CAS        | Detections |    | Max PI<br>(mg/kg) | Max RP<br>(mg/kg) | HQ (1 <sup>st</sup><br>migration<br>step) | Origin                  | Comments                                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------------------------------|------------|------------|----|-------------------|-------------------|-------------------------------------------|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                           |            | PI         | RP |                   |                   |                                           |                         |                                                                                                                                                                                                                                                                                                                                                |
| 7,9-Di-tert-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione | 82304-66-3 | 7          | 7  | 9.1               | 6.8               | -                                         | Plastic FCMs            | NIAS of Irganox 1010 (antioxidant) which is Listed in Reg. 10/2011 without a specific migration limit. Read-across approach results in no limit.                                                                                                                                                                                               |
| Octadecanoic acid, 2,3-dihydroxypropyl ester              | 123-94-4   | 6          | 7  | 159.4             | 51.9              | -                                         | Consumer products; Food | Class I Cramer. Present in Cospatox list as fatty acid/ester with a MACE of 60,000 mg/kg body weight/day, therefore no hazard considered.                                                                                                                                                                                                      |
| Phenol, 2,4-bis(1,1-dimethylethyl)-, phosphite (3:1)      | 31570-04-4 | 7          | 7  | 383.9             | 394               | -                                         | Plastic FCMs            | Listed in Reg. (EU) N. 10/2011 without a specific migration limit. Substance present in Annex 10 of the DFI ordinance on materials and objects intended to come into contact with foodstuffs - List of substances authorized for the manufacture of inks for packaging and related requirements, without migration limit, used as an additive. |
| Hydrocarbons                                              | -          | 7          | 7  | 1499.6            | 1603.5            | -                                         | Plastic FCMs            | Sum of substances recognized as a saturated hydrocarbons. Criteria in accordance with the Commission Reg. (EC) No 10/2011 of 14 January 2011. (Ref. No): 95859 with no specific migration limit.                                                                                                                                               |
| Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester | 23470-00-0 | 5          | 7  | 187.5             | 151.8             | -                                         | Plastic FCMs            | Substance referable to FCM 9, listed in Reg. 10/2011 and subsequent amendments with no specific migration limit.                                                                                                                                                                                                                               |
| Irgafos 168 Phosphate                                     | 95906-11-9 | 7          | 7  | 62.2              | 84.8              | -                                         | Plastic FCMs            | Class III Cramer. Decomposition product of Irgafos 168, which is listed under 10/2011 without a specific migration limit. Read-across approach: same classification was given to this compound.                                                                                                                                                |

|                                                    |             |   |   |      |        |      |                       |                                                                                                                                                                                                 |
|----------------------------------------------------|-------------|---|---|------|--------|------|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1-Decanol, 2-hexyl-                                | 2425-77-6   | 7 | 6 | 31.6 | 5.6    | -    | Plastic FCMs          | REF No 33120 – Listed under 10/2011 with no specific migration limit.                                                                                                                           |
| 13-Docosenamide, (Z)-                              | 112-84-5    | 5 | 6 | 33.5 | 1764.2 | -    | Plastic FCMs          | Listed in Reg. 10/2011 without specific migration limit. Listed in Annex 10 of the DFI Ordinance without migration limit, used as additive.                                                     |
| DMDBA / Bis(3,4-dimethyl-dibenzylidene sorbitol)   | 135861-56-2 | 6 | 6 | 81.6 | 119.1  | -    | Plastic FCMs          | Listed in Reg. 10/2011 without specific migration limit.                                                                                                                                        |
| n-Hexadecanoic acid                                | 57-10-3     | 3 | 6 | 17.9 | 27.9   | -    | Plastic FCMs;<br>Food | Listed in Reg. (EU) N. 10/2011 without a specific migration limit. Listed in Reg. (EC) N. 1334/2008 without limit.                                                                              |
| Glyceryl linoleate (1-Monolinolein)                | 2277-28-3   | 3 | 5 | 22.8 | 16.9   | 0.26 | Plastic FCMs          | TTC Cramer Class I. Functionally related to linoleic acid (PubChem), which is listed in Reg. 10/2011 without migration limit.                                                                   |
| Octadecanoic acid                                  | 57-11-4     | 2 | 5 | 18.9 | 28.4   | -    | Plastic FCMs;<br>Food | Listed in Reg. (EU) N. 10/2011 without a specific migration limit. Listed in Reg. (EC) N. 1334/2008 without limit. Substance present in Annex 10 of the DFI ordinance.                          |
| Phthalic anhydride                                 | 85-44-9     | 2 | 5 | 1.5  | 3.2    | -    | Plastic FCMs          | Listed in Reg. 10/2011 without specific migration limit.                                                                                                                                        |
| 2,4-Di-tert-butylphenol                            | 96-76-4     | 3 | 5 | 8    | 3.5    | 0.05 | Plastics              | Class I Cramer. CPPd: Found NIAS in PP with antioxidants Irganox 1010 and Irgafos 168; elp(PA, PE, polyolefin, PP)   CosPaTox: 2,4-Di-tert-butylphenol (degradation product of an antioxidant). |
| Hexadecanoic acid, 2-hydroxy-1,3-propanediyl ester | 502-52-3    | 3 | 4 | 4.8  | 24     | -    | Plastic FCMs          | Listed in Reg. 10/2011 FCM substance No. 50 (Ref. No. 56550) without specific migration limit.                                                                                                  |
| Irganox 1010                                       | 6683-19-8   | 3 | 4 | 10.2 | 12.2   | -    | Plastic FCMs          | Listed in Reg. 10/2011 without specific migration limit.                                                                                                                                        |

