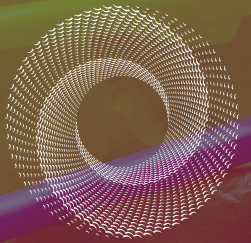


2026



COP
Circular Ocean-bound Plastic

Polymer composition of river-collected plastic

Report

May 2026

Report on Identification of polymer types and recycling possibilities in river-collected ocean-bound plastic

Publisher

Interreg South Baltic project
Circular Ocean-bound Plastic

www.circularoceanplastic.eu

Authors

Geraldo Mihut, The Foundation Plast Center Danmark
Hatice Tüzün, The Foundation Plast Center Danmark
Patrycja Jutrzenka Trzebiatowska, University of Gdansk
Emilia Gontarek-Castro, University of Gdansk



Partners in the COP project and contributors

Clean - The Danish Water and Environmental Cluster (DK) - leadpartner
Ocean Plastic Forum (DK)
Danish Materials Network (DK)
Sustainable Business Hub (SE)
Leibniz Institute for Baltic Sea Research (DE)
University of Rostock (DE)
University of Gdansk (PL)
Gdansk Water Foundation (PL)
Gdansk Sport Center (PL)

Layout

Kasper Gregersen, Clean - The Danish Water and Environmental Cluster

ISBN 978-87-975281-7-4 (digital)

Disclaimer

The report is a part of the Interreg South Baltic project Circular Ocean-bound Plastic, financed by the Interreg South Baltic Programme 2021-2027. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

For more information

To receive information about the project and other related publications, please visit www.circularoceanplastic.eu

Copyright notice

© Copyright Circular Ocean-bound Plastic 2026

Interreg
South Baltic



Co-funded by
the European Union





Executive summary

This report summarises and compares polymer identification results and recycling considerations for plastic collected from rivers in the Baltic Sea region.

The report is based on two independent case studies prepared by project partners:

- Aarhus, Denmark (Plast Center Danmark): identification of polymer types in selected river-collected fractions and discussion of recycling possibilities from Aarhus River.
- Gdańsk, Poland (University of Gdańsk): polymer identification and material characterisation of collected river waste using laboratory-based analysis, with interpretation in terms of recycling relevance from Motława River.

Across both cases, the collected plastic represents a heterogeneous stream of consumer products with varying contamination levels and unknown product histories. The findings indicate that OBP can contain recyclable polymer fractions—often dominated by common consumer polymers such as polyolefins (PP /or PE). However, the practical recycling route depends strongly on sorting quality, cleanliness, and degree of fraction purity and degree of degradation.

Multi-component products (e.g. packaging with labels, caps, multilayer packaging) and contamination remain key barriers and must be addressed through appropriate pre-treatment and separation strategies.

The full partner reports are included unchanged in Appendix A and Appendix B, while this main report provides a harmonised overview and cross-cutting conclusions.

Content

Executive summary

1. Introduction	6
1.1. Aim of this report	6
1.2. Project context and approach	6
2. Study sites and sample sources	7
2.1. Aarhus River, Aarhus (Denmark)	7
2.2. Motława River, Gdąnsk (Poland)	7
3. Methods Review	8
4. Consolidated findings	9
4.1. Polymer diversity across studies	9
4.2. Polymer identity and typical fractions	9
4.3. Contamination, multi-component products and degradation as key barriers	11
4.4. Why fractionation matters	12
5. Recycling possibilities and route selection	13
5.1. Mechanical recycling	13
5.2. Chemical recycling	13
5.3. Solvent-based recycling	14
5.4. Fractions that may require alternative handling	14
6. Conclusion	15
7. Recommendations	16
Appendix	18

1. Introduction

This report is part of the EU Interreg South Baltic project, Circular Ocean-bound Plastic (COP), which addresses the issue of plastic pollution in the South Baltic Sea region. In collaboration with 10 partners from four countries—Germany, Poland, Sweden, and Denmark—the project aims to identify challenges and opportunities related to the collection, recycling, and reuse of ocean-bound plastic (OBP). Within the project, pilot activities have been carried out in several cities, including Rostock (Germany), Gdańsk (Poland), and Aarhus (Denmark), where plastic waste has been collected from river systems for further analysis.

Plastic collected from rivers is increasingly considered a potential circular resource, as it can be intercepted before entering marine environments. However, river-collected plastic differs from conventional post-consumer feedstocks due to its high variability in composition, inconsistent material quality, frequent contamination (e.g. organic residues and dirt), and the presence of multi-material product designs.

Polymer identification in this study was carried out using standard analytical techniques, including Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), and Thermogravimetric Analysis (TGA). Resin Identification Codes (RIC) were used, where applicable, for preliminary classification. As a result, polymer identity alone is not sufficient to determine recyclability. Recycling feasibility depends on the ability to produce stable, clean, and repeatable material fractions.

1.1. Aim of this report

The aim of this report is to:

- Summarise polymer identification findings from two river-collection case studies.
- Provide a harmonised interpretation of recycling possibilities and constraints.
- Extract general conclusions and practical recommendations for sorting and recycling pathways for OBP.

1.2. Project context and approach

This report is part of a broader effort to evaluate whether river-collected plastic can be transformed from waste into a usable resource. OBP is typically heterogeneous and contaminated, requiring structured sorting and identification before recycling can be assessed. As a result, practical recycling depends on establishing realistic handling pathways that combine sorting and cleaning with polymer identification and quality assessment.

The approach applied across the two case studies can be summarised as: (i) sorting into more uniform product and material fractions, (ii) polymer identification using laboratory techniques (e.g., FTIR spectroscopy and, where relevant, thermal analysis), and (iii) interpretation of recycling possibilities based on polymer type, contamination level, and expected processability. Fractions that cannot be sufficiently purified or are strongly mixed (e.g., multilayer or multi-material items) are likely to have limited mechanical recycling potential and may require alternative handling routes depending on local infrastructure and project scope.

2. Study sites and sample sources

In this chapter, study sites and sample sources are shortly described.

2.1. Aarhus River, Aarhus (Denmark)

The Aarhus site covers polymer identification of selected fractions collected from the Aarhus river system and discusses recycling possibilities based on polymer type, contamination, and expected processability. The full partner report is provided in Appendix A.

2.2. Motława River, Gdańsk (Poland)

The Gdańsk/Motława site covers polymer identification and material characterisation of collected river waste using laboratory-based analytical techniques, with interpretation in terms of recycling relevance. The full partner report is provided in Appendix B.

Note on comparability: The two studies represent different local collection streams and conditions. Results should be interpreted as location-specific snapshots rather than a single universal polymer distribution.

3. Methods review

Across both case studies, polymer identification and recycling assessment follow a common approach:

1. Visual categorisation / sorting: items are grouped by product type or fraction (e.g. rigid packaging, bottles, caps/lids, films, mixed rigid fragments).
2. Polymer identification: Resin Identification Codes (RIC) were used, where applicable, for preliminary classification of plastic materials based on product labelling, additional laboratory techniques are used to confirm polymer types (e.g. FTIR spectroscopy) and, where relevant, thermal methods (e.g. DSC/TGA) to support characterisation (ASTM International, 2013).

For unknown polymers, FTIR was used to identify polymer types based on their characteristic infrared absorption spectra. Differential Scanning Calorimetry (DSC) was applied to assess thermal properties such as melting temperature, supporting polymer identification and evaluation of material condition. Thermogravimetric Analysis (TGA) was used to analyse thermal stability and composition by measuring mass loss as a function of temperature.

3. Recycling assessment: polymer identity is evaluated together with contamination, multi-material products, and material condition to determine realistic recycling routes.

River-collected streams are heterogeneous, therefore the purpose of identification is not only to classify polymers but also to guide practical fractionation into streams suitable for further processing. After collecting, the plastic samples were subjected to basic handling procedures prior to analysis.

- In the Aarhus case study, collected materials were stored in bags until sorting, and no additional cleaning or drying steps were applied prior to weighing. As a result, samples were analysed with residual moisture, dirt, and organic contamination present.
- In contrast, in the Gdańsk case study, excess water was removed and the materials were allowed to dry under ambient conditions prior to analysis. These differences in handling and pre-treatment may influence the level of residual moisture, contamination, and material condition, and should therefore be considered when interpreting and comparing results.

4. Consolidated findings

In this chapter, the consolidated findings from both sites are presented and compared.

4.1. Polymer diversity across studies

The two case studies demonstrate that river-collected plastic consists of a diverse range of polymer and material types, with varying degrees of degradation, reflecting the heterogeneous nature of the collected waste streams.

In the Aarhus case study, six main polymer types were identified through combined visual inspection and laboratory-based analysis (FTIR and DSC), including polyolefins (PP and PE), PET, PS, PC, and acetate-based materials.

In comparison, the Gdańsk (Motława River) case study identified a broader range of eight material types. In addition to common thermoplastics such as PE, PET, PP, and PS, the analysis included also composite materials (e.g. multilayer plastics), rubber-based materials, cellulose-based products, and other less conventional polymers.

The higher diversity observed in the Gdańsk study reflects both differences in collection methods and the inclusion of more complex and non-thermoplastic materials in the analysis. Overall, the results highlight that river-collected plastic is not a single uniform material stream but a mixture of multiple polymer types and material categories. The identified number of polymer types should therefore be interpreted as an indicator of material complexity rather than recycling potential, as many items consist of mixed, composite, or contaminated materials.

4.2. Polymer identity and typical fractions

Across both case studies, and despite differences in the number of identified polymer types, the collected material streams are largely dominated by common consumer polymers. However, the presence of these polymers does not directly imply recyclability, as many items are multi-material, contaminated, or composed of composite structures.

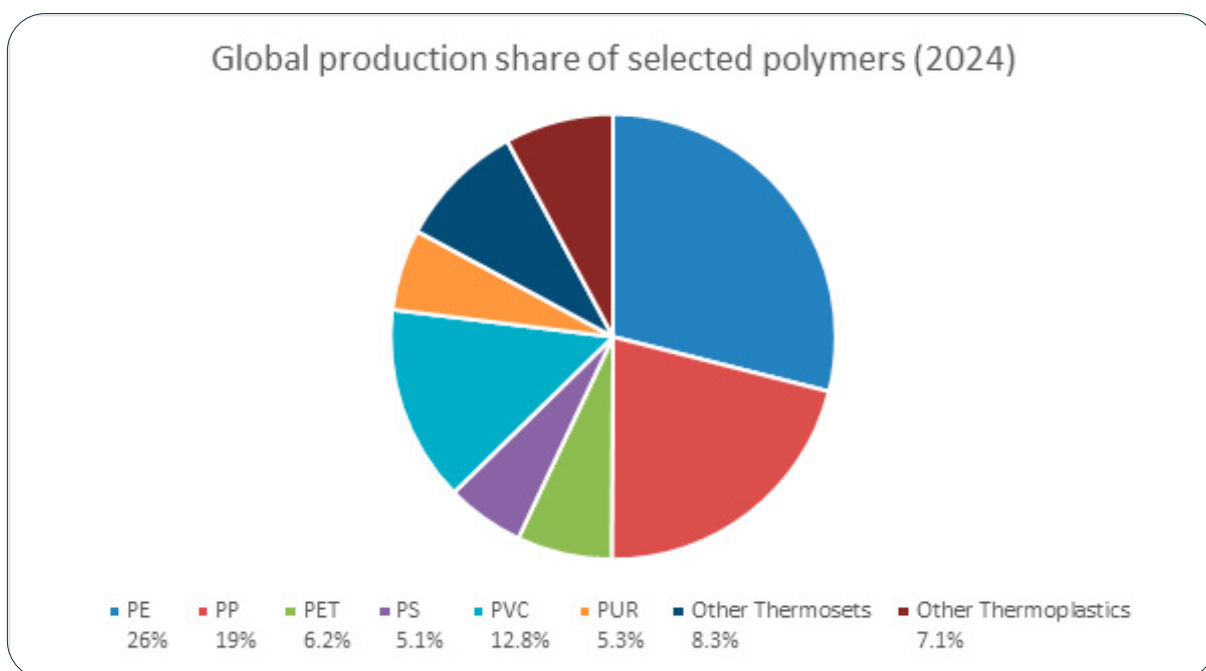


Figure 1: Global plastics production by polymer group in 2024, based on a total production volume of 430.9 million tonnes (Plastics Europe, 2025).

As shown in Figure 1, PE, PP, PET, and PS are among the major polymer groups in global plastics production. Their frequent occurrence in river-collected OBP is therefore consistent with their widespread use in packaging and consumer products. In particular, polyolefin-rich fractions such as PP and PE are highly relevant because they are widely used in rigid packaging, films, bags, caps, lids, and other short-life consumer products. PET is mainly associated with bottles and some packaging applications, while PS is typically found in lids, foams, and selected food-service products.

In practical recycling terms, the most relevant candidates for mechanical recycling are typically:

- Rigid polyolefins PP and PE (including HDPE), when sufficiently separated and cleaned.
- PET bottles, where sorting and cleanliness are adequate.
- Film fractions, only where infrastructure and pre-treatment allow stable processing, which is often challenging due to contamination and mixed compositions.

Polyolefin-rich rigid fractions are often among the most promising initial targets due to their relatively high occurrence and the existence of established recycling pathways and compatible processing infrastructure. However, even within these fractions, variability in material composition, additives, colour, labels, caps, multilayer structures, and contamination can affect processability and final material quality.

Overall, while common polymers dominate the collected waste streams, their distribution across mixed and contaminated product fractions highlights the need for effective sorting and fractionation. Recycling feasibility depends not only on polymer identity, but also on the ability to isolate sufficiently clean, homogeneous, and repeatable material fractions.

4.3. Contamination and multi-component and degradation as key barriers

Building on the general characteristics described in the introduction, a key observation across both studies is that many collected items do not consist of single, pure polymer types, but instead consist of multi-material products, composite structures, or contaminated plastics, similarly to post-consumer waste streams. However, a distinguishing characteristic of river-collected plastic is often the higher level of material degradation, resulting from prolonged environmental exposure prior to collection. This effect may be more pronounced in less structured or ad hoc collection systems, as observed in the Gdańsk case study. Such degradation further limits the processability and direct recyclability of the identified polymers.

A consistent finding is that river-collected plastic is rarely a clean or uniform raw material, as it predominantly originates from food and beverage packaging and other common consumer sources. Common barriers to recycling include:

- Dirt, organic residues, and surface contamination
- Labels, inks, and additives.
- Multi-material products (e.g. combinations of different polymers, labels, caps, or multilayer packaging).
- Variability in product history and environmental exposure.

These factors reduce both the yield and the quality of recycled material, as they introduce impurities, affect processing behaviour. Simple mixing, melting and reprocessing of such materials would result in inconsistent material properties and reduced mechanical performance. In particular, multi-component and multilayer products require additional separation steps, such as density-based separation (e.g. water or salt solutions), which are often technically challenging and not always economically feasible.

As a result, even when recyclable polymers are present, their effective recovery depends on the ability to remove contaminants and separate materials into sufficiently pure fractions. Without such pre-treatment and sorting, the identified polymer types cannot be reliably processed into stable and usable recycled materials, leading to low mechanical performance and poor surface quality in recycled outputs.

4.4. Why fractionation matters

Attempting to recycle mixed streams directly is rarely feasible at stable industrial quality. This is primarily because different polymers have different melting and processing temperatures, as well as incompatible material properties, which leads to poor material performance when processed together.

The most realistic approach is to create a limited number of repeatable fractions, for example:

- Rigid PP fraction
- Rigid PE(HDPE) fraction
- PET fraction (where present)
- Film fraction (only if quality allows)

By separating materials into more uniform fractions, it becomes possible to process them under controlled conditions, improving material consistency and enabling the selection of realistic and stable recycling pathways.

5. Recycling possibilities and route selection

In this chapter, different recycling possibilities are presented before a consolidated conclusion.

5.1. Mechanical recycling

Mechanical recycling is typically the preferred option when reasonably pure and clean fractions can be achieved. A practical pathway includes:

- Early coarse sorting (rigid vs film; bottles vs mixed rigid).
- Polymer separation (PP vs PE vs PET) where feasible.
- Washing/drying to reduce contamination and odour.
- Quality checks (visual contamination level, polymer RIC verification, and processability indicators where relevant).

5.2. Chemical recycling

Chemical recycling may be considered for fractions that are not suitable for mechanical recycling due to contamination, mixed polymer composition, complex multi-material structures or with high degradation level.

Unlike mechanical recycling, which requires relatively clean and homogeneous material streams, chemical recycling processes aim to break down polymers into smaller molecules, such as monomers, oligomers, or other feedstock components, depending on the polymer type.

Potential applications include mixed polyolefin streams, multilayer packaging, and contaminated plastic fractions that cannot be effectively separated into pure material streams. These processes can include techniques such as pyrolysis, depolymerisation, or other thermochemical treatments, depending on the polymer type and available infrastructure (Gontarek-Castro, et al., 2026). However, the feasibility of chemical recycling depends on several factors, including process availability, economic viability, and environmental considerations. In addition, pre-treatment steps such as sorting and removal of non-plastic materials are still required to ensure stable process conditions. For some processes, such as pyrolysis, a relatively pure feedstock is required needed to achieve high yields.

As a result, chemical recycling should be considered as a complementary option for specific fractions where mechanical recycling is not feasible, rather than a primary solution for all mixed plastic waste streams.

5.3. Solvent-based recycling

Solvent-based recycling involves the use of selective solvents in which target polymers are dissolved, allowing separation from additives, dyes, and contaminants through processes such as filtration, centrifugation, or phase separation. The polymer is subsequently recovered, typically through precipitation or recrystallisation, to obtain a purified material. This method is generally applicable to more homogeneous plastic fractions and can reduce the need for extensive mechanical pre-treatment. However, its feasibility depends on solvent selection, process complexity, and economic and environmental considerations (Gontarek-Castro, et al., 2026).

5.4. Fractions that may require alternative handling

For fractions with high contamination levels, mixed polymers, or complex multi-material products, both mechanical and chemical recycling options may be limited or not feasible.

In such cases, potential options include:

- Downcycling into less demanding applications (where specifications allow).
- Alternative handling routes depending on local or regional infrastructure.
- Further investigation of complementary recycling options for difficult fractions (if within project scope).

The key point is that recycling feasibility depends on the quality requirements of the target application and the achievable fraction purity.

6. Conclusion

Based on the two case studies, collected plastic shows a considerable diversity of material types. In the Aarhus study, six main polymer types were identified, while the Gdańsk (Motława River) study revealed a broader range of eight material types, including both conventional thermoplastics and non-thermoplastic or composite materials. This variation reflects differences in local waste streams, collection methods, and the inclusion of more complex material categories in the Gdańsk analysis. The results demonstrate that the number of identified polymer types primarily reflects the complexity of the waste stream rather than its immediate recycling potential. Although common consumer polymers—particularly polyolefins (PP and PE) and PET—dominate the collected material, they are frequently present in mixed, contaminated, or multi-component products, which limits their direct recyclability.

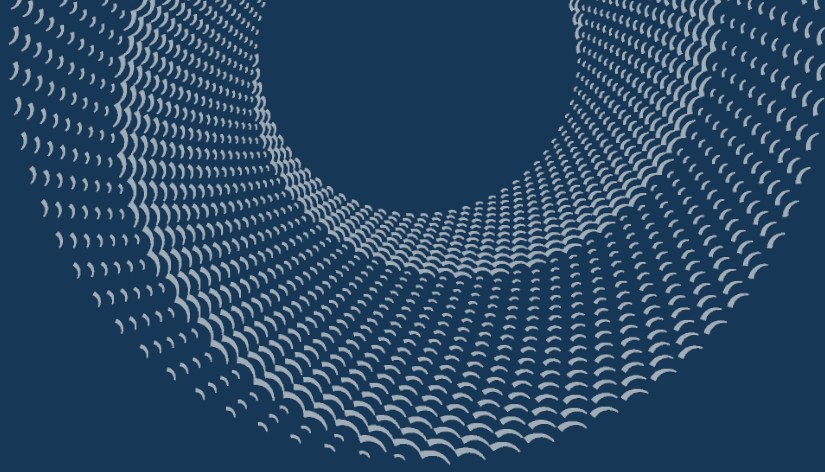
Overall, the findings confirm that successful recycling of OBP depends less on polymer identification alone and more on the ability to sort, clean, and separate materials into stable and homogeneous fractions. Without effective fractionation, contamination and multi-material constructions remain significant barriers to producing consistent and usable recycled materials.