|                                         |            |   |   |      |      |             |                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------------------------------------|------------|---|---|------|------|-------------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| N,N-bis(2-hydroxyethyl)alkyl(C13)amine  | 70955-14-5 | 4 | 4 | 31.4 | 27.5 | 1.3         | Plastic FCMs                | Listed under Regulation 10/2011 with a group limit of 1.2 mg/kg food. Listed in Annex 10 of the DFI Ordinance with migration limit equal to 0.6 mg/kg food. expressed as tertiary amine. Further modelling was needed and group restriction were considered.                                                                                                                                                                                                                                                                                                  |
| Tributyl acetylcitrate                  | 77-90-7    | 3 | 3 | 13.8 | 12.9 | -           | Plastic FCMs; Food          | Listed in Reg. (EU) N. 10/2011 with a specific migration limit, group restriction n. 32, of 60 mg/kg food. Group limit not surpassed on first modelling step. Included in the list of authorized substances in Reg. (EC) N. 1334/2008 without limit. Substance present in Annex 10 of the DFI ordinance.                                                                                                                                                                                                                                                      |
| DOF / 2-Ethylhexyl fumarate             | 141-02-6   | 4 | 3 | 4    | 1.9  | -           | Plastic FCMs; Food          | Cramer Class III. Also known as DEHF, is authorized as indirect food additive in the US and permitted for use as monomer in adhesives and coatings, in paperboard and as additive in silicones. DEHF may also be an impurity of the surfactant dioctyl sodium sulfosuccinate (DEHSS; CAS 577-11-7), however this substance is not authorized for food contact materials in the US or Europe. An ECHA dossier is available showing no hazards (NOAELs ≥ 1000 mg/kg bw/day). Therefore, no hazard was used as the approach instead of the general Cramer Class. |
| 3,5-di-tert-Butyl-4-hydroxybenzaldehyde | 1620-98-0  | 1 | 3 | 2.2  | 2.3  | 0.04        | Plastics                    | TTC (Cramer Class I). CosPaTox: degradation product of an antioxidant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Glycerol monooleate (2-Oleoylglycerol)  | 25496-72-4 | 3 | 3 | 2    | 2.8  | -           | Plastic FCMs                | Listed in Reg. 10/2011 without specific migration limit - FCM n 49.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 1-Dodecanol, 2-octyl-                   | 5333-42-6  | 2 | 3 | 6.9  | 5.5  | 0.08        | Consumer products; Plastics | TTC (Cramer Class I), Used in consumer products (Cospatox) + in plastics as a filler (CPPdb)                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Benzaldehyde, 4-propyl-                 | 28785-06-0 | 0 | 3 | 0    | 3.5  | 0.053666667 | Consumer products           | TTC (Cramer Class I)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

|                                                                                     |             |   |   |      |       |      |                   |                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------------------------------------------------------------|-------------|---|---|------|-------|------|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| N,N-bis(2-hydroxyethyl)alkyl(C15)amine                                              | 70955-14-5  | 4 | 3 | 31.6 | 27.5  | 1.3  | Plastic FCMs      | Listed under Regulation 10/2011 with a group limit of 1.2 mg/kg food. Listed in Annex 10 of the DFI Ordinance with migration limit equal to 0.6 mg/kg food. expressed as tertiary amine. Further modelling was done and group restriction were considered                                                                       |
| Triester analog of Irganox 1010                                                     | 84633-54-5  | 5 | 3 | 7.4  | 2.6   | 0.13 | Plastics          | Cramer Class II. Impurity of antioxidant.                                                                                                                                                                                                                                                                                       |
| 1-Dodecanol, 2-hexyl- (RT 25.7 min)                                                 | 110225-00-8 | 1 | 3 | 8    | 7     | 0.11 | Consumer products | TTC (Cramer Class I). PubChem mentions use as a lubricating agent for both consumer products and industry.                                                                                                                                                                                                                      |
| cis-11-Eicosenamide                                                                 | 10436-08-5  | 3 | 2 | 11.4 | 117.2 | -    | Plastic FCMs      | Listed in Reg. 10/2011 without specific migration limit.                                                                                                                                                                                                                                                                        |
| Hexanedioic acid, bis(2-ethylhexyl) ester                                           | 103-23-1    | 2 | 2 | 5    | 7.4   | 0.01 | Plastic FCMs      | Listed in Reg. (EU) N. 10/2011 with a specific migration limit of 18 mg/kgfood and group restriction of 60 mg/kgfood. Substance present in Annex 10 of the DFI ordinance with a specific migration limit of 18 mg/kgfood and group restriction no. 32 equal to 60 mg/kgfood. Group limit not surpassed on first modelling step. |
| Isopropyl myristate                                                                 | 110-27-0    | 1 | 2 | 10.9 | 6.3   | -    | Food              | Listed under 1334/2008 without restrictions                                                                                                                                                                                                                                                                                     |
| Ethyl Oleate                                                                        | 111-62-6    | 2 | 2 | 11.8 | 8.3   | -    | Food              | Listed under 1334/2008 without restrictions                                                                                                                                                                                                                                                                                     |
| 9-Octadecenoic acid (Z)-, methyl ester                                              | 112-62-9    | 2 | 2 | 4.1  | 3.6   | -    | Food              | Listed under 1334/2008 without restrictions                                                                                                                                                                                                                                                                                     |
| Behenic acid                                                                        | 112-85-6    | 1 | 2 | 5.8  | 6.8   | -    | Plastic FCMs      | Listed in Reg. (EU) N. 10/2011 without a specific migration limit.                                                                                                                                                                                                                                                              |
| 2-(4-Methylbenzyl)-2-dimethylamino-1-(4-morpholinophenyl)-1-butanone (Keycure 8179) | 119344-86-4 | 1 | 2 | 2.2  | 1.7   | 0.94 | Plastics          | CPPdb: used in plastic packaging. Listed in Annex 10 DFI Ordinance with a SML of 0,05 mg/kg.                                                                                                                                                                                                                                    |