7. Recommendations

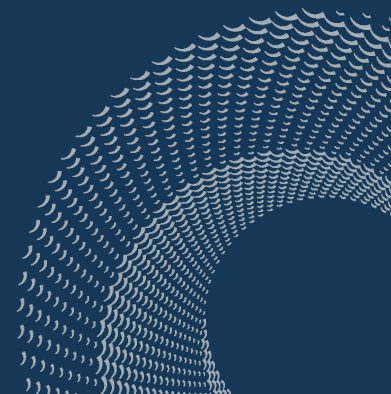
To improve the practical recycling potential of river-collected plastic streams, the following actions are recommended:

- Prioritise early sorting into a limited set of stable categories (e.g. rigid vs film; PP/PE/PET where feasible), as the diversity of polymer types reflects a highly heterogeneous material stream that requires controlled fractionation.
- Define minimum cleanliness requirements and implement washing and drying protocols suited to the local stream in order to reduce contamination and improve material quality.
- Introduce a simple quality control (QC) checklist, including polymer identification confirmation, contamination indicators, and basic processability assessment where relevant.
- Establish clear rejection criteria for complex multi-material, composite, or heavily contaminated fractions, and evaluate appropriate handling routes for these materials separately.
- When scaling operations, focus on achieving consistent and repeatable fraction quality rather than maximising mass recovery of mixed and heterogeneous streams.
- Select the recycling route based on clearly defined fraction quality criteria: fractions that are well-sorted, relatively clean (low organic and inorganic contamination), and show limited degradation should be directed to mechanical recycling or solvent based recycling.
- Fractions characterised by high contamination, significant material degradation, or mixed/multi-material composition (e.g. multilayer structures) should be directed to dedicated chemical recycling pathways (e.g. pyrolysis or depolymerisation). This allocation should be based on measurable indicators such as contamination level, fraction purity, and expected processability.

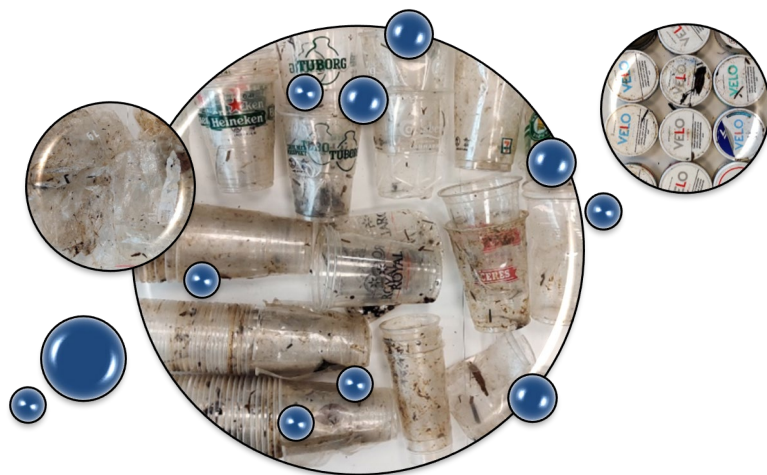




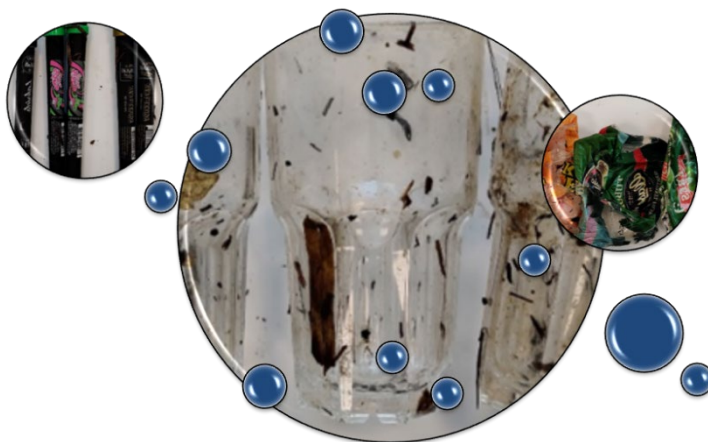
Appendix



Appendix A: Plast Center Danmark report (Aarhus case) – full report text and documentation



IDENTIFICATION OF OBP AND RECYCLING POSSIBILITIES



Introduction

This report presents the results of the Aarhus case study, focusing on polymer identification and material characterisation of plastic collected from the Aarhus river system. The OBP was analysed by Plast Center Denmark (PCD) using standard laboratory techniques to determine polymer types and assess material properties relevant for recycling. The following analyses were applied:

The collected OBP from Aarhus River in Aarhus will be analysed by Plast Center Danmark (PCD) to perform material identification by following analyses:

- Fourier Transform Infrared Spectroscopy (FTIR) analysis, which enables identification of the overall chemical structure.
- Differential Scanning Calorimetry (DSC) analysis, which determines the thermal properties of the material as glass transition temperature and melting point.

After material identification, the recycling possibilities of the polymer types will be investigated.

Plastic waste collected

On March 6th, 2024, PCD had a meeting with Ivan Krag Møller, team manager of the entrepreneur department in Aarhus Municipality. The entrepreneur department has the tasks to control and monitor the automated waste collector, SeaProtectorOne (see Figure 2), located in Aarhus River and to empty and sort the waste.

SeaProtectorOne is located such as the floating waste in the river is filtrated by the filtration unit all day long except the time, when the boom is lifted or kayaks needs to pass through. Every second hour the boom is automatically lifted and emptied into the container beside the boom. The container is emptied for waste every day by the entrepreneur department. The waste is sorted into fractions as household waste, metal, glass, plastic and residual waste. Fractions like clothes, paper and garden waste are also sorted as residual waste, as clothes and paper are wet and garden waste contains confetti and other non-garden waste, which are difficult to remove completely. (Haseler & Mihut, 2026). The entrepreneur department agreed to collect the plastic waste in a bag per week and a bag per day in the Summer. Before collecting the plastic waste, the entrepreneur is also mapping the fractions of plastic waste into pieces. As the entrepreneur department has limited resources, weighing the waste was not a task, they could offer to help with.

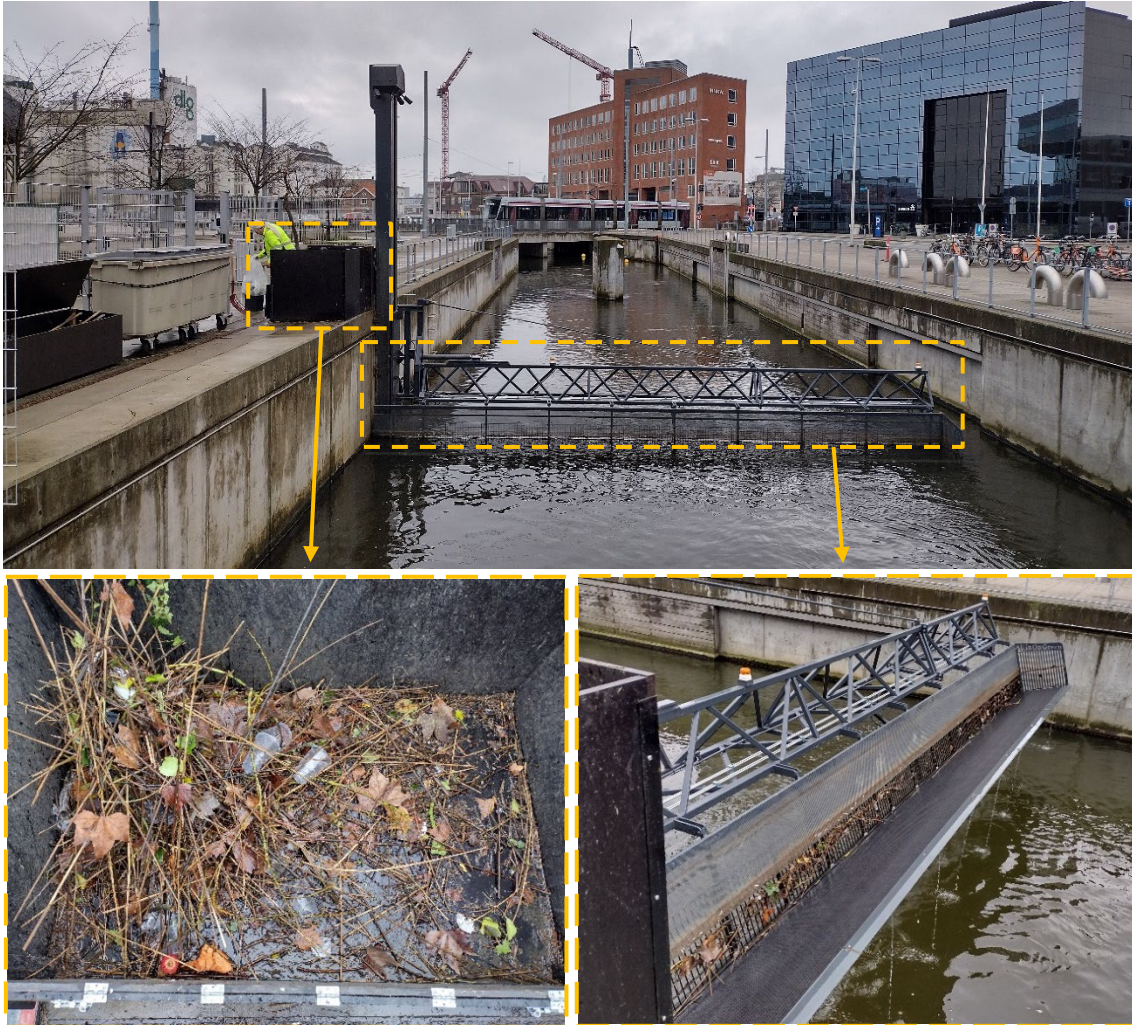


Figure 1: Waste collector, SeaProtectorOne from All In On Green ApS, is installed in Aarhus River and is collecting floating waste from the river surface (approx. 20 cm below).

In connection to the meeting, PCD received a bag of river-collected plastic from Aarhus River by SeaProtectorOne in week 8 (see Figure 3). The collected plastic waste is unsorted and represents only a given moment of the OBP in its completely "raw" and untreated state. It has been observed that collected plastic waste in Aarhus River is moist and coated with organic material. As shown in Figure 3, it is obvious to see that the OBP consists of cups, bottles and bags.



Figure 2: A bag of river-collected plastic from Aarhus River by SeaProtectorOne in week 8.

Sorting of river-collected plastic waste

The collected plastic contains a lot of different types of plastic waste. All the plastic waste is therefore roughly sorted for better visibility and then weighed to map the amount of the different fractions of plastic waste. Rough sorting and weighing of the fractions are shown in Table 1.

Table 1: Fractions of marine plastic waste in number of pieces and in wet weight collected in week 8. Fractions written with blue are already collected to be recycled for a deposit. Fractions written with orange are fractions with a wet weight above 40 g.

Plastic fraction	Amount		Wet weight	
	(pieces)	(%)	(g)	(%)
A. Single-use cups	104	59	690.00	28
B. Small boxes for tobacco products	12	7	266.00	11
C. Freezer bags	9	5	101.00	4
D. Deposit bottles (0.5 L)	6	3	165.00	7
E. Packaging films/bags	6	3	122.00	5
F. Tubes for liquorice shot (0.02 L)	5	3	54.00	2
G. Single-use lids for cups	5	3	11.50	0
H. Grocery bags	4	2	172.00	7
I. Plastic cups from café/restaurants	3	2	335.00	14
J. Waste bags	3	2	52.00	2
K. Packaging film for cans	3	2	29.00	1
L. Big waste bags	2	1	271.00	11
M. Reusable cups	2	1	80.00	3
N. Small bottles for alcohol (0.1 L)	2	1	42.50	2
O. Pots	2	1	23.00	1
P. Blue shoe covers	2	1	22.00	1
Q. Straws	2	1	5.50	0
R. Ice/candy packaging	2	1	3.00	0
S. Reusable plastic shot cups	1	1	14.50	1
T. Lid for yoghurt	1	1	8.00	0
U. Cigarette butts	1	1	1.00	0
Total	177	100	2468.0	100

As shown in Table 1, the marine plastic waste collected from Aarhus River in week 8 is consisting of 177 pieces and has a wet weight of approx. 2.5 kg. It mainly consists of single-use cups for beverages (59% of the total in pieces). This is obviously close related to the restaurant industries and bars, which are close located to the river. There are also a lot of boxes for tobacco products, bags of varied kinds and different kind of bottles for beverages and alcohols, which is possibly related to city life close to the river.

All fractions are shown with photos in Figure 4 and Figure 5.



Figure 3: The majority of the marine plastic waste consists of cups. It is observed that the marine plastic waste is moist and coated with organic material. Some fractions still contain the original content like water in the water bottle and snuff pouches in snuff boxes.



Figure 4: The continuation of the previous figure.








As shown in the figures 3-4, it is observed that the marine plastic waste is moist, coated with organic material and has a bad smell. Some fractions still contain the original content like water in the water bottle and snuff pouches in snuff boxes. As the river-collected plastic is collected from the river and has been there for a time, initial degradation cannot be excluded. It requires a thorough purification of the fractions before recycling can be considered. The properties of recycled plastic materials should be tested to see if it can

be used for the specific purpose of use, as it depends on many things, such as degree of degradation. It is necessary to identify the plastic types of the marine plastic waste, which will be performed by visual observation, FTIR and DSC analysis.

Material identification by visual observations

Plastic material identification is performed by visual observations of Resin Identification Code (RIC) symbols provided on collected plastic waste to gather material information easily. The RICs are represented with symbol of recycling triangle with numbers from 1 to 7 that defines the most common plastic types (ASTM International, 2013). The appearance of RIC symbols can vary which are shown in Table 2.

Table 2: RIC symbol that are used to easy identify plastic materials. (ASTM International, 2013)

Number	Symbol	Abbreviation	Plastic type
1		PETE or PET	Polyethylene terephthalate
2		HDPE or PE-HD	High-density polyethylene
3		PVC or V	Polyvinyl chloride
4		LDPE or PE-LD	Low-density polyethylene
5		PP	Polypropylene
6		PS	Polystyrene
7		OTHER or O	Other plastic type

The results from plastic material identification by visual observations are gathered in Table 3.

Table 3: Plastic material identification gathered by RIC symbols that are provided on the collected plastic waste.

Plastic fraction	No. of different RICs	Plastic type
A. Single-use cups	2	PP (98 cups marked with Heineken, Tuborg, Carlsberg and Fadøl and cups without branding) PET (6 cups marked with 7-eleven, Royal and Ceres)
B. Small boxes for tobacco products	1	PP (containers and lids) Unknown plastic type (labels)
C. Freezer bags	1	PE-LD (1 bag) Unknown plastic type (the other bags)
D. Deposit bottles	2	PET (bottles) PE-HD (caps) Unknown plastic type (labels)
E. Packing films/bags	3	PP (packing bag) PE-HD (bubble wrap) PE-LD (packing bag) Unknown plastic type (the other films/bags and tapes)
F. Tubes for liquorice shot	0	Unknown plastic type (tubes and lids)
G. Single-use lids for cups	1	PS (McDonalds lids) Unknown plastic type (other lids)
H. Grocery bags	1	PE-LD (2 bags) Unknown plastic type (2 bags and bag handle with reinforcement)
I. Plastic cups from café/restaurants	0	Unknown plastic type
J. Waste bags	0	Unknown plastic type
K. Packaging film for cans	0	Unknown plastic type
L. Big waste bags	0	Unknown plastic type
M. Reusable cups	1	PP
N. Small bottles for alcohol	1	PET with metal lids
O. Pots	1	PP
P. Blue shoe covers	0	Unknown plastic type (cover and elastic)
Q. Straws	0	Unknown plastic type
R. Ice/candy packaging	0	Unknown plastic type
S. Reusable plastic shot cups	0	Unknown plastic type
T. Lid for yoghurt	0	Unknown plastic type
U. Cigarette butts	0	Unknown plastic type

As shown in Table 3, visual observation of the collected waste identified four plastic types:

- Polypropylene (PP) identified in following fractions:
 - Cups
 - Small boxes for tobacco products
 - Packaging bag
 - Pots
- Low-density polyethylene (PE-LD) identified in following fractions:
 - Bags
- High-density polyethylene (PE-HD) identified in following fractions:
 - Bottle caps
 - Bubble wrap
- Polyethylene terephthalate (PET) identified in following fractions:
 - Bottles
 - Cups
- Polystyrene (PS) identified in following fraction:
 - Single-use lid

Less than half of the plastic waste was identified through visual observations, indicating that a significant proportion remains of unknown polymer type.

Identification of plastic types will therefore continue using FTIR and DSC analyses. Deposit bottles are excluded from these analyses, as they are already part of an established recycling system when labels are intact.

FTIR analysis and results

FTIR spectroscopy is a qualitative analytical method that uses infrared (IR) radiation. The analysis is carried out using the attenuated total reflectance (ATR) technique, which allows direct examination of solid materials at the surface. The obtained spectra are compared with reference libraries of known plastic types to determine the overall chemical structure of the plastic litter.

Further details on the FTIR methodology, along with the measured spectra of the OBP, are provided in **Supplementary Material A1 – FTIR analysis of plastic waste**. A summary of the identified plastic types is presented in Table 4.

Table 4: Plastic material identification gathered by RIC symbols that are provided on the collected plastic waste and by FTIR analysis.

Plastic fraction	No. of different RICs	Plastic type
A. Single-use cups	2	PP (98 cups) PET (6 cups)
B. Small boxes for tobacco products	3 (↑)	PP (boxes and lids) PET (labels) Acetate containing materials (tobacco products)
C. Freezer bags	2 (↑)	PE-LD (1 bag) PP (1 bag) PE (other bags)
E. Packaging films/bags	4	PP (packaging bag) PE-HD (bubble wrap) PE-LD (packaging bag) PE (the other films/bags) PP and PET (tapes)
F. Tubes for liquorice shot	3 (↑)	PE (4 tubes) PP (1 tube) PET (labels)
G. Single-use lids for cups	1	PS
H. Grocery bags	1	PE-LD (2 bags) PE (2 bags and bag handle)
I. Plastic cups from café/restaurants	1 (↑)	PC
J. Waste bags	1 (↑)	PE
K. Packaging film for cans	1 (↑)	Multilayer material with PE
L. Big waste bags	1 (↑)	PE
M. Reusable cups	1	PP
N. Small bottles for alcohol	1	PET with metal lids
O. Pots	1	PP
P. Blue shoe covers	2 (↑)	PE (cover) PET (cloth around the elastic)
Q. Straws	1 (↑)	PP
R. Ice/candy packaging	2 (↑)	PP (ice cream) PE (candy)
S. Reusable plastic shot cups	1 (↑)	PP
T. Lid for yoghurt	1 (↑)	PP
U. Cigarette butts	1 (↑)	Acetate containing materials (tobacco products)

As shown in the above table, several plastic fractions have been identified with FTIR analysis compared to visual observations. A lot of plastic fractions are composed of 2-3 plastic types and some of one plastic type. The different plastic types are as follows:

- Polypropylene (PP) identified in following fractions:
 - Cups
 - Small boxes for tobacco products
 - Bags
 - Tubes
 - Pots
 - Straws
 - Lids for yoghurt
- Low-density polyethylene (PE-LD) identified in following fractions:
 - Bags
- High-density polyethylene (PE-HD) identified in following fractions:
 - Bottle caps
 - Bubble wrap
- Polyethylene terephthalate (PET) identified in following fractions:
 - Bottles
 - Cups
 - Labels
 - Tape
 - Cloth
- Polystyrene (PS) identified in following fraction:
 - Lids for single-use components
- Polycarbonate (PC) identified in following fraction:
 - Plastic cups from café/restaurants
- Acetate containing materials identified in following fraction:
 - Tobacco products

The plastic waste was initially identified using FTIR analysis, providing indications of possible polymer types. However, thermal properties remain uncertain, as variations may exist within the identified materials.