|                                                                                              |            |   |   |      |      |      |              |                                                                                                                                                                                                    |
|----------------------------------------------------------------------------------------------|------------|---|---|------|------|------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Diethyl Adipate                                                                              | 123-79-5   | 2 | 2 | 11.5 | 11.3 | 0.17 | Plastics     | Cramer Class I. . No active ECHA dossiers. Present in CPPdb, therefore used in plastic packaging.                                                                                                  |
| Benzenepropanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, octadecyl ester (Irganox 1076) | 2082-79-3  | 2 | 2 | 2.9  | 8.8  | 0.04 | Plastic FCMs | Listed in Reg. (EU) N. 10/2011 with a specific migration limit of 6 mg/kgfood.<br>Listed in Annex 10 of the DFI Ordinance with specific migration limit equal to 6 mg/kgfood as sum of substances. |
| DBS / Dibenzylidene sorbitol                                                                 | 32647-67-9 | 0 | 2 | 0    | 2.8  | -    | Plastic FCMs | Listed in Reg. 10/2011 without specific migration limit.                                                                                                                                           |
| Irganox 1035 (Fenozan 30)                                                                    | 41484-35-9 | 1 | 2 | 2    | 1.8  | 0.02 | Plastic FCMs | Listed in Reg. 10/2011 with a specific migration limit of 2,4 mg/kg                                                                                                                                |
| D-Limonene                                                                                   | 5989-27-5  | 1 | 2 | 7.5  | 7    | -    | Food         | Listed under 1334/2008 without restrictions                                                                                                                                                        |
| Benzenepropanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, methyl ester                   | 6386-38-5  | 2 | 2 | 1.5  | 1.3  | 0.07 | Plastic FCMs | Cramer Class II. Degradation product of antioxidant Irganox 1310.                                                                                                                                  |
| 2-Isopropyl-5-methyl-1-heptanol                                                              | 91337-07-4 | 0 | 2 | 0    | 1.3  | 0.02 | Others       | TTC Cramer Class                                                                                                                                                                                   |
| Cyclic[TPA+EG]+[IPA+EG]                                                                      | -          | 1 | 2 | 2.1  | 1.7  | -    | Plastics     | PET oligomer as NIAS.                                                                                                                                                                              |
| Linear[TPA+EG]2+EG                                                                           | -          | 2 | 2 | 6.8  | 3.7  | -    | Plastics     | PET oligomer as NIAS.                                                                                                                                                                              |
| Ethylene diacrylate                                                                          | 2274-11-05 | 0 | 1 | 0    | 1.4  | 0.02 | Plastic FCMs | TTC Cramer Class I. CPPDb: filler, used or found in fCMs                                                                                                                                           |
| 1-Octanol, 2-butyl-                                                                          | 3913-02-8  | 3 | 1 | 6.1  | 1.9  | -    | Plastic FCMs | Class I Cramer. Listed under 10/2011 with no specific migration limit (ref 33120)                                                                                                                  |

|                                              |              |   |   |      |      |      |              |                                                                                                                                                                                                                                                                   |
|----------------------------------------------|--------------|---|---|------|------|------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sulfurous acid, 2-ethylhexyl octadecyl ester | 1000309-20-1 | 0 | 1 | 0    | 1    | 0.31 | Others       | TTC Cramer Class III, no genotoxic alerts. Origin could not be identified.                                                                                                                                                                                        |
| Phthalic acid, di(6-methylhept-2-yl) ester   | 1000377-97-3 | 1 | 1 | 9.1  | 16.3 | 0.25 | Plastics     | TTC Cramer Class I. Given its structure and phthalate nature, most likely a plasticizer residue                                                                                                                                                                   |
| Carbonic acid, eicosyl vinyl ester           | 1000382-54-3 | 3 | 1 | 4.5  | 1.1  | 0.34 | Others       | TTC Cramer Class III, no genotoxic alerts. Origin could not be identified.                                                                                                                                                                                        |
| Carbonic acid, decyl undecyl ester           | 1000383-16-0 | 1 | 1 | 1.9  | 1.1  | 0.02 | Others       | TTC Cramer Class I. Origin could not be identified.                                                                                                                                                                                                               |
| Campesterol, acetate                         | 1000419-55-2 | 0 | 1 | 0    | 4.2  | 0.06 | Others       | TTC Cramer Class I.                                                                                                                                                                                                                                               |
| (Z)-Docos-9-enenitrile                       | 1000465-48-0 | 0 | 1 | 0    | 32.6 | -    | Plastic FCMs | TTC Cramer Class III, no genotoxic alerts. FCCmigex listed. Uncommon fatty acid nitrile, likely migration from packaging components, possibly from euramide, a slip agent found as well which is listed in 10/2011 without migration limit, read-across was used. |
| Octanal, 2-(phenylmethylene)-                | 101-86-0     | 1 | 1 | 3.7  | 2.4  | -    | Food         | Listed under 1334/2008 without restrictions                                                                                                                                                                                                                       |
| AKR-15 TEGDMA                                | 109-17-1     | 1 | 1 | 0.9  | 1    | 0.02 | Plastic FCMs | TTC Cramer Class I. CPPdb: filler; colorant dye pigment; adhesive; initiator; found in FCMs.                                                                                                                                                                      |
| Octadecanoic acid, 2-hydroxyethyl ester      | 111-60-4     | 1 | 1 | 2.3  | 4.7  | 0.07 | Plastics     | TTC Cramer Class I. CPPdb: surfactant; plasticizers and esters                                                                                                                                                                                                    |
| Eicosen-1-ol, cis-9-                         | 112248-30-3  | 1 | 1 | 3.7  | 4.9  | 0.08 | Food         | TTC Cramer Class I. Present in food ingredients (PubChem)                                                                                                                                                                                                         |
| Oleic acid                                   | 112-80-1     | 1 | 1 | 36.4 | 37.7 | -    | Plastic FCMs | Listed in Reg. (EU) N. 10/2011 without a specific migration limit.                                                                                                                                                                                                |
| BBEP / Bis(2-n-butoxyethyl) phthalate (DBEP) | 117-83-9     | 1 | 1 | 2.2  | 2.3  | 0.04 | Plastics     | TTC Cramer Class I. CPPdb: plasticizers and esters                                                                                                                                                                                                                |

|                                                                     |             |   |   |       |      |      |                             |                                                                                                                                                                                                                                                          |
|---------------------------------------------------------------------|-------------|---|---|-------|------|------|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2-Benzyl-2-(dimethylamino)-4'-morpholinobutyrophenone; Irgacure 369 | 119313-12-1 | 1 | 1 | 3.9   | 1.6  | 0.49 | Plastics                    | TTC Cramer Class III, no genotoxic alerts. CPPdb: lubricant; colorant; adhesive – possibly associated.                                                                                                                                                   |
| Butylated Hydroxytoluene                                            | 128-37-0    | 1 | 1 | 4     | 1.2  | 0.01 | Plastic FCMs                | Listed under Reg. 10/2011 with SML of 3 mg/kg                                                                                                                                                                                                            |
| AKR-28 Acrylic acid, hexamethylene ester (HDDA)                     | 13048-33-4  | 1 | 1 | 2.1   | 1    | 0.02 | Plastic FCMs                | TTC Cramer Class I. CPPdb: plastics; solvent; surfactant; filler; colorant; adhesive; initiator; found in FCMs.                                                                                                                                          |
| Dodecanoic acid, 2,3-dihydroxypropyl ester                          | 142-18-7    | 1 | 1 | 112.3 | 92.6 | -    | Consumer products; Plastics | TTC Cramer Class I, ECHA dossier available. All available subacute, subchronic and chronic repeated dose toxicity studies resulted in NOAELs $\geq 1000$ mg/kg bw/day. Therefore no hazard identified. Used in cosmetic products and polymer production. |
| Isopropyl palmitate                                                 | 142-91-6    | 1 | 1 | 3.9   | 5.7  | -    | Food                        | Listed under 1334/2008 without restrictions                                                                                                                                                                                                              |
| Dodecanoic acid                                                     | 143-07-7    | 0 | 1 | 0     | 4.7  | -    | Plastic FCMs                | Listed in Reg. (EU) N. 10/2011 without a specific migration limit.                                                                                                                                                                                       |
| N-Lauryldiethanolamine                                              | 1541-67-9   | 1 | 1 | 4.1   | 3.2  | 0.98 | Plastics                    | TTC Cramer Class III, no genotoxic alerts.                                                                                                                                                                                                               |
| Pentanoic acid, 5-hydroxy-, 2,4-di- <i>t</i> -butylphenyl esters    | 166273-38-7 | 0 | 1 | 0     | 2.4  | 0.04 | Plastic FCMs                | TTC Cramer Class I. Degradation product of acrylic-based adhesives used in FCMs (ccmigex)                                                                                                                                                                |
| Irganox 1330 (Ethanox 330)                                          | 1709-70-2   | 1 | 1 | 6.4   | 5    | -    | Plastic FCMs                | Listed in Reg. (EU) N. 10/2011 without a specific migration limit.                                                                                                                                                                                       |
| Dehydroabiatic acid                                                 | 1740-19-8   | 1 | 1 | 4.8   | 1.5  | 0.02 | Plastic FCMs                | Class I Cramer. Additives in FCMs                                                                                                                                                                                                                        |
| Dodecanoic acid, 1-(hydroxymethyl)-1,2-ethanediyl ester             | 17598-94-6  | 1 | 1 | 6.8   | 8.9  | 0.14 | Consumer products           | TTC Cramer Class I                                                                                                                                                                                                                                       |
| Bicyclo[3.1.1]hept-2-ene, 2,6-dimethyl-6-                           | 17699-05-7  | 0 | 1 | 0     | 2.1  | 0.03 | Plastic FCMs                | TTC Cramer Class I, Found in paper FCMs and virgin/recycled PET (ccmigex).                                                                                                                                                                               |

|                                                                                                        |             |   |   |     |      |      |                                    |                                                                                                                                                                                                                                                     |
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| (4-methyl-3-pentenyl)-                                                                                 |             |   |   |     |      |      |                                    |                                                                                                                                                                                                                                                     |
| 2-Ethylhexyl stearate                                                                                  | 22047-49-0  | 0 | 1 | 0   | 10.1 | 0.15 | Plastic FCMs;<br>Consumer products | TTC Cramer Class I. Fatty acid/ ester with wide applications in plastics, cosmetics and personal care products, can include printing inks coatings and others. (Cospatox, CPPdb, ECHA)                                                              |
| 9-Octadecenoic acid (Z)-, hexadecyl ester                                                              | 22393-86-8  | 1 | 1 | 6.6 | 11.1 | 0.17 | Food; Consumer products            | Class I Cramer.                                                                                                                                                                                                                                     |
| 1-[4-(4-Benzoylphenyl)sulfanylphenyl]-2-methyl-2-[(4-methylphenyl)sulfonyl]propan-1-one (Esacure 1001) | 272460-97-6 | 1 | 1 | 7.1 | 6.3  | 1.2  | Plastic FCMs                       | TTC Cramer Class III, no genotoxic alerts. Annex 10 DFI Ordinance 0.15 limit ECHA dossier available.                                                                                                                                                |
| 1,3,5-Tris(3,5-di-tert-butyl-4-hydroxybenzyl)-1,3,5-triazinane-2,4,6-trione (Irganox 3114)             | 27676-62-6  | 1 | 1 | 1.1 | 5.3  | 0.03 | Plastic FCMs                       | Listed in Reg. (EU)10/2011 with a specific migration limit of 5 mg/kg                                                                                                                                                                               |
| AKR-14 eoTMPTA 428                                                                                     | 28961-43-5  | 1 | 1 | 1.3 | 1.4  | 0.02 | Plastics                           | TTC Cramer Class I. CPPdb: Propylidynetrimethanol, ethoxylated, esters with acrylic acid. m-plastics; m-rubber; solvent; filler; colorant; adhesive; adhesion promoters                                                                             |
| 2,3-Dioctylphenol                                                                                      | 29988-16-7  | 1 | 1 | 2.9 | 2.6  | 0.13 | Consumer products                  | TTC Cramer Class II, surfactant intermediate used in detergents, emulsifiers, and resin modifiers.                                                                                                                                                  |
| Tributyl (E)-Aconitate                                                                                 | 343599-72-4 | 0 | 1 | 0   | 0.7  | 0.01 | Plastic FCMs                       | TTC Cramer Class I. Plasticizers non phthalate (Cospatox).                                                                                                                                                                                          |
| 1,30-Triacontanediol                                                                                   | 36645-68-8  | 0 | 1 | 0   | 11.6 | 0.18 | Plastics                           | TTC Cramer Class I, no genotoxic alerts - no ECHA dossier, not in the databases. Potentially originating from Triacontane or Triacontanedioic acid or 1-Triacontanol, probably from oxidized long-chain hydrocarbons used in the polyolefins itself |
| Hexadecanoic acid, 2-hydroxyethyl ester                                                                | 4219-49-2   | 1 | 1 | 2.1 | 3.8  | 0.06 | Consumer products                  | TTC Cramer Class I                                                                                                                                                                                                                                  |