The results indicate a high diversity of plastic types within each fraction. While FTIR analysis provides preliminary identification, these findings will be further confirmed through DSC analysis in the following section.

DSC analysis and results

Differential Scanning Calorimetry (DSC) is a calorimetric technique used to determine the thermal properties of plastic materials. The obtained thermograms are analysed to identify melting behaviour and are compared with reference data for known polymers to support material identification.

Further details on the DSC methodology, along with the measured thermal properties of the OBP, are provided in **Supplementary Material A2 – DSC results of plastic waste**. A summary of the identified plastic types is presented in Table 5.

Table 5: Plastic material identification gathered by RIC symbols that are provided on the collected plastic waste and by DSC analysis.

Plastic fraction	No. of different RICs	Plastic type
A. Single-use cups	2	PP (98 cups) PET (6 cups)
B. Small boxes for tobacco products	4 (↑)	PP (boxes and lids) PP (2 labels) PE-LD+PE-HD (1 label) Acetate containing materials (tobacco products)
C. Freezer bags	2	PE-LD+PE-LLD (2 bags) PP (1 bag) PE-LLD (3 bags)
E. Packaging films/bags	4	PP (packaging bag) PE-HD (bubble wrap) PE-LD+PE-LLD (2 bags) PE-LLD (2 films/bags) PP and PET (tapes)
F. Tubes for liquorice shot	3	PE-HD (4 tubes and caps) PE-HD+PE-LD (4 labels) PP (1 tube, cap and label)
G. Single-use lids for cups	1	PS
H. Grocery bags	1	PE-LD+PE-LLD (3 bags and bag handle) PE-LD (1 bag and bag handle)
I. Plastic cups from café/restaurants	1	PC
J. Waste bags	1	PE-LLD (2 bags) PE-LD+PE-LLD (2 bags)
K. Packaging film for cans	1	PE-LD+PE-LLD
L. Big waste bags	1	PE-LD+PE-LLD
M. Reusable cups	1	PP
N. Small bottles for alcohol	1	PET with metal lids
O. Pots	1	PP
P. Blue shoe covers	2	PE-LLD (cover) PET (cloth around the elastic)
Q. Straws	1	PP
R. Ice/candy packaging	2	PP (ice cream) PE-HD (candy)
S. Reusable plastic shot cups	1	Copolymer PP
T. Lid for yoghurt	1	PP
U. Cigarette butts	1	Acetate containing materials (tobacco products)

As shown in the above table, several plastic fractions have been identified with DSC analysis compared to visual observations and FTIR analysis. A lot of plastic fractions consist of 2-4 plastic types and some of one plastic type. The different plastic types are as follows:

- Polypropylene (PP) identified in following fractions:
 - Cups
 - Small boxes for tobacco products
 - Bags

- Tubes
- Pots
- Straws
- Ice cream wrapping
- Lids for yoghurt
- Low-density polyethylene (PE-LD and PE-LLD) identified in following fractions:
 - Bags
 - Shoe covers
- High-density polyethylene (PE-HD) identified in following fractions:
 - Tubes with caps and labels
 - Bubble wrap
 - Candy wrapping
- Polyethylene terephthalate (PET) identified in following fractions:
 - Bottles
 - Cups
 - Tape
 - Cloth
- Polystyrene (PS) identified in following fraction:
 - Lids for single-use components
- Polycarbonate (PC) identified in following fraction:
 - Cups from café/restaurants
- Acetate containing materials identified in following fraction:
 - Tobacco products

The plastic waste is identified by DSC analysis with possible plastic types, which are consistent with FTIR analysis. Some of the conclusions are changed, as the thermal properties are more information about the plastic material than FTIR analysis, which gives information about the surface of the plastic material. The surface covered with ink can give an incorrect information about the plastic material.

It can be concluded that there are a lot of plastic types in each plastic fraction. The plastic types are determined based on FTIR analysis and is confirmed by DSC analysis.

Distribution of OBP composition

After material identification of the OBP, it was possible to perform weighing of components made of different plastic type, which can be seen in Table 6.

Table 6: Distribution of OBP into plastic types after material identification of each component of collected OBP in one week (week 8, 2024). The distribution is based on the weight of each component.

Overall group	Plastic fraction	Plastic type					
		PP	PE	PC	PET	PS	CA
Cups	A. Single-use cups	630.0	-	-	60.0	-	-
	I. Plastic cups from café/restaurants	-	-	335.0	-	-	-
	M. Reusable cups	80.0	-	-	-	-	-
	S. Reusable plastic shot cups	14.5	-	-	-	-	-
<i>Subtotal</i>		<i>724.5</i>	<i>-</i>	<i>335.0</i>	<i>60.0</i>	<i>-</i>	<i>-</i>
Bags and foils	C. Freezer bags	3.0	98.0	-	-	-	-
	E. Packaging films/bags	13.0	109.0	-	-	-	-
	H. Grocery bags	-	172.0	-	-	-	-
	J. Waste bags	-	52.0	-	-	-	-
	K. Packaging film for cans	-	29.0	-	-	-	-
L. Big waste bags	-	271.0	-	-	-	-	
<i>Subtotal</i>		<i>16.0</i>	<i>731.0</i>	<i>-</i>	<i>-</i>	<i>-</i>	<i>-</i>
Bottles	D. Deposit bottles	-	7.0	-	158.0	-	-
	F. Tubes for liquorice shot	8.0	46.0	-	-	-	-
	N. Small bottles for alcohol	-	-	-	42.5	-	-
<i>Subtotal</i>		<i>8.0</i>	<i>53.0</i>	<i>-</i>	<i>200.5</i>	<i>-</i>	<i>-</i>
Other products	G. Single-use lids for cups	-	-	-	-	11.5	-
	O. Pots	23.0	-	-	-	-	-
	P. Blue shoe covers	-	22.0	-	-	-	-
	Q. Straws	5.5	-	-	-	-	-
	R. Ice/candy packaging	1.5	1.5	-	-	-	-
T. Lid for yoghurt	8.0	-	-	-	-	-	
<i>Subtotal</i>		<i>38.0</i>	<i>23.5</i>	<i>-</i>	<i>-</i>	<i>11.5</i>	<i>-</i>
Tobacco products	B. Small boxes for tobacco prod.	266.0	-	-	-	-	-
	U. Cigarette butts	-	-	-	-	-	1.0
<i>Subtotal</i>		<i>266.0</i>	<i>-</i>	<i>-</i>	<i>-</i>	<i>-</i>	<i>1.0</i>
Total		1052.5	807.5	335.0	260.5	11.5	1.0

As shown in Table 6, it is possible to see that all kinds of cups are mostly composed of PP, PC and PET materials. Bags and foils are mostly composed of PE material and few of PP material. Bottles are mostly composed of PET material with lids of PE material and tubes of PP material. Other products as food contact packagings, agricultural products and hygiene products are mostly composed of PP, PE and PS.

In total the percentage distribution of the plastic types collected in one week in Aarhus River can be seen in Table 7.

Table 7: Percentage distribution of overall fraction group per plastic type collected in one week (week 8, 2024) in Aarhus River by SeaProtectorOne.

Overall group	Percentage distribution of plastic type					
	PP	PE	PC	PET	PS	CA
Cups	69	0	100	23	0	0
Bags and foils	2	91	0	0	0	0
Bottles	1	7	0	77	0	0
Other products	4	3	0	0	100	0
Tobacco products	25	0	0	0	0	100
<i>Total</i>	<i>100</i>	<i>100</i>	<i>100</i>	<i>100</i>	<i>100</i>	<i>100</i>
Percentage distribution in total	43	33	14	11	0	0

As shown in Table 7, some plastic types are dominating in the overall fraction groups. PP material is dominating in cups, PE material is dominating in bags and foils, PC material is dominating in cups, PET material is dominating in bottles, PS material is dominating in other products, and CA material is dominating in tobacco products. This also visualized in Figure 6.

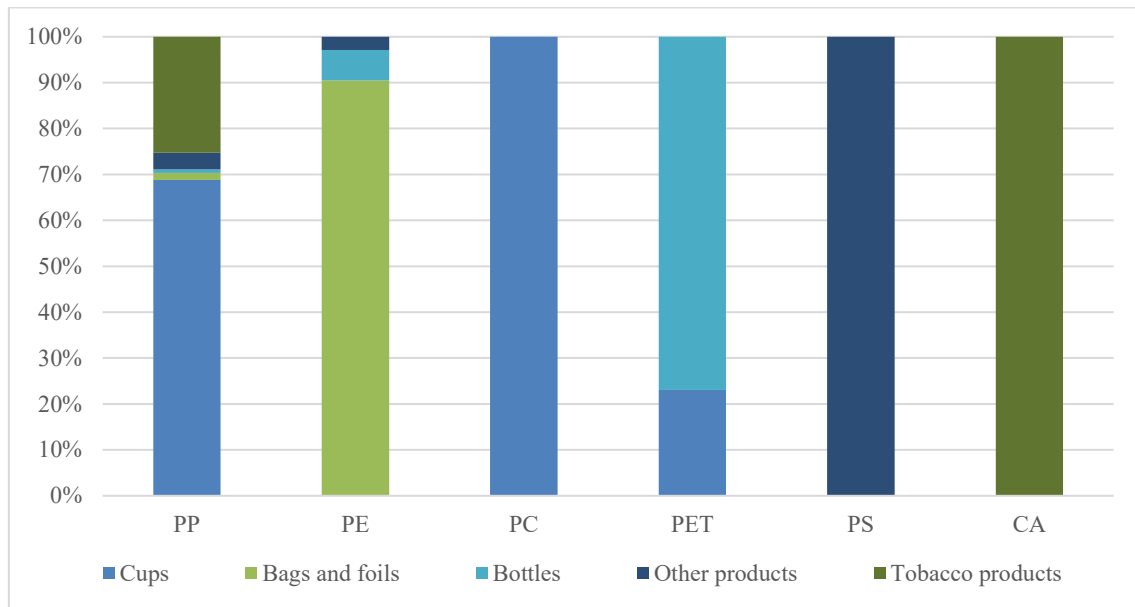


Figure 5: Percentage distribution of overall fraction group per plastic type visualized in diagram.

It is valuable to observe that the dominating plastic types of the 6 mentioned are PP followed by PE. But this is just one week out of 52 weeks in a year. Unfortunately, it is not possible to predict it will show same trend or a second. The composition of the plastic type is depending on behavioural acts in city life, the products in the market and restaurant and the actual events at specific times.

Possible recycling

The waste management hierarchy shows that prevention and reuse should be considered before recycling (see Figure 7) according to the Waste Framework Directive (2008/98/EC).

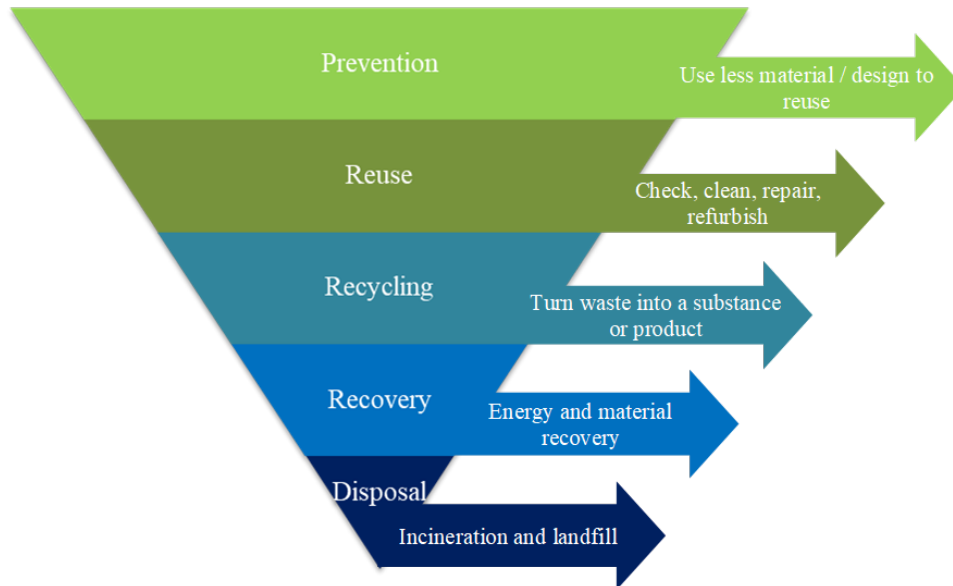


Figure 6: Waste management hierarchy (European Commission, 2026).

Prevention and reuse are the most preferred options as it is waste avoidance. Despite this, all kinds of plastic fractions are ending up in the river. Whether it is caused by coastal weather conditions or behavioural actions by citizens. It is a mix of single-use and reusable plastic waste. The third option is waste recycling. This involves collecting and processing waste materials to make new products or new raw materials, either mechanically or chemically.

The OBP was collected from Aarhus River, which means the waste is wet, soiled with organics from the river and it smells like the river. It can be stated that the OBP might have been degraded because of exposure to sunlight and water for some time. For possible recycling the OBP will require a washing treatment of the plastic waste. Upon visual observations and analyses, it is found that the collected OBP consists of many different plastic types. See Figure 8 for the plastics pyramid for different types of thermoplastics.

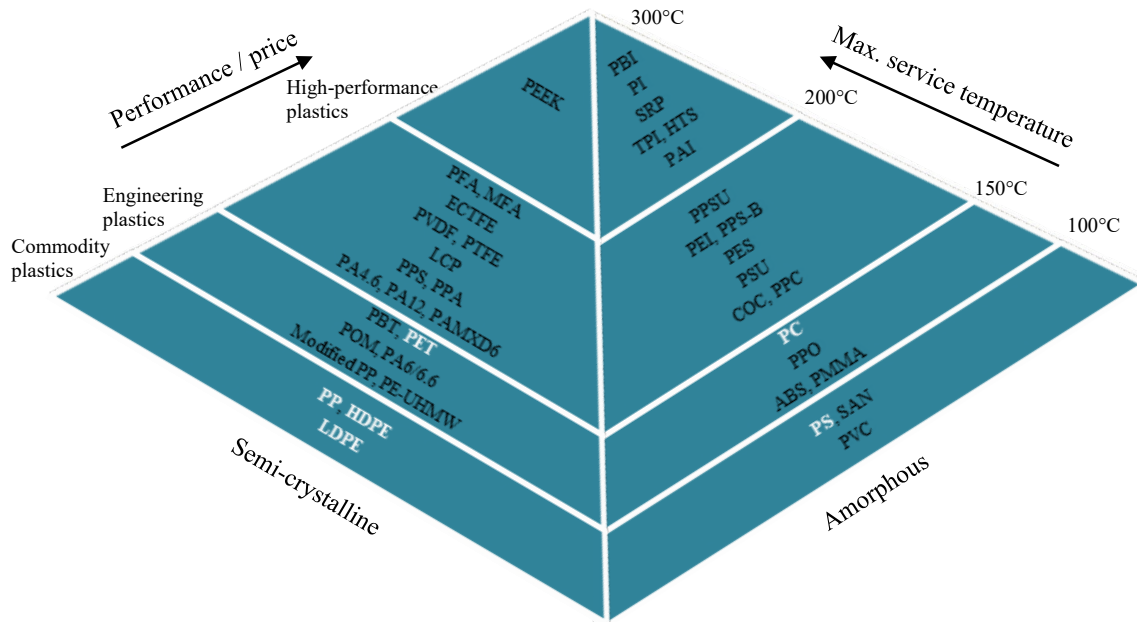


Figure 7: Plastics pyramid (Plastics Technology, n.d.)

As shown in the plastics pyramid, most of the collected OBP is made of semi-crystalline thermoplastics. Semi-crystalline thermoplastics are materials that consist of highly ordered molecular structure. Depending on the length of molecular structure, each plastic type has a characteristic melting point. Because of this, different plastic types cannot be recycled together. Mechanical recycling involves melting the plastic waste. Mechanical recycling at a temperature suitable for one of the plastic types will degrade the other and will not even melt the third. So, the quality of the recycled plastic depends on an extensive sorting into the different plastic types.

Mono-material litter per OBP

Most of the collected OBP are made of only one plastic type and is the same kind of product. This type of waste only requires sorting into the respective kind of product without further treatment.

In Figure 9 mono-material litter fractions are gathered, which are easy to recognise for mechanical recycling.



Figure 8: Mono-material litter fractions are gathered; Green with fraction J, K and L: PE-LD+PE-LLD, Orange with fraction I: PC, Blue with fraction M, O, Q, S and T: PP, and Purple with fraction G: PS.

Most of mono-material litter fraction are made of PE (in total 5% in pieces or 14% in weight) and PC (in total 2% in pieces or 14% in weight) followed by PP (in total 4% in pieces or in weight) and PS (in total 3% in pieces or 0% in weight).

It is noted that three of the mono-material litter fractions are reusable (Fraction I, M and S) and are substitutes for single-use plastics, that should not end in rivers.

Mono-material litter but different plastic types per river-collected plastic

Some of the collected plastic litters are made of mono-material, but of different plastic types although it is the same product. This is possibly due to the differences in suppliers or functions required for the product. This type of waste requires continuously identification to sort into the respective plastic types.

A challenge in this can be collecting enough plastic waste of the same plastic type. Though not for the single-use cups as there are a lot of these made of PP.

In Figure 10 mono-material litter fractions made of different plastic types are gathered. Especially cups are easy to recognise as they are marked with RIC, which is suitable for mechanical recycling. Bags and packaging are not easy to identify visually.

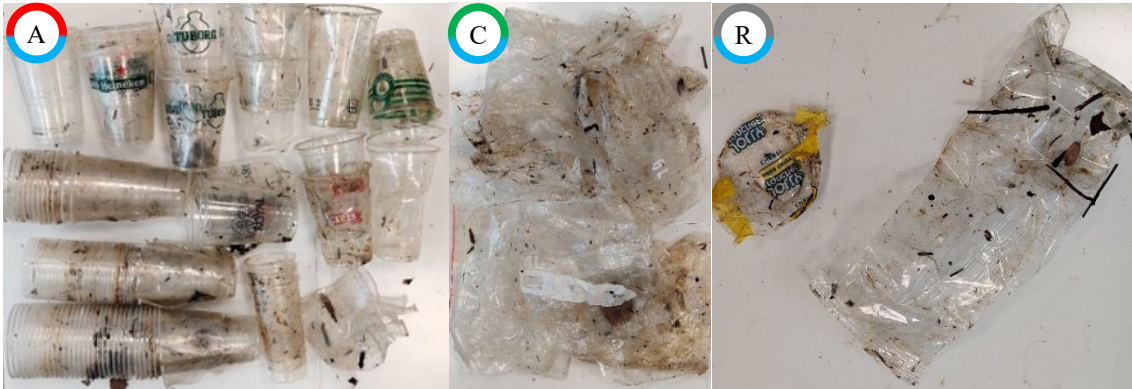


Figure 9: Mono-material litter fractions made of different plastic types are gathered; **Blue**: PP, **Green**: PE-LD+PE-LLD, **Grey**: PE-HD and **Red**: PET.

In the collected plastic litter, there are litters made of multi-components, which are products composed of labels, tapes and lids. Some components are made of different plastic types or metal, which require separation of components to be recycled mechanically. A few are made of the same plastic type as grocery bags and are suitable for mechanical recycling.

Multi-component OBP

In Figure 11 multi-component litter fractions are gathered.



Figure 10: Multi-component litter fractions made of different plastic types are gathered; **Blue**: PP, **Green**: PE-LD+PE-LLD, **Grey**: PE-HD, **Red**: PET and **Black**: Rubber.

Grocery bags are multi-component and mono-material litter fraction, which are easy to recognise and can be recycled mechanically with other bags (Fraction J, K and L). If

proper separation cannot be performed on multi-component and multi-material litter fraction, chemical recycling will be more suitable.

All in all, most of the litter are suitable to be recycled mechanically with proper sorting and washing as the OBP materials are made of thermoplastic materials. It should be remarked that the properties of the mechanically recycled material will be different each time depending on the quality of the plastic types gathered. Especially the mechanical, thermal and physical properties will be affected without additives supplied. The odour of the recycled material will be significant if the organics are not washed properly off, dried or processed properly with enough ventilation in the production process. After washing the material, the sewage must be treated as it is contaminated with surfactants and sludge. The appearance of the recycled material will have a dark colour if it is not separated into colours. This is because small amounts of black or dark coloured materials will contaminate the bulk material.

There are a lot of properties and points that need to be considered. Will mechanical recycling be justifiable economically and environmentally, when it requires resources to sort, grind, wash, process, add additives and treat sewage? To get a recycled material that has inferior properties than a virgin material. Most recyclers use production waste to recycle mechanically as it is of known quality and directly from production, which is clean from organic contaminations. This is the cheapest way of mechanical recycling as it doesn't require any adjustments in the production line. Some recyclers are able to use household waste to recycle mechanically, but the output are products with low requirements like flowerpots, traffic poles, driving plates, etc. With structured sorting and separation of different plastic types and great amounts of same plastic types, mechanical recycling will be a possibility. But it is important to obtain pure fractions with single plastic types to maintain the quality.

From here, it must be recommended that the easily identifiable and recyclable fractions are sorted out and the residual plastic are incinerated with energy recovery, which is currently done in Denmark, or to invest in chemical recycling, where a chemical compound can be formed for new plastic or for fuel.

Conclusion

In connection with the Interreg project, Circular Ocean-Bound (COP), PCD has performed material identification on the collected plastic waste from Aarhus River to determine the possibilities of recycling the plastic waste.

For this purpose, a rough sorting of plastic waste has been carried out by visual observations, followed by FTIR and DSC analyses and finally to assess whether recycling is possible. Overview of the possible plastic types of the river-collected plastic waste are shown in Table 8.

Table 8: Overview of the possible plastic types of OBP collected in one week from Aarhus River.

Plastic fraction	Composition (%)		No. of different RICs after:		
	Amount	Weight	Visual observation	FTIR analysis	DSC analysis
A. Single-use cups	59	28	PP & PET	PP & PET	PP & PET
B. Small boxes for tobacco products	7	11	PP & N/A	PP, PET & Acetate contg. materials	PP, PE-LD+PE-HD & Acetate contg. materials
C. Freezer bags	5	4	PE-LD & N/A	PE-LD, PP & PE	PE-LD+PE-LLD, PP & PE-LLD
D. Deposit bottles	3	7	PET, PE-HD & N/A	Not performed as they are pawned.	
E. Packaging films/bags	3	5	PP, PE-HD, PE-LD & N/A	PP, PE-HD, PE-LD, PE & PET	PP, PE-HD, PE-LD+PE-LLD, PE-LLD & PET
F. Tubes for liquorice shot	3	2	N/A (tubes and lids)	PE, PP & PET	PE-HD, PE-HD+PE-LD & PP
G. Single-use lids for cups	3	0	PS & N/A	PS	PS
H. Grocery bags	2	7	PE-LD & N/A	PE-LD & PE	PE-LD+PE-LLD & PE-LD
I. Plastic cups from café/restaurants	2	14	N/A	PC	PC
J. Waste bags	2	2	N/A	PE	PE-LLD & PE-LD+PE-LLD
K. Packaging film for cans	2	1	N/A	Multilayer PE	PE-LD+PE-LLD
L. Big waste bags	1	11	N/A	PE	PE-LD+PE-LLD
M. Reusable cups	1	3	PP	PP	PP
N. Small bottles for alcohol	1	2	PET with metal lids	PET with metal lids	PET with metal lids
O. Pots	1	1	PP	PP	PP
P. Blue shoe covers	1	1	N/A	PE & PET	PE-LLD & PET
Q. Straws	1	0	N/A	PP	PP
R. Ice/candy packaging	1	0	N/A	PP & PE	PP & PE-HD
S. Reusable plastic shot cups	1	1	N/A	PP	Copolymer PP
T. Lid for yoghurt	1	0	N/A	PP	PP
U. Cigarette butts	1	0	N/A	Acetate contg. materials	Acetate contg. materials

As shown in the above table, every plastic fraction consists of at least one plastic type. It needs structured sorting and separation of different plastic types and great amounts of same plastic types before mechanical recycling is a possibility. Then, it may be possible to obtain "clean" fractions with used plastic types. Or else chemical recycling would be a proper recycling method for OBP.

Although it is an option to recycle plastic waste mechanically, sorting, grinding and purifying the plastic waste with wastewater treatment before melting in a plant is resource-intensive and can be environmentally harmful.

If the collected plastic waste is not sorted, ground and cleaned before being processed in heat, it will be difficult to produce usable new products out of it. There will be problems with the properties of the plastic, such as odour, appearance, flow properties and mechanical properties.

From this, it is recommended that the easily identifiable and recyclable fractions be sorted out and the residual plastic be incinerated with energy recovery, as it currently is done in Denmark, or to focus on chemical recycling, where chemical compounds can be formed for new plastic or for diesel.

Completed on 31st August 2025 by:



Hatice G. Tüzün
Laboratory Engineer – B.Sc. Chem. Eng.
Plast Center Danmark

Supplementary Material A1 – FTIR analysis of plastic waste

FTIR spectroscopy is a qualitative analysis that uses infrared radiation (IR) and is carried out by the attenuated total reflectance (ATR) method, which enables materials to be examined directly in the solid state.

The irradiated material absorbs the radiation, causing the molecule to vibrate. The vibrational energy depends on which characteristic chemical groups are in the molecule. The material's transmittance of IR radiation is measured as a function of the wavelength, which is expressed in the spectrum as a wavenumber given in cm^{-1} . Background scan and sample spectra are obtained with 32 scans in the wave number range $4000\text{-}500\text{ cm}^{-1}$.

The FTIR spectra of the OBP are presented in the following sections.

Cups

There are collected different kinds of cups (fraction A, I, M and S). It is obvious that cups are composed of mono-material items as there are no labels or caps attached. FTIR analysis is performed on fraction A of different brands and size and fraction I, M and S. Spectra of cups are shown in Figure 12 – Figure 14.

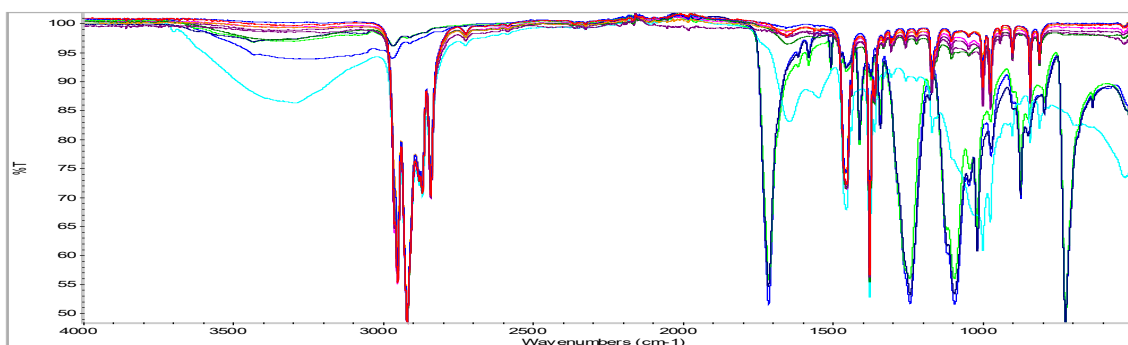


Figure 11: Spectra of fraction A, cups; 7-Eleven (dark blue), Carlsberg (purple), Ceres (light green), Fadøl (turquoise), Heineken (pink), Royal (black), Tuborg (blue), clear (dark purple), clear and narrow (red), clear w/ moulded text at top (yellow) and clear w/ moulded text at bottom (green).

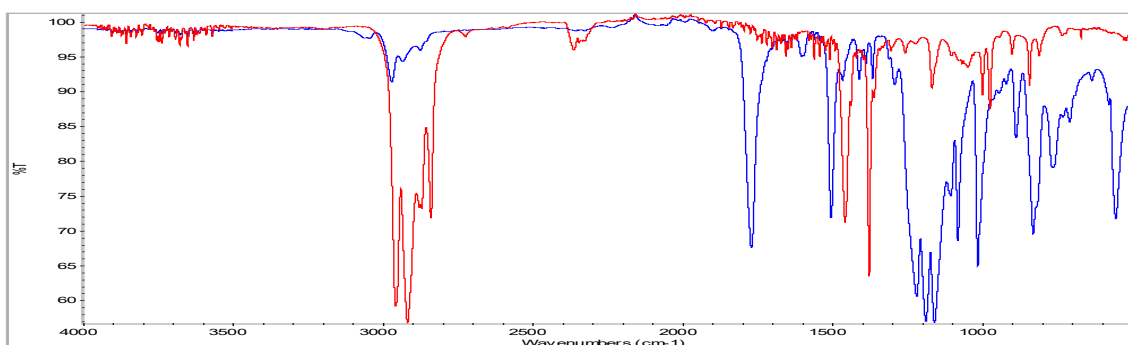


Figure 12: Spectra of fraction I and S, cups; fraction I (blue) and fraction S (red).

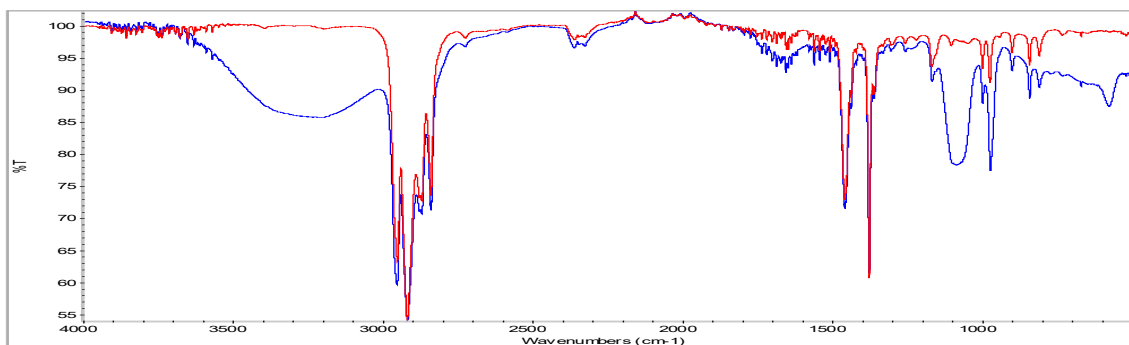


Figure 13: Spectra of fraction M, cups; Green text (red) and Absolut (blue).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 9.

Table 9: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
A	7-Eleven	58,1% with PET (ID 543)
	Carlsberg	89,7% with PP+PE/PP (ID 324)
	Ceres	62,5% with PET (ID 543)
	Fadøl	87,4% with PP+PE/PP (ID 324)
	Heineken	90,2% with PP+PE/PP (ID 324)
	Royal	61,8% with PET (ID 543)
	Tuborg	88,8% with PP+PE/PP (ID 324)
	Clear	89,8% with PP+PE/PP (ID 324)
	Clear and narrow	90,0% with PP+PE/PP (ID 324)
	Clear w/ moulded text at top	88,7% with PP+PE/PP (ID 324)
	Clear w/ moulded text at bottom	89,7% with PP+PE/PP (ID 324)
I	75,5% with PC (ID 670)	
M	Green text	90,0% with PP (ID 41)
	Absolut	86,0% with PP (ID 942)
S	91,3% with PP (ID 41)	

As shown in the above table, most of the cups have highest percentage match with PP, some have highest percentage match with PET and polycarbonate (PC). It can be concluded that cups of different kinds consist of at least three different plastic types. The greatest number of cups consist of PP.

Small boxes for tobacco products

There are collected different brands of containers for tobacco products and cigarette butts (fraction B and U). It is observed that the containers consist of other components like label and lid and have some tobacco products inside the containers.

FTIR analysis is performed on fraction B and U of different brands and associated components.

Containers

Spectra of containers are shown in Figure 15.

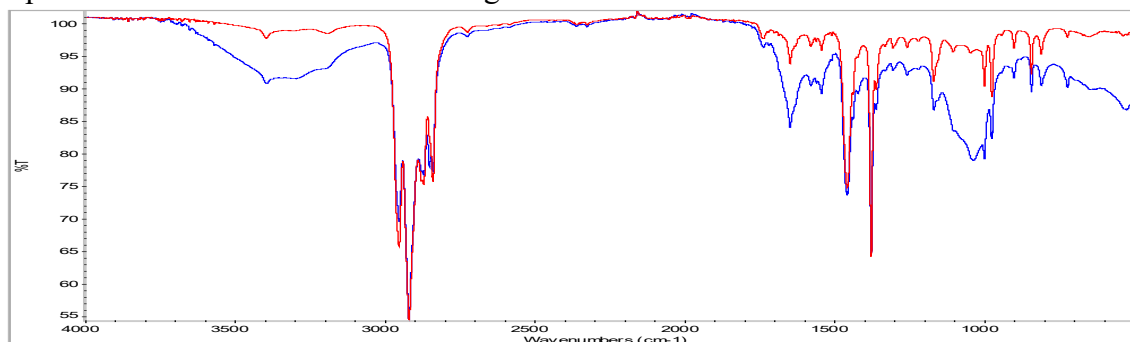


Figure 14: Spectra of fraction B, container; Oden's (blue) and Velo (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 10.

Table 10: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
B	Odens, container	89,7% with PP+PE/PE (ID 324)
	Velo, container	91,3% with PP (ID 41)

As shown in the above table, all containers have highest percentage match with PP. It can be concluded that containers of different brands consist of one plastic type.

Lids

Spectra of lids are shown in Figure 16.

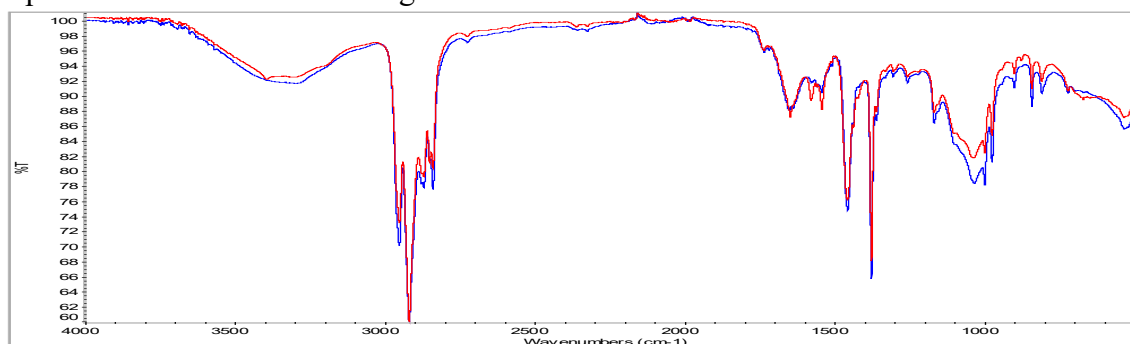


Figure 15: Spectra of fraction B, lids; Oden's (blue) and Velo (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 11.

Table 11: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
B	Odens, lid	89,7% with PP+PE/PE (ID 324)
	Velo, lid	91,3% with PP (ID 41)

As shown in the above table, lids have highest percentage match with PP. It can be concluded that lids of different brands consist of one plastic type.

Labels

Spectra of labels are shown in Figure 17.

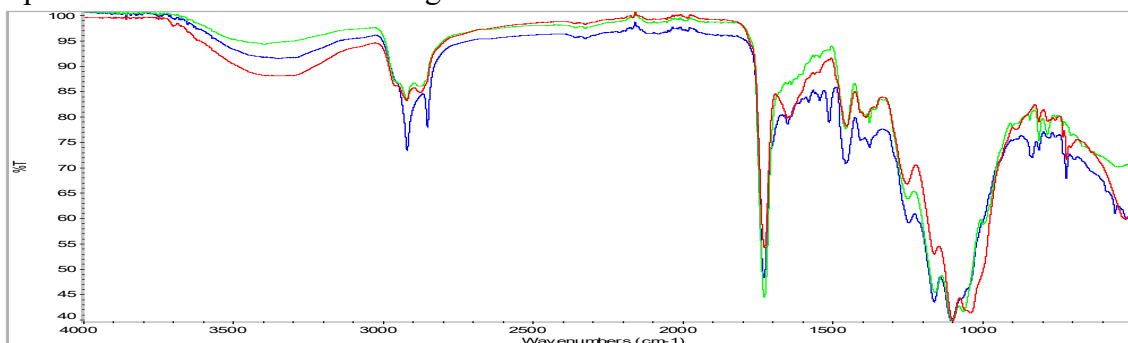


Figure 16: Spectra of fraction B, labels; Oden's label on lid (blue), Velo (red) and Velo's label on lid (light green).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 12.

Table 12: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
B	Oden's, label on lid	71,2% with PET (ID 439)
	Velo, label	72,3% with PET (ID 441)
	Velo, label on lid	76,0% with PET (ID 439)

As shown in the above table, all the labels have highest percentage match with PET. It can be concluded that labels of different brands consist of one plastic type.

Snuff and cigarette butts

Spectra of tobacco products are shown in Figure 18.

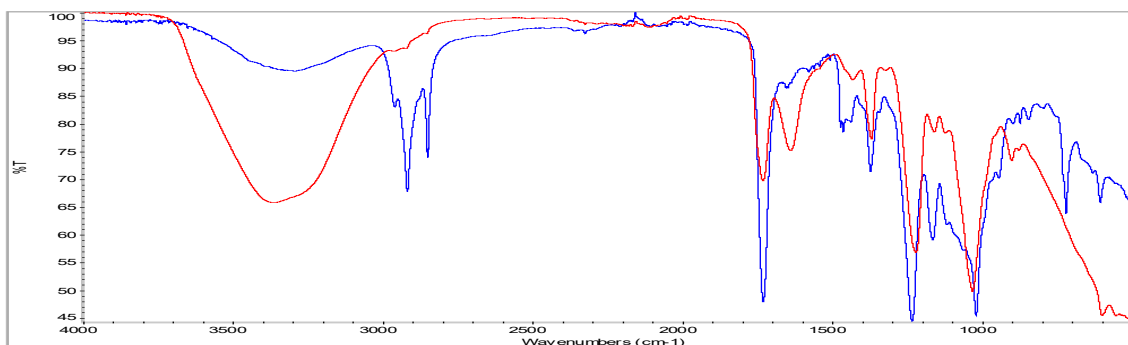


Figure 17: Spectra of fraction B, lids; Snuff in Velo (blue) and cigarette butt (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 13.

Table 13: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
B	Snuff	72,2% with acetate containing molecule (ID 29)
U	Cigarette butts	61,8% with acetate containing molecule (ID 1553)

As shown in the above table, all the tobacco products have highest percentage match with acetate containing molecules, not necessarily the same molecule. It can be concluded that tobacco products of different kinds consist of acetate containing components, which is not necessarily the same.

Bags

There are collected different kinds and brands of bags (fraction C, H, J and L) for lunch storage/freezing down food, grocery shopping, waste and garden waste. It is observed that some bags consist of other components like bag handle reinforcement. FTIR analysis is performed on fraction C, H, J and L of different kinds and brands and associated components.

Bags

Spectra of bags are shown in Figure 19 – Figure 22.