|                                              |            |   |   |      |      |      |                             |                                                                                                                                                   |
|----------------------------------------------|------------|---|---|------|------|------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| $\beta$ -Bisabolene                          | 495-61-4   | 1 | 1 | 18.8 | 5.4  | -    | Food                        | Listed under 1334/2008 without restrictions                                                                                                       |
| 2-Oxepanone                                  | 502-44-3   | 0 | 1 | 0    | 1.8  | 0.99 | Plastic FCMs                | Listed in Reg. (EU) N. 10/2011 and subsequent amendments, with a group restriction of 0.05 (group n 29). Only substance detected from this group. |
| Arachidic acid (Eicosanoic acid)             | 506-30-9   | 3 | 1 | 8.2  | 1.9  | -    | Plastic FCMs                | Listed in Reg. (EU) N. 10/2011 and subsequent amendments, without a specific migration limit                                                      |
| Heptadecanoic acid, 16-methyl-, methyl ester | 5129-61-3  | 1 | 1 | 2.7  | 2.9  | 0.04 | Plastic FCMs                | TTC Cramer Class I. Found in plastics FCMs (fccmigex)                                                                                             |
| Hexadecanoic acid, hexadecyl ester           | 540-10-3   | 1 | 1 | 9.2  | 14   | 0.21 | Consumer products; Plastics | Class I Cramer. Present in Cospatox and CPPdb.                                                                                                    |
| Glycerol monopalmitate                       | 542-44-9   | 2 | 1 | 1    | 1    | 0.02 | Consumer products           | TTC Cramer Class I. CosPaTox (consumer products): Fatty acids/esters.                                                                             |
| 2-Ethylhexyl benzoate                        | 5444-75-7  | 1 | 1 | 0.7  | 0.8  | 0.01 | Plastics                    | TTC Cramer Class I                                                                                                                                |
| Octyl methoxycinnamate                       | 5466-77-3  | 2 | 1 | 0.9  | 0.7  | 0.01 | Plastic FCMs                | Class I Cramer . UV absorber (p.26), Found in PP film FCMs samples (Fccmigex)                                                                     |
| Octan-2-yl palmitate                         | 55194-81-5 | 1 | 1 | 5.9  | 11.3 | 0.17 | Plastic FCMs                | Both building blocks (octanol and palmitic acid) are authorised in 10/2011 without a specific migration limit. Cramer Class I                     |
| Benzaldehyde, 3,4-dimethyl-                  | 5973-71-7  | 0 | 1 | 0    | 3.1  | 0.05 | Consumer products           | Class I Cramer . CosPaTox (consumer products) - Aldehydes.                                                                                        |
| Hexadecanoic acid, ethyl ester               | 628-97-7   | 1 | 1 | 1.7  | 1.6  | -    | Food                        | Listed under 1334/2008 without restrictions                                                                                                       |

|                                                                |            |   |   |      |      |         |              |                                                                                                                                                                                                                                  |
|----------------------------------------------------------------|------------|---|---|------|------|---------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Behenic alcohol                                                | 661-19-8   | 0 | 1 | 0    | 6.4  | -       | Plastic FCMs | Substance attributable to FCM 3 corresponding to saturated, linear, primary aliphatic monoalkols (C4-C22), present in Reg. (EU) N. 10/2011 of January 14, 2011 and subsequent amendments, without specific migration limitation. |
| Trimethylolpropane diacrylate 3-(hexamethyleniminy) propionate | 73003-78-8 | 1 | 1 | 1.4  | 1.6  | 0.02    | Plastics     | Class I Cramer. Due to its triacrylate natural, likely originating from plastics industry                                                                                                                                        |
| Triethylene glycol caprate caprylate                           | 7346-78-3  | 0 | 1 | 0    | 0.8  | 0.01    | Plastics     | Class I Cramer. CPPdb: plasticizers and esters                                                                                                                                                                                   |
| 1,3:2,4-Bis-O-(4-methylbenzylidene)-D-sorbitol                 | 81541-12-0 | 1 | 1 | 3.9  | 4.1  | -       | Plastic FCMs | Listed in Reg. 10/2011 without a specific migration limit                                                                                                                                                                        |
| Bis(2-hydroxyethyl) phthalate                                  | 84-73-1    | 1 | 1 | 1.4  | 3.6  | 0.06    | Plastics     | TTC Cramer Class I. Bis(2-hydroxyethyl) phthalate (CAS 84-73-1) is a bifunctional phthalate diester used mainly as a reactive monomer/crosslinker and plasticizer in polyester, polyurethane and PET chemistry,                  |
| Caryophyllene                                                  | 87-44-5    | 1 | 1 | 5    | 1.6  | -       | Food         | Listed under 1334/2008 without restrictions                                                                                                                                                                                      |
| Irganox 1081 (Thioalkofen BP)                                  | 90-66-4    | 0 | 1 | 0    | 0.9  | 0.28    | Plastics     | TTC Cramer Class III, no genotoxic alerts                                                                                                                                                                                        |
| β-Sitosterol acetate                                           | 915-05-9   | 0 | 1 | 0    | 6.2  | 0.10    | Others       | TTC Cramer Class I.                                                                                                                                                                                                              |
| Triethylene glycol di(2-ethylhexoate)                          | 94-28-0    | 1 | 1 | 26.8 | 23.7 | 0.36    | Plastics     | Class I Cramer . CPPdb found in: acrylics; CPE; CR; CSM; fluoropolymers; nitrile rubber; PVC. ECHA CHEM: Industrial formulation of lubricant additives, lubricants and greases                                                   |
| Linear[TPA+CHDM]                                               | -          | 0 | 1 | 0    | 2.4  | -       | Plastics     | PET oligomer as NIAS.                                                                                                                                                                                                            |
| Bumetrizole                                                    | 3896-11-05 | 1 | 0 | 19   | 0.1  | 0.00009 | Plastics     | Listed in Reg. (EU) N. 10/2011 with a specific migration, group restriction n.12, equal to 30 mg/kgfood, expressed as the sum of the substances. Only substance present from this group.                                         |
| 1,7,15,21-Tetraazacyclo-octacosane-8,14,22,2-tetrone           | -          | 1 | 0 | 2.2  | 0.1  | 0.03    | Plastics     | Likely referring to PA 66 dimer. TTC Cramer Class III                                                                                                                                                                            |