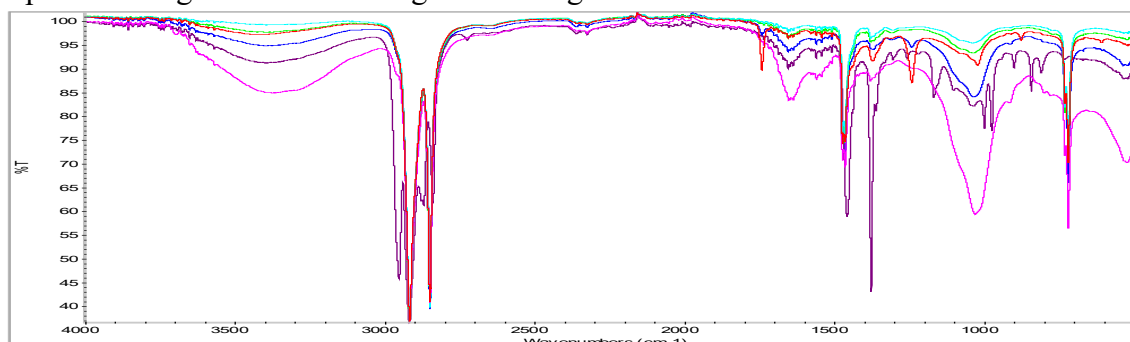


Figure 18: Spectra of fraction C, freezer bags; Rema (pink), with dots (purple), clear (blue), svan marked (red), mark on machine direction (light green), with red edge (turquoise).

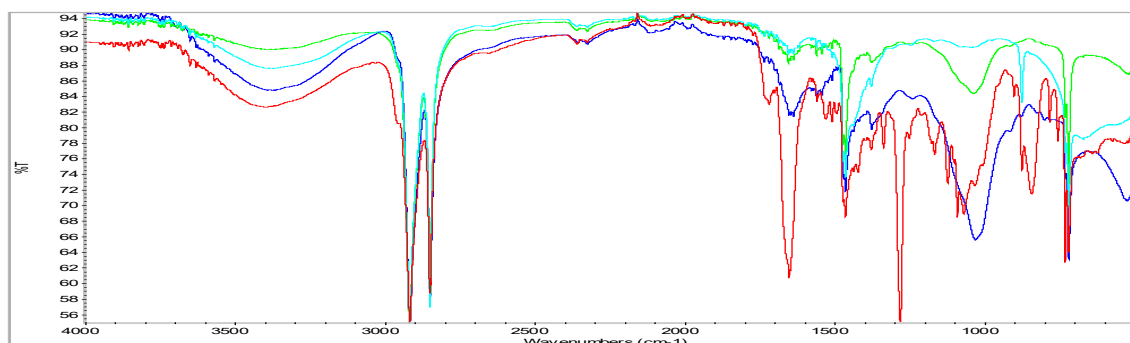


Figure 19: Spectra of fraction H, bags; Black (blue), fakta (red), Føtex (light green) and Rema (turquoise).

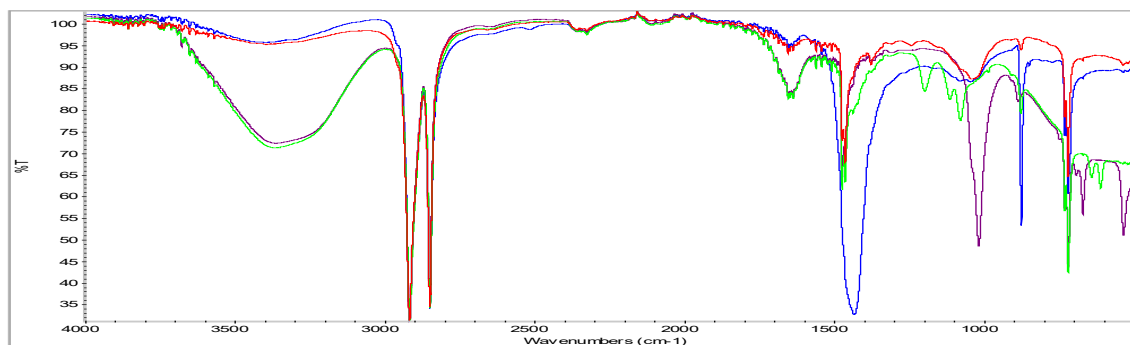


Figure 20: Spectra of fraction J, bags; Dog waste (blue), banan bag (purple), clear (light green) and bio waste (red).

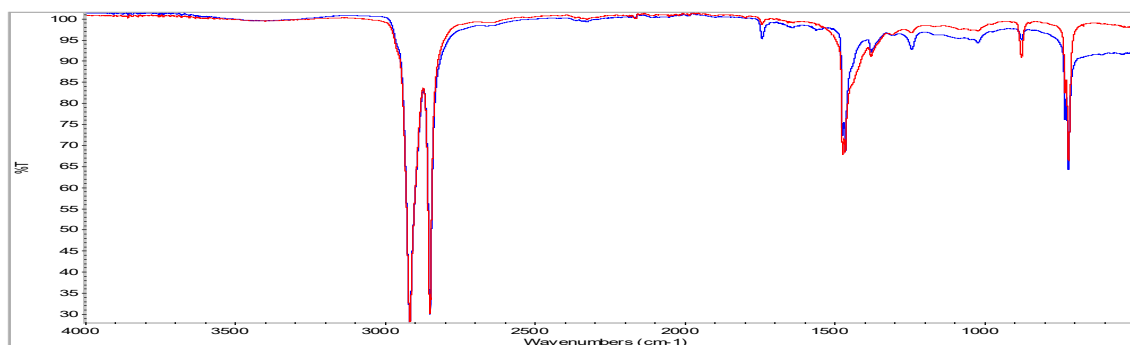


Figure 21: Spectra of fraction L, bags; Clear (red) and black (blue).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 14.

Table 14: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
C	Rema	89,1% with PE (ID 625)
	With dots	91,0% with PP (ID 942)
	Clear	92,4% with PE (ID 625)
	Svan marked	92,2% with PE (ID 625)
	Mark on machine direction	93,4% with PE (ID 625)
	With red edge	93,0% with PE (ID 625)
H	Black	85,9% with PE (ID 625)
	Fakta	58,6% with PE (ID 625)
	Føtex	93,2% with PE (ID 625)
	Rema	93,1% with PE (ID 625)
J	Dog waste	75,3% with PE (ID 95)
	Banan bag	84,6% with PE (ID 625)
	Clear	85,5% with PE (ID 625)
	Bio waste	93,7% with PE (ID 625)
L	Clear	92,1% with PE (ID 625)
	Black	92,8% with PE (ID 625)

As shown in the above table, all bags have highest percentage match with PE except the freezer bag with dots, which has highest percentage match with PP. It can be concluded that bags of different kinds and brands consist of at least two plastic types.

Bag handle reinforcements

Spectra of bag handle reinforcements are shown in Figure 23.

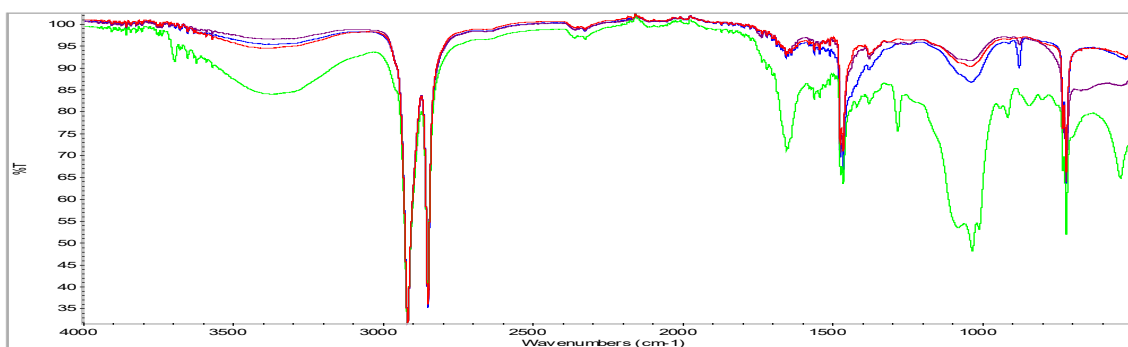


Figure 22: Spectra of fraction H, bags; Black (blue), fakta (purple), Føtex (light green) and Rema (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 15.

Table 15: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
H	Black	92,2% with PE (ID 625)
	Fakta	93,2% with PE (ID 625)
	Føtex	86,8% with PE (ID 625)
	Rema	93,1% with PE (ID 625)

As shown in the above table, all bag handle reinforcements have highest percentage match with PE. It can be concluded that bags with handle reinforcement of different brands consist of one plastic type, which is the same plastic type as the bag.

Bottles/tubes and associated components

There are collected different kinds of bottles and tubes (fraction D, F and N). It is observed that the bottles consist of other components like label and cap. FTIR analysis is performed on fraction F of different brands and associated components and fraction N, only the bottle as the cap is metal and the label is paper. Fraction D is excluded from the analysis as it already can be recycled.

Bottles

Spectra of bottles are shown in Figure 24.

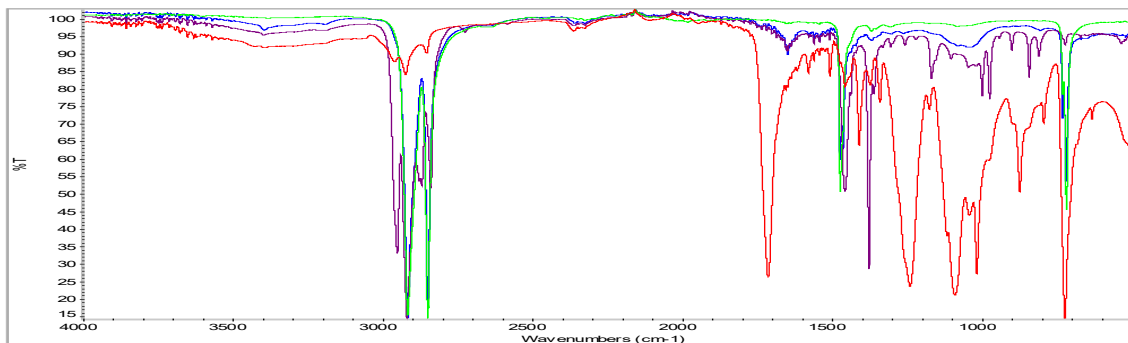


Figure 23: Spectra of fraction F and N, tubes and bottles; Fraction F – Sismo (blue), fraction F – Urban (light green), fraction F - Pure Shots (purple) and fraction N - Akvavit (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 16.

Table 16: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
F	Sismo, tube	88,8% with PE (ID 625)
	Urban, tube	85,2% with PE (ID 625)
	Pure Shots, tube	91,8% with PP+PE/PP (ID 324)
N		55,7% with PET (ID 543)

As shown in the above table, the bottles are made of PET and tubes are made two different plastic types. It can be concluded that bottles of different kinds and brands consist of one plastic types and tubes of different brands can consist of minimum two different plastic types.

Caps

Spectra of caps are shown in Figure 25.

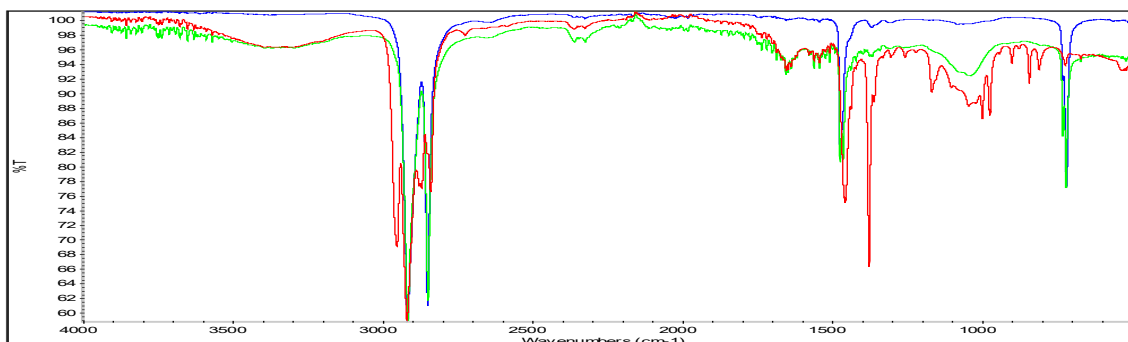


Figure 24: Spectra of fraction F, caps; Sismo (green), Urban (blue) and Pure Shots (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 17.

Table 17: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
F	Sismo, green cap	87,5% with PE (ID 95)
	Urban, golden cap	88,1% with PE (ID 95)
	Pure Shots, black cap	91,0% with PP+PE/PP (ID 324)

As shown in the above table, most of the tubes have highest percentage match with PE, and the rest have highest percentage match with PP. It can be concluded that tube caps of different brands consist of at least two different plastic types.

Labels

Spectra of labels are shown in Figure 26.

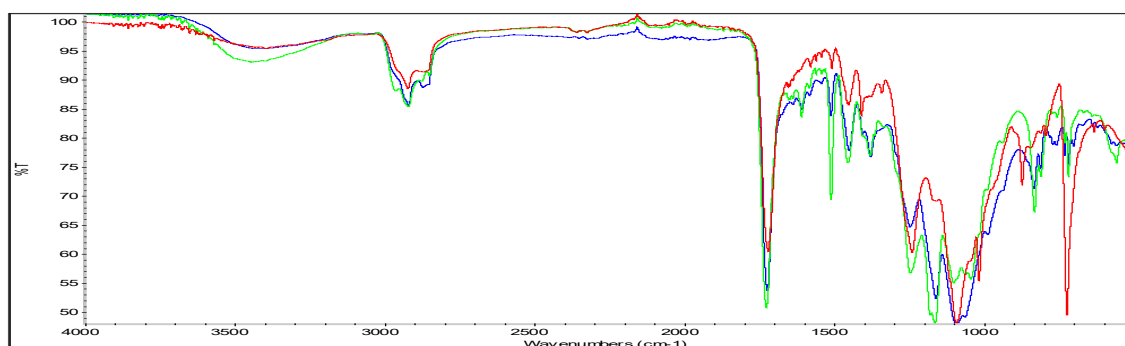


Figure 25: Spectra of fraction F, labels; Sismo (green), Urban (blue) and Pure Shots (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 18.

Table 18: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
F	Sismo, black label	64,0% with PET (ID 36)
	Urban, black label	63,9% with PET (ID 36)
	Pure Shots, black label	57,0% with PET (ID 543)

As shown in the above table, all labels have highest percentage match with PET. It can be concluded that labels of different brands consist of one plastic type.

Other plastic foils

There are collected different kinds and brands of foils (fraction E, K, O and R) for protecting products and/or mailing products. It is observed that some bags consist of other components like tape. FTIR analysis is performed on fraction E, K, O and R of different kinds and brands and associated components.

Bags/foils

Spectra of bags/foils are shown in Figure 27 – Figure 30.

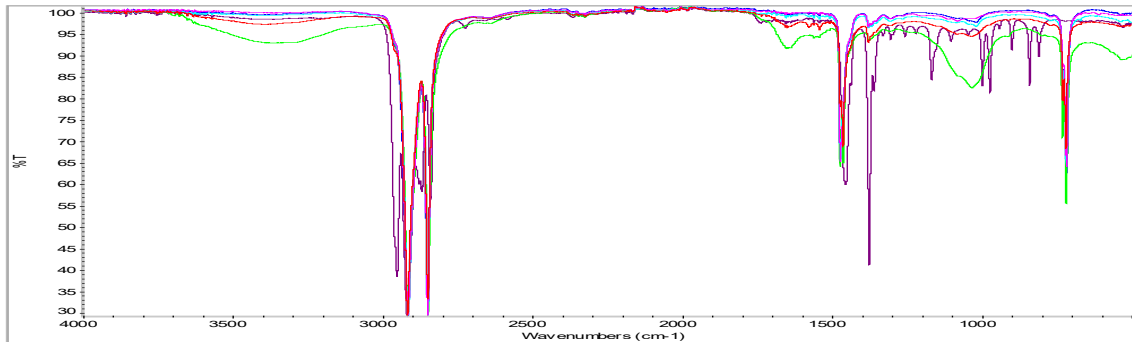


Figure 26: Spectra of fraction E, foils and bags; Transport film (red), long bag (pink), bubble wrap (light green), blue package (purple), bag with barcode (blue) and clear bag (turquoise).

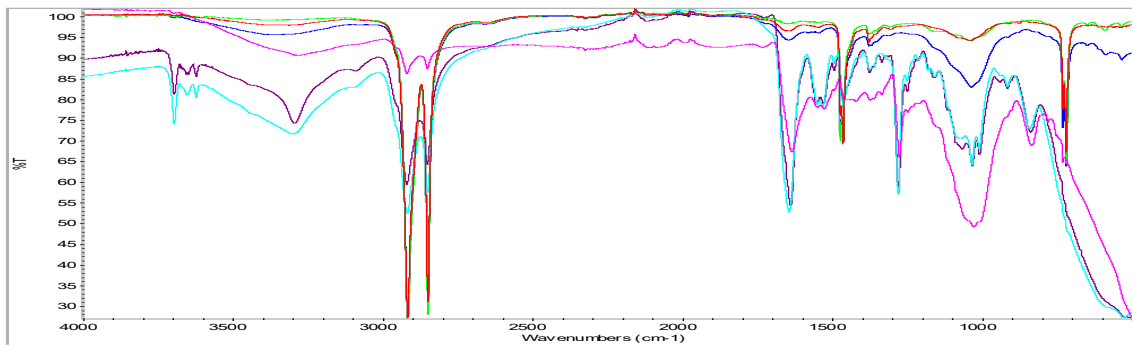


Figure 27: Spectra of fraction K, foils; Ceres (purple and blue), Faxo (turquoise and light green) and Tuborg (red and pink).

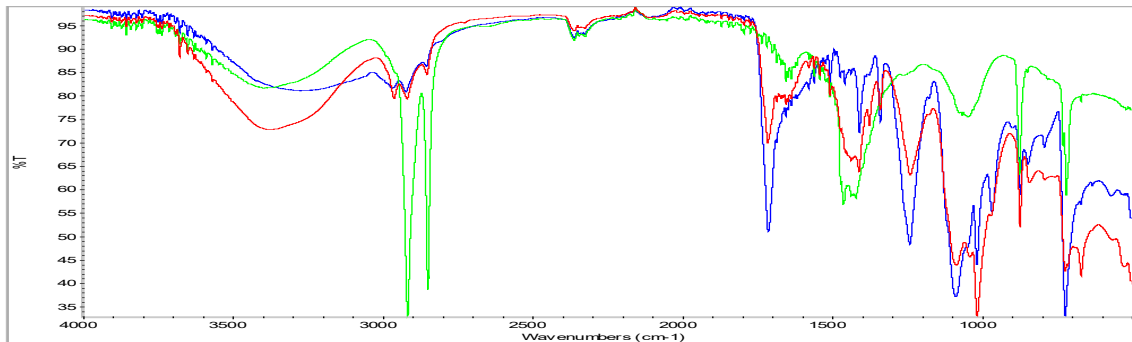


Figure 28: Spectra of fraction P, shoe cover; Shoe cover (light green), elastic band in shoe covers (red) and cloth around the elastic band (blue).

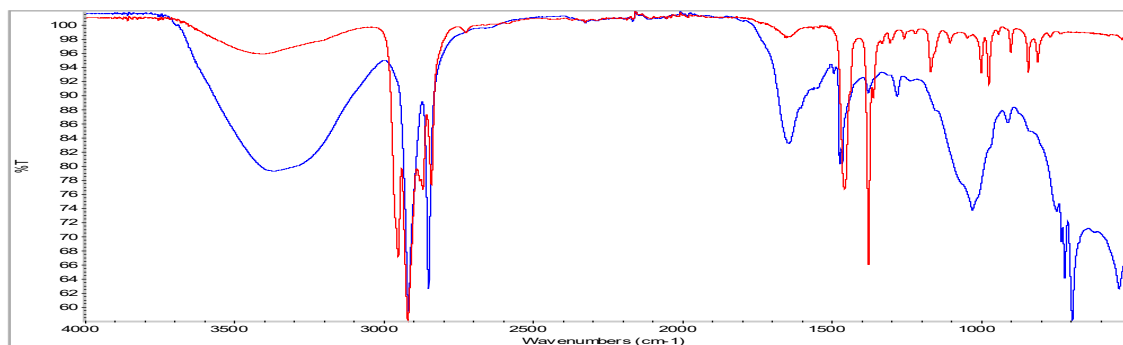


Figure 29: Spectra of fraction R, foils; Candy paper (blue) and ice cream (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 19.