|                                                             |              |   |   |     |     |       |                   |                                                                                                                                                                                                                                                                                                                    |
|-------------------------------------------------------------|--------------|---|---|-----|-----|-------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Formic acid, 3,7,11-trimethyl-1,6,10-dodecatrien-3-yl ester | 1000132-11-0 | 1 | 0 | 7.5 | 0.1 | 0.002 | Others            | TTC Cramer Class I. Origin could not be identified.                                                                                                                                                                                                                                                                |
| Dodecyl octyl ether                                         | 1000406-38-4 | 1 | 0 | 3.1 | 0.1 | 0.002 | Others            | Class I Cramer. Origin could not be identified.                                                                                                                                                                                                                                                                    |
| Geranyl acetate                                             | 105-87-3     | 1 | 0 | 0.9 | 0.1 | -     | Food              | Listed under 1334/2008 without restrictions                                                                                                                                                                                                                                                                        |
| Dibutyl adipate                                             | 105-99-7     | 1 | 0 | 1.4 | 0.1 | 0.06  | Plastic FCMs      | "Swiss FDHA Regulation of 16 December 2016 on materials and articles intended to come into contact with foodstuffs (RS 817.023.21), including Annex 10, as amended." 0,05                                                                                                                                          |
| Triethylene glycol (TEG)                                    | 112-27-6     | 1 | 0 | 0.7 | 0.1 | -     | Plastic FCMs      | Listed in Reg. 10/2011 without specific migration limit.                                                                                                                                                                                                                                                           |
| Decanal                                                     | 112-31-2     | 1 | 0 | 1.6 | 0.1 | -     | Food              | Included in the list of authorized substances in Reg. (EC) N. 1334/2008 without limit.                                                                                                                                                                                                                             |
| 1-Octadecanol                                               | 112-92-5     | 1 | 0 | 10  | 0.1 | -     | Plastics; Food    | Substance present in the list of authorized substances in Reg. (EC) No. 1334/2008 without restriction. REF No 33120 - Listed under 10/2011 with no specific migration limit.                                                                                                                                       |
| 2-Ethylhexyl salicylate                                     | 118-60-5     | 1 | 0 | 3.6 | 0.1 | 0.002 | Consumer products | Class I Cramer. Present in Cospatox                                                                                                                                                                                                                                                                                |
| Ethyl 4-hydroxybenzoate (Ethylparaben)                      | 120-47-8     | 1 | 0 | 1.1 | 0.1 | -     | Plastic FCMs      | Listed in Reg. 10/2011 without specific migration limit.                                                                                                                                                                                                                                                           |
| Diethylene glycol dibenzoate                                | 120-55-8     | 1 | 0 | 0.9 | 0.1 | 0.002 | Plastic FCMs      | Class I Cramer Present in CPPdb: plastics; fc; softener; plasticizer; filler; adhesive; NIAS, contaminant from recycled processes (plasticizer from PVC); use in FCMs increases since seen as alternative to some SVHCs. Used or found in: acrylics; CAB; EC; EVA; natural rubber; nitrile rubber; nitrocellulose; |

|                                                 |             |   |   |     |     |        |                         |                                                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------------------------|-------------|---|---|-----|-----|--------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                 |             |   |   |     |     |        |                         | PVAC; PVC; SBR; cellulose acetate butyrate; cellulose nitrate resins; ethyl cellulose resins; PMMA resins; polyvinyl acetate; fcpcs; recycled PET; elp(PET); ABS; cellulose; nitrile rubber; PS; PVAC; PVC; acrylics; CAB; EC; EVA; natural rubber; nitrocellulose; PVC; SBR; ABS; cellulose; nitrile rubber; PS; PVAC; PVC   CosPaTox (consumer products):Benzoates. |
| 4-phenylbut-3-en-2-one                          | 122-57-6    | 1 | 0 | 2   | 0.1 | 0.002  | Food; Consumer products | TTC Cramer Class I. Manufacture of Benzalacetone, ingredient in food and perfumes                                                                                                                                                                                                                                                                                     |
| DLTDP / Dilaurylthiodipropionate (Cyanox LTDP)  | 123-28-4    | 1 | 0 | 3.2 | 0.1 | 0.0006 | Plastic FCMs            | Listed in Reg. 10/2011 with group limit of 5. Only substance present from this group.                                                                                                                                                                                                                                                                                 |
| Caprylic acid (Octanoic acid)                   | 124-07-2    | 1 | 0 | 0.7 | 0.1 | -      | Food                    | Included in the list of authorized substances in Reg. (EC) No. 1334/2008 without restriction.                                                                                                                                                                                                                                                                         |
| Benzil                                          | 134-81-6    | 1 | 0 | 1.3 | 0.1 | 0.002  | Plastic FCMs            | TTC (Cramer Class I). FCCmigex: degradation product of UV photoinitiator in food packaging                                                                                                                                                                                                                                                                            |
| Triethylene glycol monobutyl ether              | 143-22-6    | 1 | 0 | 1.3 | 0.1 | 0.03   | Plastics                | TTC Cramer Class III, no genotoxic alerts. CPPdb m-plastics; m-rubber; pr; va; solvent; lubricant; filler; colorant; adhesive<br>Used or found in: fcpcs                                                                                                                                                                                                              |
| Irganox 1135                                    | 146598-26-7 | 1 | 0 | 1.4 | 0.1 | 0.002  | Plastics                | TTC Cramer Class I. ECHA CHEM: Use as an additive in plastics particularly PU                                                                                                                                                                                                                                                                                         |
| AKR-26 Trimethylolpropane triacrylate (TMPTriA) | 15625-89-5  | 1 | 0 | 0.9 | 0.1 | 0.06   | Plastic FCMs            | List in Annex 10 DFI Ordinance with SML of 0,05 mg/kg)                                                                                                                                                                                                                                                                                                                |
| Phenylbis(2,4,6-trimethylbenzoyl)phos           | 162881-26-7 | 1 | 0 | 3   | 0.1 | 0.03   | Plastics                | TTC Cramer Class III, no genotoxic alerts. m-plastics; m-rubber; pr; colorant; adhesive in CPPdb                                                                                                                                                                                                                                                                      |