Table 19: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
E	Transport film	93,8% with PE (ID 625)
	Long bag	88,9% with PE (ID 625)
	Bubble wrap	85,7% with PE (ID 625)
	Blue package bag	91,3% with PP (ID 942)
	Bag with barcode	90,2% with PE (ID 95)
	Clear bag	88,3% with PE (ID 625)
K	Ceres	91,7% with PE (ID 625)
		64,7% with cellulose nitrate (ID 757)
	Faxe	91,9% with PE (ID 625)
		65,3% with cellulose nitrate (ID 757)
Tuborg	93,7% with PE (ID 625)	
	47,5% with cellulose nitrate (ID 757)	
P	Shoe cover	85,5% with PE (ID 95)
	Elastic band in shoe covers	53,4% with additive for rubbers (ID 313)
	Cloth around the elastic band	55,7% with PET (ID 543)
R	Candy	83,2% with PE (ID 625)
	Ice cream	90,2% with PP+PE/PP (ID 324)

As shown in the above table, most of the bags/foils have highest percentage match with PE except the mailing bag and ice cream packaging, which has highest percentage match with PP and shrink wraps, which possible are a multiple layer foils and have highest percentage match with PE and cellulose nitrate. Shoe covers are composed of different plastic types and have highest percentage match with PE for the cover, with rubber for the elastic band and PET for cloth around the elastic band. It can be concluded that bags/foils of different kinds and brands consist of at least four plastic types.

Tape

Spectra of tapes are shown in Figure 31.

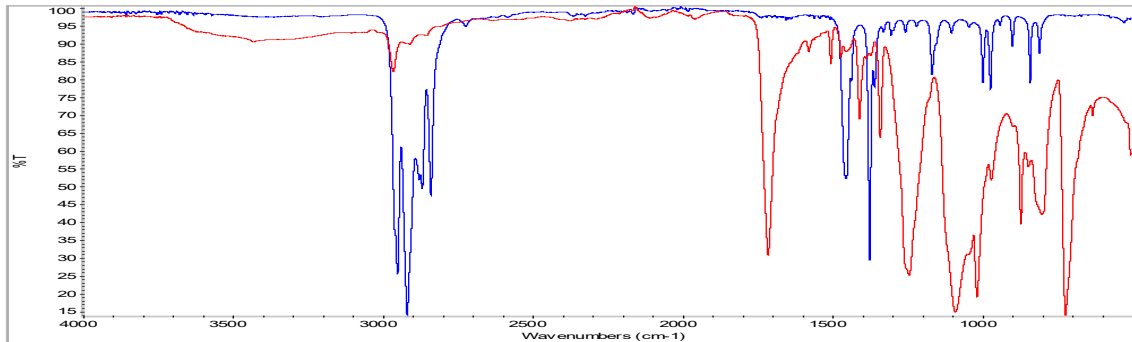


Figure 30: Spectra of fraction E, tapes; Tape on bag with barcode (blue) and Tape on clear bag (red).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 20.

Table 20: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
E	Tape on bag with barcode	90,6% with PP+PE/PP (ID 324)
	Tape on clear bag	57,2% with PET (ID 543)

As shown in the above table, tapes have highest percentage match with PP and PET. It can be concluded that tapes can consist of at least two plastic types.

Other rigid products

There are collected different kinds of single-use products (fraction G and Q) for cups. It is observed that the products do not consist of other components. FTIR analysis is performed on fraction G and Q of different kinds and brands. Spectra of rigid products are shown in Figure 32 – Figure 33.

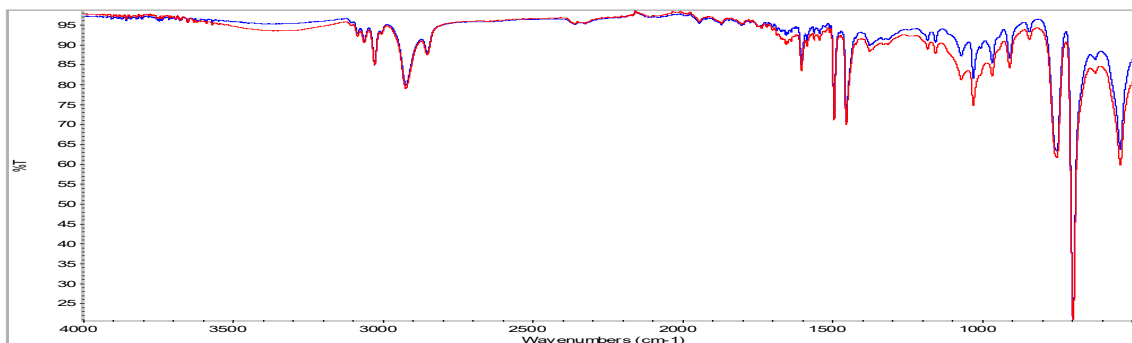


Figure 31: Spectra of fraction G, lids; Lid from McDonalds (blue) and unknown lid (red).

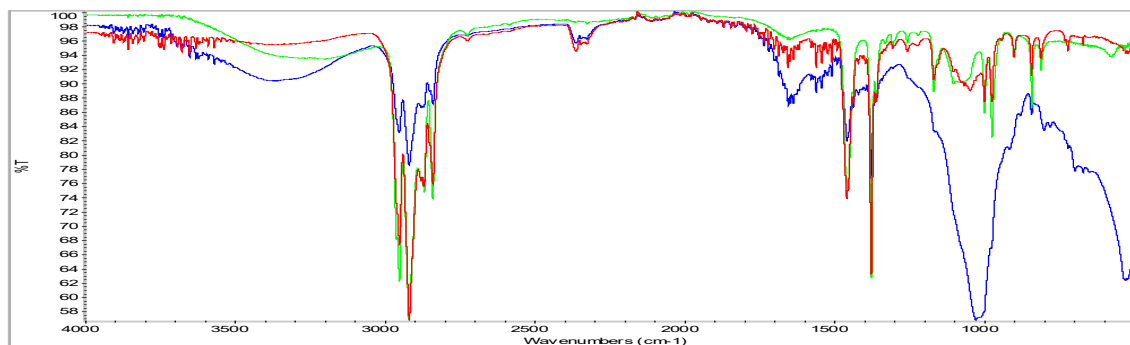


Figure 32: Spectra of fraction Q, O and T, lids; Fraction Q - straw (red), fraction O - pot (blue) and fraction T - lid for yoghurt (light green).

Spectra are compared with the library of the FTIR instrument to determine overall chemical structure and the highest matches with reference materials are shown in Table 21.

Table 21: The highest percentage match with reference material from the FTIR library.

Plastic fraction		Highest match with reference material
G	Lid, McDonalds	72,7% with PS (ID 46)
	Unknown lid	73,0% with PS (ID 46)
Q	Straw	88,1% with PP+PE/PP (ID 324)
O	Pot	68,0% with PP+PE/PP (ID 324)
T	Lid, yoghurt	89,1% with PP+PE/PP (ID 324)

As shown in the above table, lids have highest percentage match with PS and the rest of the rigid products have highest percentage match with PP. It can be concluded that other rigid products can consist of at least two plastic types.

Supplementary Material A2 – DSC results of plastic waste

Differential Scanning Calorimetry (DSC) is a calorimetric analyzer that uses a temperature program to measure the heat capacity. The measurement will appear as a thermogram, which depicts heat flow as a function of temperature. Of this, thermal properties are determined, such as glass transition temperature and melting point. Temperature program is composed by a single heating from room temperature to 450°C.

Fractions of the marine plastic waste are presented in the following sections.

Cups

There are collected different kinds of cups (fraction A, I, M and S). It is obvious that cups consist of mono-material items as there are no labels or caps attached.

DSC analysis is performed on fraction A of different brands and size and fraction I, M and S. The results from DSC analyses of cups are shown in Table 22.

Table 22: Results from DSC analyses of Fraction A, I, M and S (cups) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
A	7-Eleven	72.6	250.4
	Carlsberg	-	161.7
	Ceres	70.6	248.9
	Fadøl	-	162.5
	Heineken	-	164.2
	Royal	70.5	252.5
	Tuborg	-	163.5
	Clear	-	166.0
	Clear and narrow	-	167.3
	Clear w/ text at top	-	168.2
	Clear w/ text at bottom	-	166.4
I		145.3	-
M	Green text	-	168.4
	Absolut	-	149.4, 129.6
S		-	146.5

As shown in the above table, most of the cups have similar melting point as homopolymer PP (157-166°C), fraction S has similar melting point as copolymer PP (130-164°C), fraction M has similar melting points as copolymer PP and HDPE (130-137°C) with PET (255-258°C) and fraction I has similar glass transition temperature as polycarbonate (PC: 145°C) (Bashford, 1997).

The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that cups of different kinds consist of at least four different plastic types. The greatest number of cups consist of PP.

Small boxes for tobacco products and associated components

There are collected different brands of containers for tobacco products and cigarette butts (fraction B and U). It is observed that the containers consist of other components like

label and lid and have some tobacco products inside the containers. DSC analysis is performed on fraction B and U of different brands and associated components.

Containers

The results from DSC analyses of containers are shown in Table 23.

Table 23: Results from DSC analyses of Fraction B (containers) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
B	Odens, container	-	165.9
	Velo, container	-	169.2

As shown in the above table, all containers have similar melting point as homopolymer PP (157-166°C) (Bashford, 1997). The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that containers of different brands consist of one plastic type.

Lids

The results from DSC analyses of lids are shown in Table 24.

Table 24: Results from DSC analyses of Fraction B (lids) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
B	Odens, lid	-	166.8
	Velo, lid	-	167.3

As shown in the above table, lids have similar melting point as homopolymer PP (157-166°C) (Bashford, 1997). The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that lids of different brands consist of one plastic type.

Labels

The results from DSC analyses of labels are shown in Table 25.

Table 25: Results from DSC analyses of Fraction B (labels) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
B	Oden's, label on lid	-	165.2
	Velo, label	-	117.5, 129.4
	Velo, label on lid	-	165.4

As shown in the above table, labels on lid have similar melting point as homopolymer PP (157-166°C) and label on box has similar melting points as Low Density Polyethylene (LDPE: 105-115°C) and High Density Polyethylene (HDPE: 130-137°C) (Bashford, 1997). The identification obtained by DSC results are not consistent with the FTIR results.

This is possibly because the labels consist of foil coated with ink, that is identified as PET by FTIR. It can be concluded that labels consist of more than one plastic type.

Snuff and cigarette butts

The results from DSC analyses of snuff and cigarette butts are shown in Table 26.

Table 26: Results from DSC analyses of Fraction B (snuff) and Fraction U are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
B	Snuff	-	126.6, 254.0
U	Cigarette butt	-	229.9

As shown in the above table, the tobacco products have similar melting point as cellulose acetate (230 – 300°C) (Ashter, 2018). The snuff contains another melting point, which is similar to the melting point for cellulose acetate butyrate (127-205°C). (Thermo Fisher Scientific, 2023) The identification obtained from the DSC results is consistent with the FTIR results. Additional testing indicated that the tobacco products may contain cellulose acetate-based materials, which are not suitable for mechanical recycling.

Bags

There are collected different kinds and brands of bags (fraction C, H, J and L) for lunch storage/freezing down food, grocery shopping, waste and garden waste. It is observed that some bags consist of other components like bag handle reinforcement. DSC analysis is performed on fraction C, H, J and L of different kinds and brands and associated components.

Bags

The results from DSC analyses of bags are shown in Table 27.

Table 27: Results from DSC analyses of Fraction C, H, J and L (bags) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
C	Rema	-	124.1
	With dots	-	163.2, 145.1
	Clear	-	123.9
	Svan marked	-	122.7, 115.3
	Mark on MD	-	121.6
	With red edge	-	122.0, 109.9
H	Black	-	123.5, 117.9
	Fakta	-	123.5, 117.4
	Føtex	-	110.1
	Rema	-	123.2, 118.7
J	Dog waste	-	121.7, 117.5
	Banan bag	-	127.3
	Clear	-	126.9
	Bio waste	-	123.2, 119.2
L	Clear	-	108.0, 116.1, 121.7
	Black	-	107.7, 117.5, 121.9

As shown in the above table, all bags have similar melting point as PE (LDPE: 105-115 and LLDPE: 122-124) except the freezer bag with dots, which has similar to the melting point of PP (157-166°C). The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that bags of different kinds and brands consist of at least two plastic types.

Bag handle reinforcements

The results from DSC analyses of bag handle reinforcements are shown in Table 28.

Table 28: Results from DSC analyses of Fraction H (bag handle reinforcements) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
H	Black	-	123.6, 109.5
	Fakta	-	108.1, 123.2
	Føtex	-	109.6
	Rema	-	109.2, 117.3

As shown in the above table, all bag handle reinforcements have similar melting point as PE (LDPE: 105-115 and LLDPE: 122-124). The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that bags with handle reinforcement of different brands consist of one plastic type, which is the same plastic type as the bags, respectively.

Bottles/tubes and associated components

There are collected different kinds of bottles and tubes (fraction D, F and N). It is observed that the bottles consist of other components like label and cap. DSC analysis is performed on fraction F of different brands and associated components and fraction N, only the bottle

as the cap is metal and the label is paper. Fraction D is excluded from the analysis as it already can be recycled.

Bottles/tubes

The results from DSC analyses of bottles/tubes are shown in Table 29.

Table 29: Results from DSC analyses of Fraction F and N (bottles) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
F	Sismo, tube	-	135.5
	Urban, tube	-	132.3
	Pure Shots, tube	-	164.8
N		-	251.7

As shown in the above table, the bottles have similar melting point as PET (255-258°C) and tubes of Sismo and Urban have similar melting point as HDPE (130-137°C) and tubes of Pure Shots have similar melting point as PP (157-166°C). The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that bottles of different kinds and brands consist of one plastic types and tubes of different brands can consist of at least two different plastic types.

Caps

The results from DSC analyses of caps are shown in Table 30.

Table 30: Results from DSC analyses of Fraction F (caps) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
F	Sismo, green cap	-	130.4
	Urban, golden cap	-	131.0
	Pure Shots, black cap	-	167.9

As shown in the above table, caps for tubes of Sismo and Urban have similar melting point as HDPE (130-137°C) and caps for tubes of Pure Shots have similar to the melting point of PP (157-166°C). The identification obtained by DSC results are consistent with the FTIR results.

It can be concluded that tube caps of different brands consist of at least two different plastic types, which is the same plastic type as the tubes, respectively.

Labels

The results from DSC analyses of caps are shown in Table 31.

Table 31: Results from DSC analyses of Fraction F (labels) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
F	Sismo, black label	-	128.9, 115.1
	Urban, black label	-	128.7, 115.9
	Pure Shots, black label	-	156.0

As shown in the above table, labels for Sismo and Urban have similar melting point as HDPE (255-258°C) and LDPE (105-115°C) and label for Pure Shots have similar melting point as PP (157-166°C). The identification obtained by DSC results are not consistent with the FTIR results. This is possibly because the labels consist of foil coated with ink, that is identified as PET by FTIR. It can be concluded that labels of different brands consist of at least two plastic types.

Other plastic foils

There are collected different kinds and brands of foils (fraction E, K, O and R) for protecting products and/or mailing products. It is observed that some bags consist of other components like tape. DSC analysis is performed on fraction E, K, O and R of different kinds and brands and associated components.

Bags/foils

The results from DSC analyses of bags/foils are shown in Table 32.

Table 32: Results from DSC analyses of Fraction E, K, P and R (bags/foils) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
E	Transport film	-	122.4
	Long bag	-	116.7, 121.1
	Bubble wrap	-	126.1
	Blue package bag	-	137.6, 158.3, 165.7
	Bag with barcode	-	122.0
	Clear bag	-	117.2, 121.4
K	Ceres	-	125.3, 112.4
	Faxe	-	124.9, 112.6
	Tuborg	-	116.9, 112.6
P	Shoe cover	-	121.6
	Cloth of elastic band	-	253.1
R	Candy	-	127.7
	Ice cream	-	154.4, 165.1

As shown in the above table, most of the bags/foils including shrink wraps have similar melting point as PE (LDPE: 105-115°C and LLDPE: 122-124°C) except the blue package bag and ice cream packaging, which have similar melting point as PP (157-166°C).

Shoe covers are composed of different plastic types and rubber. The cover has similar melting point as LLDPE (122-124°C) and the cloth around the elastic has similar melting point as PET (255-258°C). The rubber is not analysed as it is not thermoplastic material

that can melt. The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that bags/foils of different kinds and brands consist of at least four plastic types.

Tape

The results from DSC analyses of tapes are shown in Table 33.

Table 33: Results from DSC analyses of Fraction E (tapes) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
E	Tape on bag with barcode	-	164.9
	Tape on clear bag	-	255.6

As shown in the above table, tapes have similar melting point as PP (157-166°C) and PET (255-258°C). The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that tapes can consist of at least two plastic types.

Other rigid products

There are collected different kinds of single-use products (fraction G and Q) for cups. It is observed that the products do not consist of other components. DSC analysis is performed on fraction G and Q of different kinds and brands. The results from DSC analyses of tapes are shown in Table 34.

Table 34: Results from DSC analyses of Fraction G, Q, O and T (other rigid products) are gathered.

Plastic fraction		Glass transition (°C)	Melting point (°C)
G	Lid, McDonalds	97,5	-
	Unknown lid	96,9	-
Q	Straw	-	167,5
O	Pot	-	163,2
T	Lid, yoghurt	-	162,6

As shown in the above table, lids have similar melting point as PS (90-110°C) (Mettler Toledo, 1997) and the rest of the rigid products have similar to the melting point of PP (157-166°C). The identification obtained by DSC results are consistent with the FTIR results. It can be concluded that other rigid products can consist of at least two plastic types.

**Appendix B: University of Gdańsk report (Gdańsk/Motława case)
– full report text and documentation**

Report on Identification of the collected OBP from Motława river

Emilia Gontarek-Castro, Onur Cavdar, Anna Malankowska, Anna Gołąbiewska,
Patrycja Jutrzenka Trzebiatowska

*Department of Environmental Technology, Faculty of Chemistry, University of Gdansk, 80-308 Gdansk,
Poland*

This annex report is related to the identification of the plastic waste collected in Gdańsk-River Motława, during a 4-week period, for a snapshot view of the type of collected items.

Abbreviations used: *C/LDPE- composite or multilayer material containing LDPE (Low-Density Polyethylene); C-PP- composite or multilayer material containing polypropylene (PP); FTIR- Fourier-Transform Infrared Spectroscopy; HDPE-high density polyethylene; LDPE- low density polyethylene; PE – polyethylene; PET -poly(ethylene terephthalate); PP- polypropylene; PS- polystyrene; PVC -poly(vinyl chloride); TGA- Thermogravimetric Analysis*

Plastic waste collection

The waste was collected from the Motława River during the “Ekokajak” initiative, organized by one of the project partners – the Gdańsk Sports Centre (Figure 1). This initiative involves participants using kayaks to collect floating litter and other waste items directly from the river surface and riverbanks. The waste subjected to identification originated from collections conducted over a 4-week period, between 15 July and 12 August, 2025, and at specific locations along the Motława River. Since a limited 4-week period is evaluated for purposes of this report, the dataset should be viewed as a snapshot of the types of plastic entering this part of the river during the sampling period rather than a fully representative picture of all plastic pollution or seasonal variability. However, it is worth to note that summer is a high tourist season in Gdańsk, especially the beginning of August when Festival - the St. Dominics Fair is held. The waste was initially pre-sorted by the Gdańsk Sports Centre and the plastic fraction was subsequently transferred to the University of Gdańsk (Figure 2).