|                                                                                    |            |   |   |      |     |       |                   |                                                                                                                                                                                                              |
|------------------------------------------------------------------------------------|------------|---|---|------|-----|-------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| phine oxide; Irgacure 819                                                          |            |   |   |      |     |       |                   |                                                                                                                                                                                                              |
| 9-Octadecenoic acid (Z)-, octadecyl ester                                          | 17673-49-3 | 1 | 0 | 3    | 0.1 | 0.002 | Others            | Class I Cramer.                                                                                                                                                                                              |
| cis- $\alpha$ -Bergamotene                                                         | 18252-46-5 | 1 | 0 | 9.5  | 0.1 | 0.002 | Others            | Class I Cramer. PubChem reports it as a plant metabolite and occurrence in several organisms.                                                                                                                |
| Behenyl acrylate                                                                   | 18299-85-9 | 1 | 0 | 2    | 0.1 | 0.002 | Plastics          | TTC Cramer Class I. ECHA dossier registration.: Use as an intermediate in polymers, Coatings and paints, thinners                                                                                            |
| trans-Isomyristicin                                                                | 18312-21-5 | 1 | 0 | 0.4  | 0.1 | 0.03  | Others            | TTC Cramer Class III, no genotoxic alerts.                                                                                                                                                                   |
| Cyclohexanol, 2-methyl-5-(1-methylethenyl)-, (1 $\alpha$ ,2 $\alpha$ ,5 $\beta$ )- | 18675-33-7 | 1 | 0 | 2.9  | 0.1 | 0.002 | Consumer products | TTC Cramer Class I Assessed by EFSA, Flavouring Group Evaluation 9.                                                                                                                                          |
| 1,4-Bis{2-[(2-methyl-2-propanyl)peroxy]-2-propanyl}benzene                         | 25155-25-3 | 1 | 0 | 0.9  | 0.1 | 0.03  | Plastics          | TTC Cramer Class III, no genotoxic alerts. CPPdb - plastics, initiator, also is registered in ECHA CHEM.                                                                                                     |
| Hexaethylene glycol                                                                | 2615-15-8  | 1 | 0 | 1.3  | 0.1 | 0.03  | Plastic FCMs      | TTC Cramer Class III, no genotoxic alerts. Present in virgin plastics FCMs (fccmigex)                                                                                                                        |
| Di-isodecyl phthalate (DIDP / Ftalan di-isodecylu)                                 | 26761-40-0 | 1 | 0 | 2.8  | 0.1 | 0.002 | Plastics          | Listed in Reg. (EU) N. 10/2011 without a specific migration limit, group restrictions n26 of 1,8 mg kg food and n32 of 60 mg/kgfood. Latter group limit not surpassed. Only substance present from group 26. |
| (+)-4-Carene                                                                       | 29050-33-7 | 1 | 0 | 15.1 | 0.1 | 0.002 | Others            | TTC Cramer Class I                                                                                                                                                                                           |
| Monoisopropyl phthalate                                                            | 35118-50-4 | 1 | 0 | 0.8  | 0.1 | 0.002 | Plastics          | TTC Cramer Class I. Like a degradation product from a plasticizer.                                                                                                                                           |
| Diester analog of Irganox 1010                                                     | 36913-60-7 | 1 | 0 | 1.2  | 0.1 | -     | Plastic FCMs      | Irganox 10/2011 is listed under Reg. 10/2011 without specific migration limit.                                                                                                                               |
| Pentaethyleneglycol                                                                | 4792-15-8  | 1 | 0 | 0.9  | 0.1 | -     | Plastics          | REF No 33120 - Listed under 10/2011 with no specific migration limit.                                                                                                                                        |

|                                               |           |   |   |      |     |          |                |                                                                                                                                                                                                                                                                   |
|-----------------------------------------------|-----------|---|---|------|-----|----------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tetradecanoic acid                            | 544-63-8  | 1 | 0 | 2.5  | 0.1 | -        | Plastics; Food | Listed in Reg. (EU) N. 10/2011 and Included in the list of authorized substances in Reg. (EC) N. 1334/2008 without restriction.                                                                                                                                   |
| Benzaldehyde, 2,4,5-trimethyl-                | 5779-72-6 | 1 | 0 | 3.9  | 0.1 | 0.002    | Plastic FCMs   | TTC Cramer Class I. solvent, degradation of antioxidants (fccmigex)                                                                                                                                                                                               |
| Hexadecanamide                                | 629-54-9  | 1 | 0 | 9.1  | 0.1 | 0.0006   | Plastics       | Substance belonging to the FCM 1065 mixture present in reg 10/2011 with a limit of 5 mg/kg food                                                                                                                                                                   |
| 2,5-Bis(5-tert-butyl-2-benzoxazolyl)thiophene | 7128-64-5 | 1 | 0 | 10.9 | 0.1 | 0.005    | Plastic FCMs   | Listed in Reg. (EU) N. 10/2011 and subsequent amendments, with a specific limit of 0,6                                                                                                                                                                            |
| Triethyl citrate                              | 77-93-0   | 1 | 0 | 0.8  | 0.1 | 0.00005  | Plastic FCMs   | Listed in Reg. (EU) N. 10/2011 and subsequent amendments, with a group restriction of 30 (group n 32). Group limit not surpassed on first modelling step.                                                                                                         |
| Linalool                                      | 78-70-6   | 1 | 0 | 3.4  | 0.1 | -        | Food           | Substance present in the list of authorized substances in Reg. (EC) No. 1334/2008 without restriction.                                                                                                                                                            |
| 4,4'-Isopropylidenedicyclohexanol             | 80-04-6   | 1 | 0 | 1.9  | 0.1 | 0.002    | Plastics       | TTC Cramer Class I. CPPdb listed.                                                                                                                                                                                                                                 |
| Diethyl phthalate (Ftalan dietylu)            | 84-66-2   | 2 | 0 | 1.1  | 0.1 | 0.002    | Plastics       | Cramer Class I. Well known plasticizer, especially in rubber and PVC products. Can also be used in printing inks (It is similar to phthalic acid, dimethyl ester 131-11-3 which is present in Swiss Ordinance with a specific migration limit of 0.05 mg/kg food. |
| Ethoxyquin                                    | 91-53-2   | 1 | 0 | 1.6  | 0.1 | 0.005    | Food           | TTC Cramer Class II. Food antioxidant.                                                                                                                                                                                                                            |
| Bis(2-hydroxyethyl) terephthalate             | 959-26-2  | 1 | 0 | 6.4  | 0.1 | 0.002    | Plastics       | Class I Cramer. Together with 2-hydroxyethyl terephthalic acid, bis(2-Hydroxyethyl) terephthalate is an intermediate in the production of poly(ethylene terephthalate). It is the product of the glycolysis reaction of PET with Ethylene glycol.                 |
| Caprolactam cyclic trimer                     | -         | 1 | 0 | 2.6  | 0.1 | 0.000552 | Plastic FCMs   | Polyamide NIAS used in kitchenware, not genotoxic. BfR set a group limit of 5 mg/kg                                                                                                                                                                               |
| Irganox 1010 with additional oxygen           | -         | 1 | 0 | 1.3  | 0.1 | -        | Plastic FCMs   | Degradation product of Irganox 1010. Listed in Reg. 10/2011 without a specific migration limit                                                                                                                                                                    |

|                                    |   |   |   |     |     |       |          |                                                                                                                                                                                                                                                                                                                                       |
|------------------------------------|---|---|---|-----|-----|-------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Irganox 1135, one methyl split off | - | 1 | 0 | 0.9 | 0.1 | 0.002 | Plastics | TTC Cramer Class I. Use as an additive in plastics particularly PU.                                                                                                                                                                                                                                                                   |
| Linear[TPA+EG]3+EG                 | - | 2 | 0 | 2.7 | 0.1 | -     | Plastics | PET oligomer as NIAS.                                                                                                                                                                                                                                                                                                                 |
| Octylphenol ethoxylates (OPEO5)    | - | 1 | 0 | 1.8 | 0.1 | 0.004 | Plastics | Self-derived SML (mg/kg food) for NPE (nonylphenol ethoxylate) limit based on Environmental Project No. 512 2000 Miljøprosjekt Toxicological Evaluation and Limit Values for Nonylphenol, Nonylphenol Ethoxylates, Tricresyl, Phosphates and Benzoic Acid" – 0,78. These are also endocrine disruptors. Used in plastics and rubbers. |

Regarding the risk assessment, 40% of substances did not require a risk assessment as they were listed without a restriction under Regulation (EU) 10/2011 and/or Regulation (EC) 1334/2008. When considering the overestimation of a 100% migration scenario for the remaining substances, 58% of the substances were shown to be within the safety exposure. As a result, the first assessment was able to evaluate the safety of 98% of substances. None of the substances identified were genotoxic. A full explanation for this first risk assessment for each individual substance is given in **Error! Reference source not found..**

For remaining substances, a risk assessment was made considering the second modelling step. None of these compounds were present in the flakes or pellets of “PP\_caps\_GE\_B”, “PP\_HS\_FI\_B\_Batch” and “other printed cups”. All these substances are related to plastic food contact materials, particularly to printing inks.

Considering the origin of the substances and the fact that only one sample per source, and material type (flakes and pellets) was analysed, it was decided that the worst-case scenario would apply to all sources, even the ones where the second modelling step did not need to apply. From the two substances presented in **Error! Reference source not found.**, the worst-case scenario corresponds to the group limit for N,N-bis(2-hydroxyethyl)alkyl(C13) and (C15) amines. Consequently, based on the worst-case assessment, the use of post-consumer PP should be limited to:

- 65% for all refrigerated applications without heating;
- 40% for applications involving long-term storage (365 days at 25°C) without heating.

EFSA overestimates the migration modelling results in its assessment of plastic recycling technologies. It has set the values of 5 and 10 times more the estimated modelled migration for PET in their Scientific Guidance for post-consumer PET mechanical recycling depending on the molecular weight of the contaminant [4], and it has considered the factor of 2 for HDPE in past evaluations of post-consumer HDPE recycling technologies before Regulation (EU) 2022/1616 entered into force [5]. A recent novel technology report [6] has considered the HDPE factor also applicable to PP. Considering that the risk

assessment performed for N,N-bis(2-hydroxyethyl)alkyl(C13) and (C15) amines considered with the Swiss legislated limit of 0.6 mg/kg food (half the EU limit established in Regulation (EU) 20/2011), it was considered sufficiently conservative.

The results are well within the minimum recycling content targets of 10% and 25% for non-beverage PP food packaging and 30% and 65% for PP beverages (a much less common application) set in Packaging and Packaging Waste Regulation (PPWR).

*Table 13. Results from the second modelling step*

| Compound                                                                                                | CAS         | Restriction in food worst-case (mg/kg food) | HQ Refrigerated | Long-term storage |
|---------------------------------------------------------------------------------------------------------|-------------|---------------------------------------------|-----------------|-------------------|
| Sum of N,N-bis(2-hydroxyethyl)alkyl(C13) and (C15)amine                                                 | 70955-14-5  | 0.6                                         | 1.5             | 2.4               |
| 1-[4-(4-Benzoylphenyl)sulfanyl]phenyl]-2-methyl-2-[(4-methylphenyl)sulfonyl]propan-1-one (Esacure 1001) | 272460-97-6 | 0.15                                        | 0.2             | 0.5               |

## 8. Conclusion & recommendations

The results demonstrated that post-consumer recycled PP can be used safely considering the PPWR minimum recycled content targets. Although most substances were related to plastic packaging and food industry, many substances remain unregulated under EU legislation. There are mostly related to decorative parts of plastic packaging and other NIAS. It should be noted that it is difficult to trace back the origin of every possible NIAS present in a recycled plastic compared to a virgin material due to not only the life service of the product, but the thermal degradation of substances presents in the packaging that occurs during mechanical recycling. This knowledge is also missing from the laboratories. Therefore, harmonized databases and spectra library are needed to bridge this gap.

This work could be further improved as it considered a limited number of samples with limits of detection of 0.1 mg/kg. To assess the genotoxic potential of PP, it is recommended to test a broader sample pool and lower the limit of detection (at least 0.01 mg/kg). Furthermore, further targeted testing and genotoxic screening (e.g. AMES test) should also be considered to provide a full spectrum of possible substances. Nevertheless, a recent report on the notification of a novel technology based on mechanical recycling of post-consumer PP showcased that the plastic input (flakes) have a contamination level of 0.02 mg/kg (100 times less than the 3 mg/kg concentration set for post-consumer PET) based on 700 samples analysed representing 17500 flakes via headspace chromatography [7], which demonstrates the potential of this material.

Considering however the currently available novel technology reports available in the Union Register [8], key differences can be observed in the migration modelling parameters and exposure conditions applied. These differences have a significant impact on the resulting risk assessments, underscoring the urgent need for an EFSA dedicated scientific guidance covering other polymers than PET.

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