Figure 33. “Ekokajak” initiative, organized by one of the project partners – the Gdańsk Sports Centre



Figure 2. A batch of marine plastic waste collected from Motława River by Ekokajak during the period 15-20.07

All items were subsequently divided and categorized according to their intended use, as presented in Tables 1 and 2. Referring to both tables, the largest fraction, both in terms of number and weight, of the collected plastic waste consisted of plastic bottles. These were subsequently separated from labels and caps, due to the different types of plastics used in the manufacture of these elements, as shown in Figure 3. A significant proportion of the waste also comprised plastic food packaging, foils, and shopping bags

(Figure 4). In addition, fragments of polystyrene, small rigid plastic containers, fishing accessories, plastic cups, lids, balloons, and even nitrile gloves were found, although these items represented a clear minority.

Table 135: Fractions of marine plastic waste in number of pieces and in wet weight collected in weeks 1 and 2.

Plastic fraction	Amount		Wet weight	
	(pieces)	(%)	(g)	(%)
Bottles	16	21.1	477.07	60.1
Bottle caps	15	19.7	33.81	4.3
Bottle labels	7	9.2	4.24	0.5
Single-use cups	3	3.9	16.36	2.1
Cup lid	1	1.3	2.77	0.3
Small containers with lids	6	7.9	63.21	8.0
Grocery/Shopping bags	12	15.8	124.13	15.6
Product Packaging	1	1.3	7.39	0.9
Food product wrappers/packaging	14	18.4	61.26	7.7
Balloon	1	1.3	3.1	0.4
Total	76	100	793.34	100

Table 2: Fractions of marine plastic waste in number of pieces and in wet weight collected in weeks 3 and 4.

Plastic fraction	Amount		Wet weight	
	(pieces)	(%)	(g)	(%)
Bottles	38	27.3	870.37	60.8
Bottle caps	30	21.6	67.42	4.7
Bottle labels	22	15.8	22.52	1.6
Food product cups	3	2.2	18.1	1.3
Small containers	4	2.9	117.17	8.2
Polystyrene foam	8	5.8	49.88	3.5
Fishing gear	1	0.7	5.09	0.4
Pieces of plastic foil	5	3.6	136.95	9.6
Grocery/Shopping bags	10	7.2	78.06	5.5
Food product wrappers/packaging	17	12.2	62.51	4.4
Nitrile glove	1	0.7	3.28	0.2
Total	139	100	1431.26	100

Both periods show PET bottles dominating by weight (>60%) and by amount (over 20%), indicating consistency in the bottle-based litter profile of the Motława River. The second highest found fraction would be bottle caps and food product packaging.

In summary, the compilation presented in Tables 1 and 2 shows that during the four-week “Ekokajak” initiative, a total of 215 plastic waste items were collected, with a combined weight of 2224.6 g.



Figure 34: The majority of the marine plastic waste consists of bottles

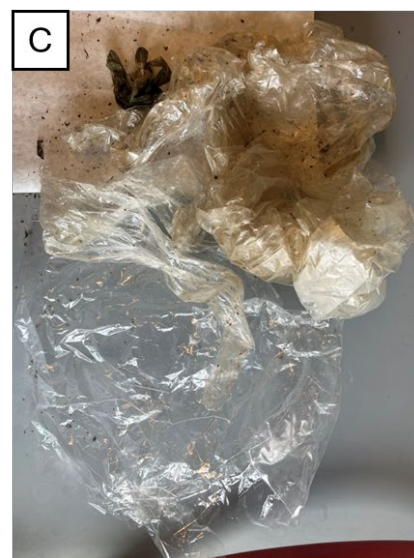


Figure 435 Examples of plastic waste collected, A – food product packaging, B – shopping plastic bags, C – pieces of plastic foil



Material identification

Upon receipt, all collected waste was sorted into predefined categories based on item type (e.g., bottle, cap, wrapper, film). Each item was counted, weighed (wet weight), and recorded in a digital dataset. Material identification began with visual inspection focused on locating the Resin Identification Code (RIC). These codes, typically printed on plastic items, appear as a recycling triangle containing numbers from 1 to 7, each indicating a common polymer type. Although this method provides a straightforward first assessment, it can be limited when symbols are faded, missing, or obscured by dirt. Examples of RIC symbol variations are shown in Table 3.

For items without a visible RIC or when visual identification was uncertain, polymer type was determined using ATR-FTIR spectroscopy and following TGA to confirm material identity.

Table 3 Plastic wastes categorized according to RIC identification

Waste fraction	No. of different RICs	Plastic type (numer of items)
A. Bottles	1	PET (53) Unknown plastic type (1)
B. Small containers	2	PET (3) PP (7)
C. Bottle caps	2	HDPE (41) PP (1) Unknown plastic type (3)
D. Bottle labels	2	PP (6) Unknown plastic type (23)
E. Grocery bags	1	LDPE (13) Unknown plastic type (9)
F. Product packaging	2	PET (1) C/LDPE (1)
G. Food product wrappers/packaging	2	LDPE (3) PP (10) C-PP (6) Unknown plastic type (11)
H. Single use cups	1	PP (2) Unknown plastic type (1)
I. Food product cups	1	PP (3)
J. Cup lid	1	PS (1)
K. Styrene foam	1	PS (8)
L. Nitrile glove	0	Nitrile 1
M. Fishing gear	0	Unknown plastic type (1)
N. Pieces of plastic foil	0	Unknown plastic type (5)
O. Balloon	0	Unknown plastic type (1)

The most diverse fraction were food product wrappers/packaging, small containers or cups. This group of waste is expected to represent a range of polymeric and composite materials commonly applied in the food industry. Based on the product categories, several material types can be anticipated. Packaging of this kind is frequently manufactured from plastic films, with PE, PP or PET. For instance, PE in the form of low-density polyethylene is often applied in bread bags and general-purpose wrapping films. PP is commonly used in bakery and snack packaging, while PET may be a component of multilayer snack wrappers, often combined with aluminium foil and an inner sealing layer of PE or PP. In addition to these major polymers, some of the samples may contain thin functional coatings, such as waxes or copolymers, which are less dominant but still relevant for packaging performance.

From Table 3 and Figure 5, it is evident that the largest shares of collected plastic waste are PET (27%, mostly bottles), HDPE (20%), and miscellaneous/unknown plastics (28%). The relatively high proportion of HDPE is linked to the high share of PET, as many HDPE items were bottle caps. Due to EU Directive 2019/904 on single-use plastics, bottle caps (for containers up to 3 liters) must remain attached to the bottle, making them harder to remove and therefore collected with PET bottles.

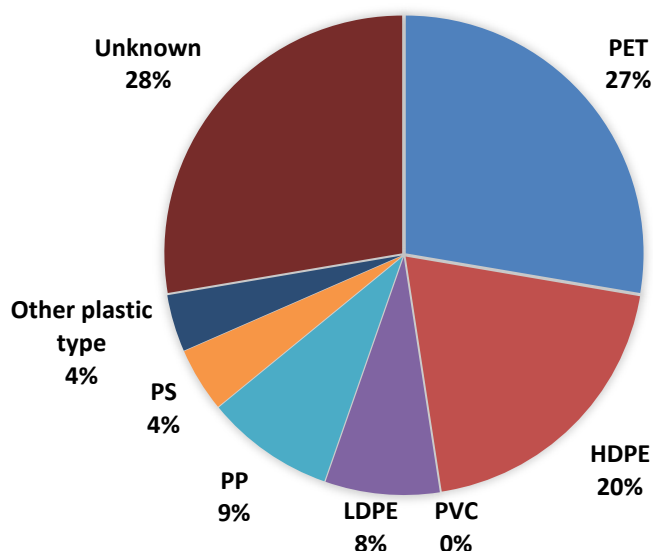


Figure 5. Percentage share of collected plastics by polymer type

Identification of unknown litter via FTIR

For items without a visible RIC or when visual identification was uncertain, polymer type was determined using ATR-FTIR spectroscopy. Each sample's FTIR spectrum was recorded and compared with reference spectra to assign the most probable polymer type. Details about the measured FTIR spectra of the marine plastic waste are shown in **Supplementary material 1 to the Annex B, FTIR analysis of unknown plastic**. This method allows for the precise determination of polymer composition by analysing the characteristic absorption spectra of the materials. FTIR is particularly useful for identifying plastics without visible RIC markings, degraded materials, or multi-layered products that are difficult to classify visually. Approximately 28% of items that could not be identified using the RIC system.

The miscellaneous materials of previously unidentified RIC plastic items are summarized in Table 4.

Table 4. The collected unknown plastic litter of the previously unidentified RIC plastic items

Waste type	Number of collected items	Polymer type
Fishing gear	1	PET
Bottle labels	23	20 PP, 3, PET
Pieces of plastic foil	5	3 PE, 1 PET, 1 PP
Grocery/Shopping bags	9	9 PE
Food product wrappers/packageging	11	7 PP, 3 PE, 1 PET
Bottle	1	PET
Bottle caps	3	2 PP, 1 PE
Single-use cups	1	Cellulose-based (other)
Balloon	1	Rubber-based (other)

As shown in the above table, several additional plastic fractions have been identified with FTIR analysis compared to visual observations. The different plastic types are as follows:

- Polypropylene (PP) identified in following fractions: pieces of plastic foil; food product wrappers, bottle caps, bottle labels.
- Polyethylene (PE) identified in following fractions: pieces of plastic, grocery bags, food product wrappers, bottle caps.
- Polyethylene terephthalate (PET) identified in following fractions bottles, fishing gear, bottle labels, pieces of plastic foil, food product wrappers, bottle.
- Cellulose-based material identified in single use cup.
- Rubber-based material identified in ballon.

In conclusion, FTIR spectroscopy proved to be an effective tool for the identification of river-collected plastic waste. The method is fast, straightforward, and does not require extensive sample preparation, as cleaning of the material before analysis is not necessary. The collected litter was also mostly composed of PP, PE or PET, with additional items from cellulose- and rubber-based materials. However, a limitation of this technique is the difficulty in distinguishing between LDPE and HDPE, as their spectra are highly similar.

Determination of PE type via TGA

Finally, thermogravimetric (TGA) analysis was conducted on several PE samples to evaluate the feasibility of using this technique to differentiate between HDPE and LDPE. The distinction between these two materials can be made based on differences in their thermal degradation behaviour. HDPE, having a higher degree of crystallinity and fewer branching points, typically exhibits a higher decomposition onset temperature and greater thermal stability compared to LDPE (Molefi et al., 2010). Details about TGA analysis of PE fraction is shown in **Supplementary material 2 to the Annex B, TGA analysis of polyethylene fraction**. Table 5 shows identified fractions of polyethylene materials.

Table 5. Distinguished fractions of PE by TGA.

Plastic fraction	Number of collected items	Polymer type
Pieces of plastic foil	2	LDPE
Grocery/Shopping bags	3	HDPE
Food product wrappers/packaging	1	HDPE

In conclusion, six samples identified as PE were subjected to TGA analysis. These originated from three grocery shopping bags, two pieces of plastic foil, and one food-product wrapper. The only sample characterized as LDPE was one of the unknown pieces of plastic foil. Therefore, it can be concluded that HDPE is more prevalent than LDPE among the plastic waste found in the Motława River.

Summary of the collected data

Considering the overall dataset from Tables 3 and 4, the most frequently identified polymer in the collected plastic waste was polyethylene (PE), including both LDPE and HDPE, with a total share of 34%. PET was the second most common polymer, with 30% share, predominantly from beverage bottles. The third most abundant material was polypropylene (PP), found in a wide range of applications such as packaging, containers, and various household items. These findings align well with global polymer production trends, where PE (LDPE and HDPE) is the most widely produced resin. Also, 99% of items were related with food consumption.

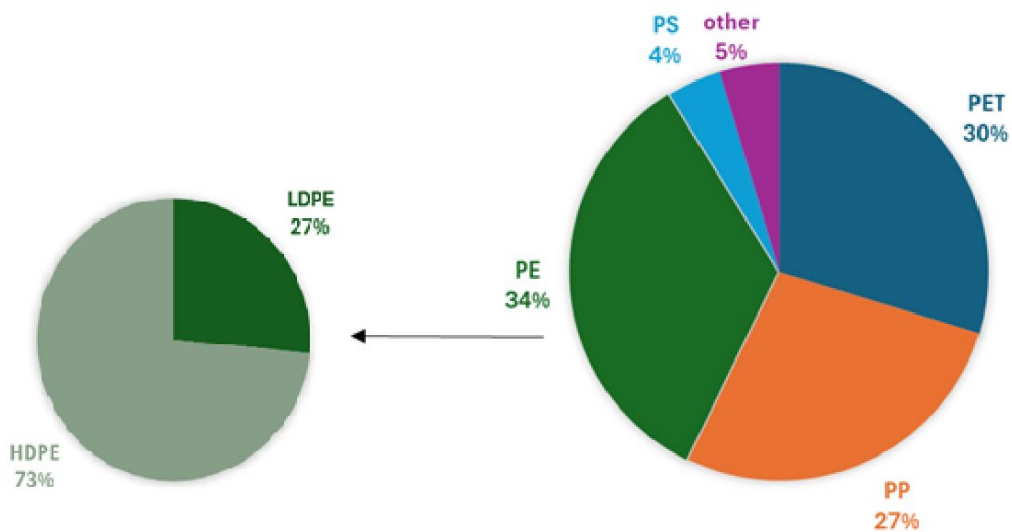


Figure 6. Total share of identified collected plastic waste

Recycling

From a waste management perspective, prevention and reuse remain the most effective strategies, as they eliminate waste at the source. However, the collected plastic waste from the Motława River demonstrates that a wide variety of materials still enter the aquatic environment, largely as a result of improper disposal and environmental transport, mostly related with food, beverages consumption.

Recycling is possible pathway, but its applicability to the collected waste is significantly limited. The collected materials were heavily contaminated with organic matter, wet, and often emitted strong odours, indicating prolonged exposure to river conditions. Moreover, a portion of the items showed clear signs of degradation, including discoloration, embrittlement, and fragmentation, which reduces their mechanical properties and recycling value. In addition, the waste stream was highly heterogeneous, consisting of multiple polymer types such as PE, PP, and PET, as well as multilayer packaging and composite materials. While rigid, single-polymer items like PET bottles and some HDPE or PP containers are generally suitable for mechanical recycling, their condition in this case would require intensive washing and sorting. Flexible films, foils,



Interreg
South Baltic



Co-funded by
the European Union

and multilayer food packaging, frequently identified in the collected samples, are difficult to recycle and are typically excluded from standard recycling systems. Therefore, for many found fractions, an option would be chemical recycling, that helps recovery starting chemicals of these materials (monomers, oligomers or petrochemical fractions) and is less affected by degradation. However, also this method requires pre-sorting and cleaning operation, that would allow for obtaining high-value added products. In conclusion, the selection of recycling options depends not only on polymer type, but also on contamination level, degradation, and the presence of multi-material products.

Supplementary Material B1 – FTIR analysis of unknow plastic

FTIR analysis of unknow plastic

The infrared spectrum measurement was performed using a Perkin Elmer Fourier spectrometer in transmittance mode. The spectra were obtained after 64 scans in a range from 4000 to 400 cm^{-1} with a resolution of 4 cm^{-1} . To identify the collected samples, we compared their FTIR spectra with the characteristic absorption bands of the three most common plastic types: PET, PE, and PP (Table S1). These diagnostic bands were used to determine the corresponding polymer. For atypical materials, such as balloons or cellulose-based cups, identification was performed individually using literature-derived reference spectra.

Table S1. Characteristic FTIR peak assignments for identification of PE, PET and PP (Fang et al., 2012), (Pereira et al., 2017), (Wang et al., 2015), (Gulmine et al., 2002) (Ioakeimidis et al., 2016)

	Wave number (cm^{-1})	Vibration type	Assignment
PET	700 - 900	Out-of-plane bending	Aromatic (C-H)
	1000 - 1200	In-plane bending and stretching	Aromatic C-C
	1453	Stretching	C-O
	1730	Stretching	C=O
PE	720-730	Rocking	C-CH ₂
	1378	Symmetric bending	C-CH ₃
	1473, 1463	Bending	C-H
	2850	Symmetric Stretching	C-H
	2920	Asymmetric Stretching	C-H
PP	1376	Symmetrical bending	CH ₃
	1456	Symmetrical bending	CH ₃
	2870	Stretching	CH ₃
	2920	Asymmetrical stretching	CH ₂
	2950	Asymmetrical stretching	CH ₃

Bottle caps

Firstly, three bottle caps were analysed using FTIR (Figure S1). The spectrum of Cap 2 displayed characteristic absorption peaks of PE: 2920 cm^{-1} , 2850 cm^{-1} , 1465 cm^{-1} , and 721 cm^{-1} . In contrast, Caps 1 and 3 exhibited additional peaks at 2954 cm^{-1} and 1378 cm^{-1} corresponding to CH_3 groups, indicative of polypropylene (PP). Thus, FTIR confirmed that Cap 2 was composed of PE, while Caps 1 and 3 were made of PP.

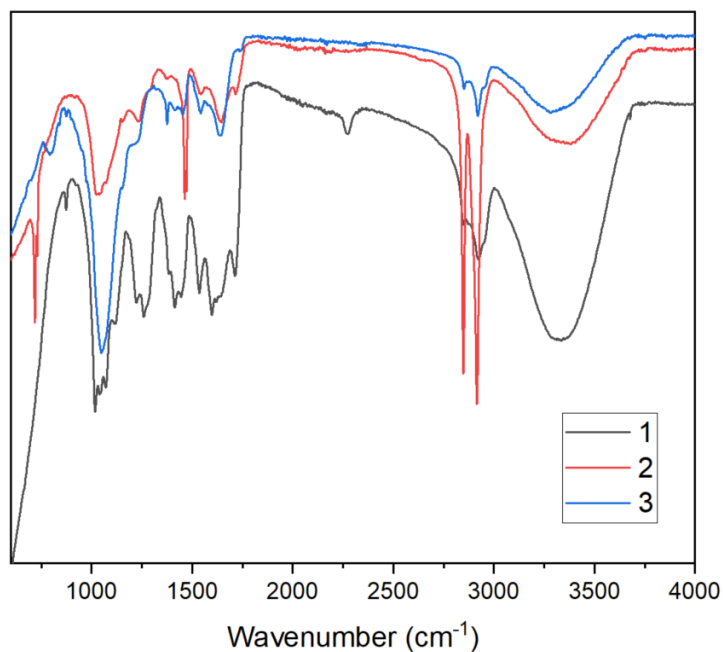


Figure S1. FTIR spectra of bottle caps

Plastic bottle

For the plastic bottle (Figure S2), although no RIC code was visible, there was a high probability that the material was PET based on visual inspection. This assumption was confirmed by FTIR analysis, which revealed the characteristic absorption bands of PET; 1715 cm^{-1} , 1245 cm^{-1} , 1100 cm^{-1} , 870 cm^{-1} , and 730 cm^{-1} .

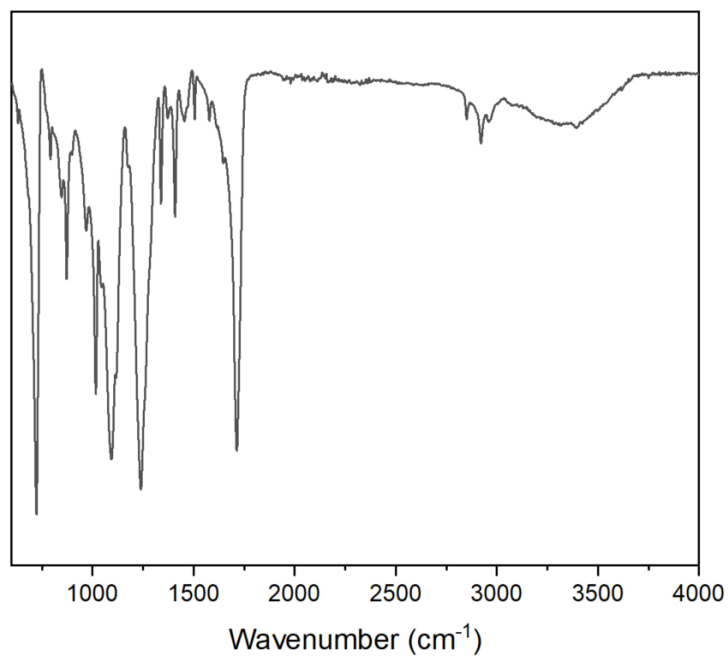


Figure S2. FTIR spectra of the bottle

Balloon

The FTIR spectrum of the balloon sample exhibits characteristic absorption bands corresponding to cis-1,4 polyisoprene, the primary polymer component of natural rubber (Wei et al., 2014). The observed peaks at 2960 cm^{-1} , 2927 cm^{-1} , and 2852 cm^{-1} are attributed to C–H stretching vibrations of aliphatic –CH and –CH₂– groups. The band at 1661 cm^{-1} corresponds to C=C stretching of the cis-1,4 double bonds in the polymer backbone. Additionally, the peaks at 1448 cm^{-1} and 1376 cm^{-1} are assigned to the C–H deformation vibrations of –CH₂– and –CH₃ groups, respectively, while the band at 835 cm^{-1} is indicative of C–H out-of-plane bending of the =C–H moiety. These spectral features are consistent with the molecular structure of cis-1,4 polyisoprene, confirming the presence of natural rubber in the sample.

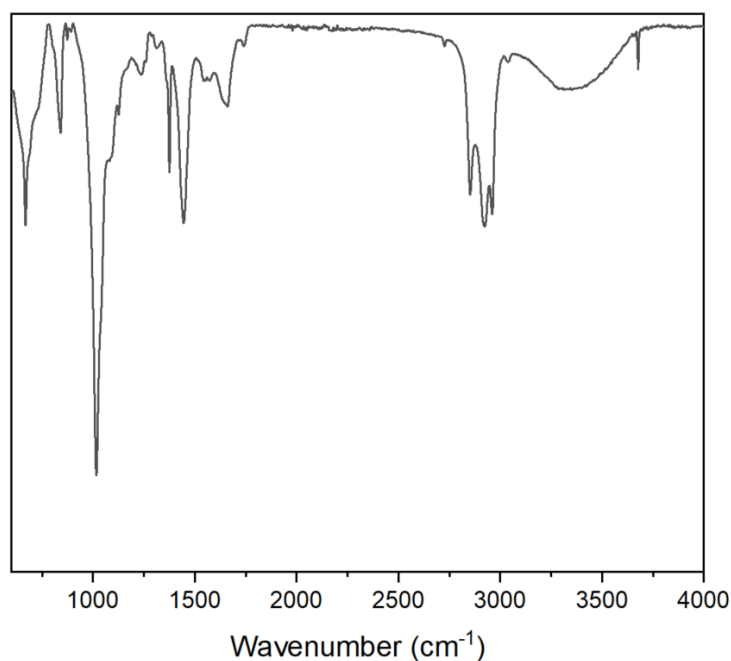


Figure S3. FTIR spectra of balloon

Food product wrappers

Food product wrappers/packaging waste included 11 items of unknown composition. These items were further classified into 8 subcategories (e.g., 3 chocolate bar wrappers - sample 5, 2 bread packaging- sample 7). All samples were subsequently subjected to FTIR analysis. This group of waste is expected to represent a range of polymeric and composite materials commonly applied in the food industry.

Sample 1 exhibited typical for PE absorption peaks. Samples 2 and 4 follow a similar spectral pattern to Sample 1 and can also be classified as PE. However, the peaks appear less well-defined, and additional signals are present, most likely due to surface contamination or sample impurities. Sample 6 shows peaks characteristic for PET. On the other hand, samples 3, 5, 7 and 8 exhibit overall spectral features like PE. However, two additional peaks characteristic of PP can also be observed.

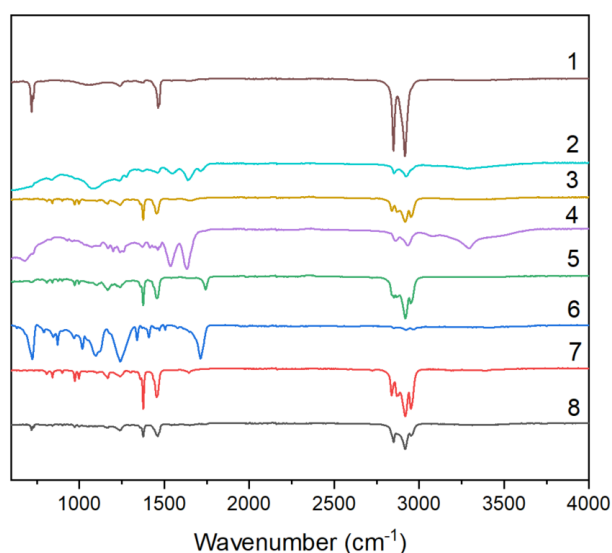


Figure S4. FTIR spectra of food product wrappers/packaging

Plastic bottle labels

Plastic bottle labels are another interesting category of packaging waste, and their composition can vary depending on the brand, product type, and recycling considerations. In general, most labels are designed to be lightweight, printable, and resistant to moisture, but they are not always made from the same material as the bottle itself. Typically, bottle labels are produced from PP or PE films. In our waste samples we were able to distinguish two types of bottle labels: one consisting of a thin, flexible film (sample 1, 20 items), and the other of a thicker, stiffer material that is more resistant to bending and deformation (sample 2, 3 items). Based on the spectra presented in Figure S5 and the previous description, it can be assumed that the spectrum of sample 1 corresponds to PP, while that of sample 2 corresponds to PET.

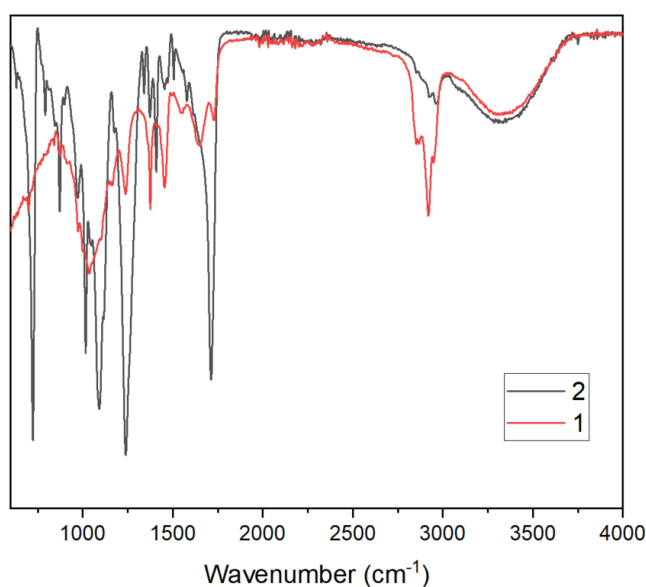


Figure S5. FTIR spectra of two types of bottle labels

Single-use cups

The collected single-use coffee cup represents a composite type of packaging material. In most cases, the main body of the cup is produced from paperboard, which provides the required mechanical strength and rigidity. To ensure resistance to liquids and prevent leakage, the paper is coated on the inner surface with a thin polymer film, most commonly polyethylene (PE) and in some cases polypropylene (PP). As a result, the FTIR spectra of such cups typically exhibit characteristic cellulose signals of paper, such as broad O–H stretching around 3300 cm^{-1} and C–O stretching in the $1050\text{--}1150\text{ cm}^{-1}$ range, alongside polymer-specific peaks of PE or PP, such as CH_2 and CH_3 stretching between 2915 and 2848 cm^{-1} and bending vibrations around 1465 and 1375 cm^{-1} (Hospodarova et al., 2018). The spectrum (figure S6) confirms that the material is cellulose-based; however, its precise composition cannot be determined solely by FTIR analysis.

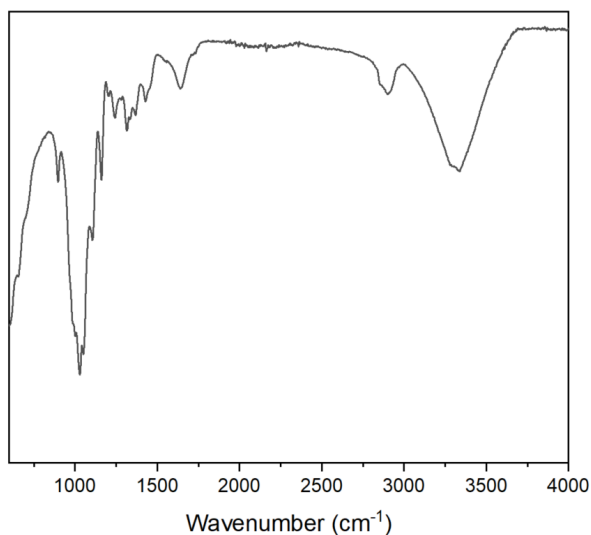


Figure S6. FTIR spectra of single use cup

Shopping or grocery bags

Among the collected waste, nine unidentified samples were classified as shopping or grocery bags. These were divided into three subcategories: sample 1 – standard thin disposable bags (5 items), sample 2 – thicker reusable bags with printed graphics (3 items), and sample 3 – a thicker reusable bag heavily affected by the marine environment (1 item). The FTIR spectra of the shopping bags (figure S7) exhibit characteristic absorption bands of PE. These features are particularly clear and well-defined in sample 1, which was fully transparent and free from prints. In contrast, the spectra of samples 2 and 3 are influenced by the presence of printed layers, which introduce additional signals and reduce the clarity of the PE peaks.

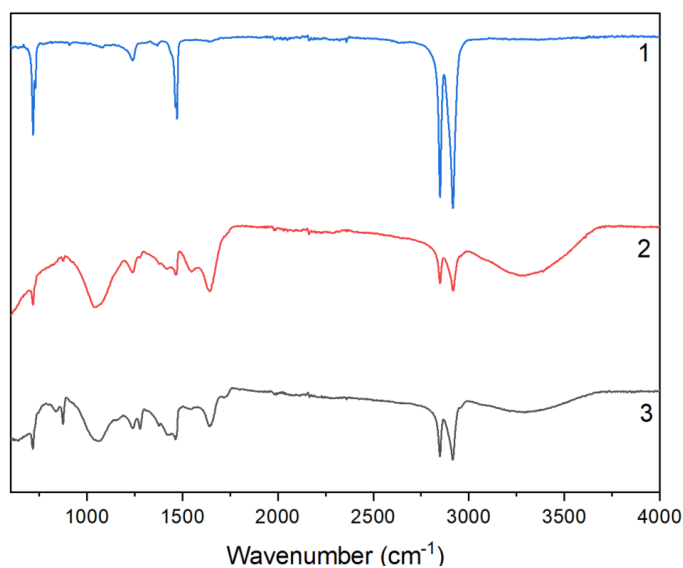


Figure S7. FTIR spectra of grocery/shopping bags

Pieces of plastic foil

Five unidentified pieces of plastic foil were analysed, and their FTIR spectra are presented in Figure S8. Samples 2, 4, and 5 exhibited characteristic absorption bands for PE. Sample 3 showed spectral features consistent with PET. This finding is further supported by its distinct appearance, as the foil was noticeably shinier and more transparent than the other samples. Finally, Sample 1 displayed spectral characteristics typical of PP, which align with the results and discussion presented for previously analysed samples.

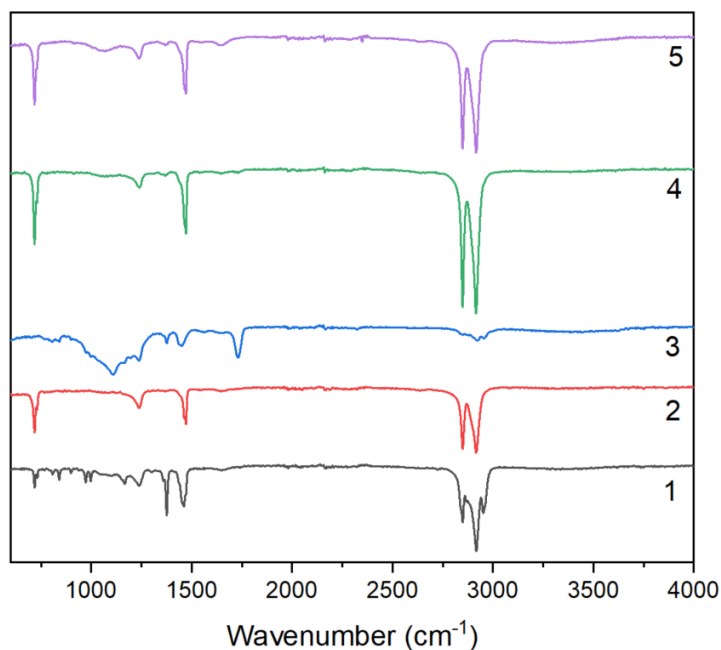


Figure S8 FTIR spectra of pieces of plastic foil

Fishing gear

The final identified item was a fragment of fishing gear, composed of a hard and durable plastic material. According to the FTIR analysis, its spectrum displayed characteristic absorption bands consistent with PET.

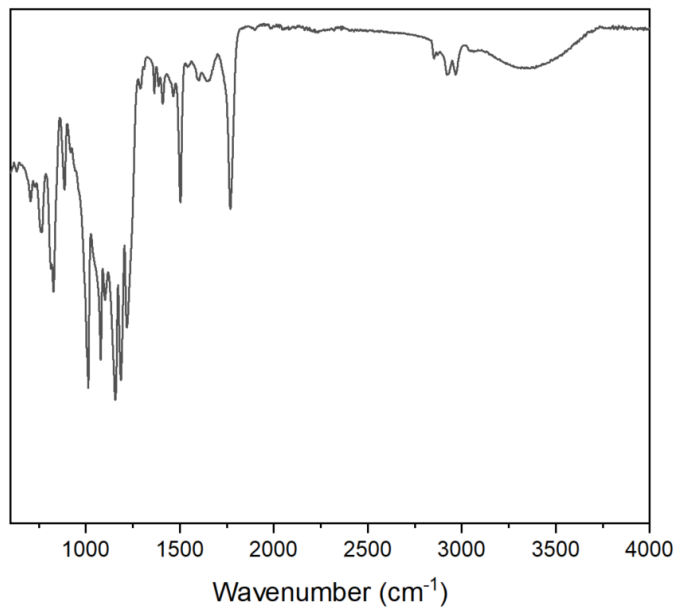


Figure S9 FTIR spectra of pieces of fishing gear

Supplementary Material B2 – TGA results of PE

TGA analysis of polyethylene fraction

The thermal analysis was performed on TGA 8000 (Perkin Elmer) equipment. Samples were heated from room temperature to 900°C at a heating rate of 10°C/min under a nitrogen atmosphere.

TGA measurements were performed for six unidentified PE film samples. The DTGA curves in figure 13 revealed that one of the samples exhibited a lower peak decomposition temperature (460 °C) compared to the remaining five samples (approximately 480 °C). This difference may indicate a variation in polymer type, as LDPE typically decomposes at slightly lower temperatures than HDPE. Therefore, TGA can serve as a useful analysis for distinguishing between these two PE types (Figure S10).

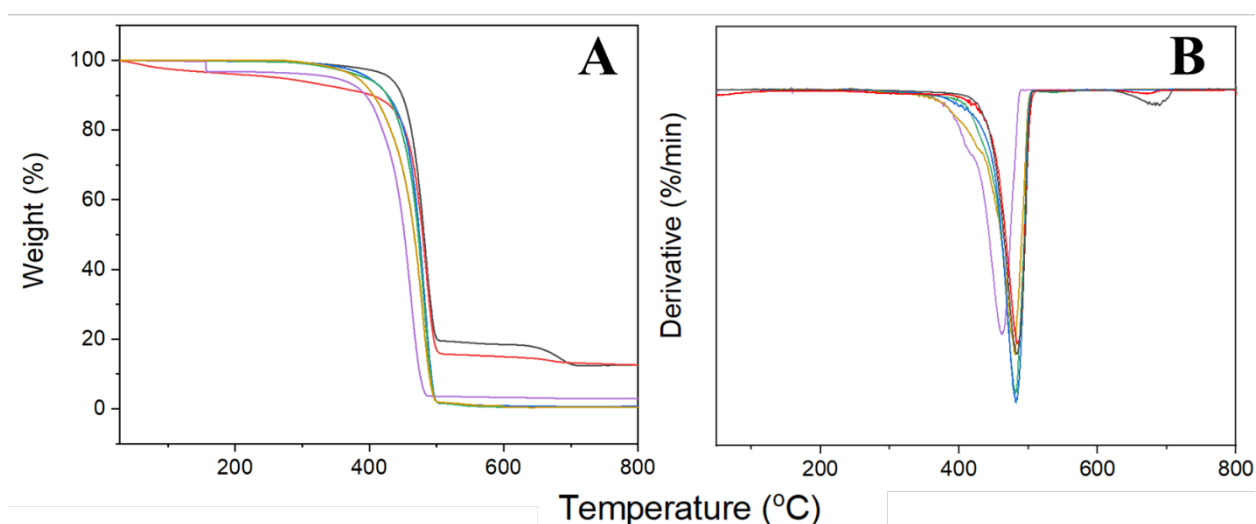


Figure S10 TGA and DTGA curves of PE samples.

References for appendix B

- Fang J, Zhang L, Sutton D, Wang X, Lin T. Needleless Melt-Electrospinning of Polypropylene Nanofibres. *J Nanomater* 2012;2012:1–9. <https://doi.org/10.1155/2012/382639>.
- Gulmine J., Janissek P., Heise H., Akcelrud L. Polyethylene characterization by FTIR. *Polym Test* 2002;21:557–63. [https://doi.org/10.1016/S0142-9418\(01\)00124-6](https://doi.org/10.1016/S0142-9418(01)00124-6).
- Hospodarova V, Singovszka E, Stevulova N. Characterization of Cellulosic Fibers by FTIR Spectroscopy for Their Further Implementation to Building Materials. *Am J Anal Chem* 2018;09:303–10. <https://doi.org/10.4236/ajac.2018.96023>.
- Ioakeimidis C, Fotopoulou KN, Karapanagioti HK, Geraga M, Zeri C, Papanthassiou E, et al. The degradation potential of PET bottles in the marine environment: An ATR-FTIR based approach. *Sci Rep* 2016;6:23501. <https://doi.org/10.1038/srep23501>.
- Molefi JA, Luyt AS, Krupa I. Comparison of LDPE, LLDPE and HDPE as matrices for phase change materials based on a soft Fischer – Tropsch paraffin wax. *Thermochim Acta* 2010;500:88–92. <https://doi.org/10.1016/j.tca.2010.01.002>.
- Pereira AP dos S, Silva MHP da, Lima Júnior ÉP, Paula A dos S, Tommasini FJ. Processing and Characterization of PET Composites Reinforced With Geopolymer Concrete Waste. *Mater Res* 2017;20:411–20. <https://doi.org/10.1590/1980-5373-mr-2017-0734>.
- Wang C, Wang Y, Dang Y, Jiao Q, Li H, Wu Q, et al. Synthesis of a novel titanium complex catalyst and its catalytic performance for olefin polymerization. *Russ J Appl Chem* 2015;88:1723–7. <https://doi.org/10.1134/S1070427215100262>.
- Wei F, Yu H, Zeng Z, Liu H, Wang Q, Wang J, et al. Preparation and structure characterization of hydroxylethylmethacrylate grafted natural rubber latex. *Polímeros Ciência e Tecnol* 2014;24:283–90. <https://doi.org/10.4322/polimeros.2014.068>.

Circular Ocean-bound Plastic

Breaking the waves of ocean plastic pollution
- From source to solution

www.circularoceanplastic.eu

The report is co-funded by:



Interreg
South Baltic



Co-funded by
the European Union



Interreg South Baltic
Circular Ocean-Bound Plastic
www.circularoceanplastic.eu