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Leading a more circular plastics value chain

RECOUP RECYCLABILITY CASE STUDIES
MRF PROCESSES - Understanding Material Sorting

February 2024

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About RECOUP

RECOUP is the UK's leading independent authority and trusted voice on plastics resource efficiency and recycling. As a registered charity, our work is supported by members who share our commitments including a more sustainable use of plastics, increased plastics recycling, improved environmental performance and meeting legislative requirements. We achieve these by leading, advising, challenging, educating and connecting the whole value chain to keep plastics in a circular system that protects the environment, underpinned by evidence and knowledge.

Our commitments

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More sustainable use of plastics

Meeting legislative requirements

Increased plastics recycling

Improved environmental performance

Connecting the whole value chain to keep plastics in a circular system that protects the environment, underpinned by evidence and knowledge.

Leading

Advising

Challenging

Educating

Our work

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Contents

Introduction

As the general public becomes increasingly concerned about their environmental impact, the importance of recycling has never been more apparent. This case study aims to illustrate the intricate processes which make up the recycling chain, from the initial disposal of plastic packaging to the baled materials destined to be recycled into new products.

The recycling chain is a complex, five stage process beginning with the responsible disposal of recyclable materials. This stage involves the collection of waste materials from kerbside collections. The collected co-mingled recyclables are transported to a materials recovery facility, where the process of recycling can begin.

At the materials recovery facility (MRF), the recyclable materials undergo a rigorous sorting process. This is a critical stage in the recycling chain, as it ensures that the materials are correctly separated into their material fractions ready to be recycled. The materials recovery facility is equipped with advanced machinery including disc screens, near infrared spectrometers, and air jets, which aid in the efficient sorting of the materials.

One of the crucial components of the sorting process is the use of near infrared spectroscopy, which is used to identify and sort packaging materials based on their material composition. Near infrared (NIR) works by analysing the infrared light reflected by the recyclable materials, this allows for the accurate identification of different types of plastics and other materials being processed at the site.

Following the sorting process the materials are baled and transported to recyclers and reprocessors. This involves treating and processing the materials into flakes, and then finally pellets, transforming them into a form that can be used to manufacture new products. This final stage of the recycling chain closes the loop, allowing for the reclaimed materials to be given a new life as a new product or package.

This case study provides a detailed examination of how plastic packaging travels through each stage of the recycling chain, with a particular emphasis on the processes within the materials recovery facility. The case study will show how packaging is seen by near infrared spectrometers and how the design of packaging can affect the sortability of different packs, looking at details such as material choice, labelling, multi-component construction and colour.

By developing an understanding of these processes, we can better appreciate the complexities involved in the recycling chain and the importance of designing packaging in such a way that it can be successfully captured in the sorting process.

The scope of this case study is limited to the systems in operation in United Kingdom based materials recovery facilities and the equipment and specifications used. In the UK materials collected for recycling differ from those collected in Europe and other countries, the analysis presented refers to the infrastructure in general use within the UK only. The study will also focus on plastic packaging, particularly the main target materials of high-density polyethylene, polyethylene terephthalate, and polypropylene.

The recycling chain

There are five stages in the recycling chain, and if a piece of packaging is to be recycled it must be able to pass through each of the five stages. If a piece of packaging fails at any stage, it will not complete the recycling cycle and the chain will be broken.

- **Disposal**: Consistent messaging is essential to ensure consumers know how to dispose of packaging.
- **Collection**: The packaging is collected kerbside by local authorities.
- **Sorting**: The collected packaging is then sorted at a materials recovery facility into different recycling fractions and baled for distributed to reprocessors.
- **Reprocessing**: The baled materials are then reprocessed and are pelletised ready for manufacturing of new products.
- **Recycling**: The pellets are used by manufacturers to create new products or packaging depending on the grade of the recycled pellets.

The Materials Recovery Facility Sequence

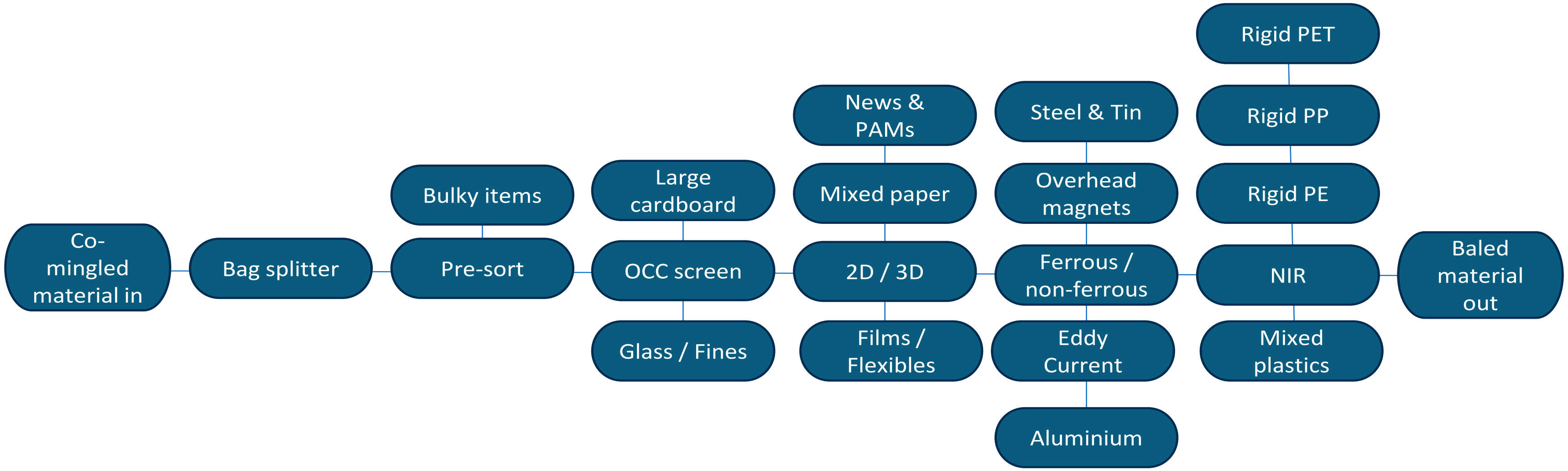

Figure 1: the stages and outputs of the sorting sequence.

The co-mingled recyclable packaging is collected kerbside by local authorities and transported to a materials recovery facility (MRF) for sorting. The MRF employs a number of mechanical and manual applications to sort the material into fractions for recycling.

The processes are illustrated in the image above, from point of entry, right through multiple sorting stations, to the final baled material leaving the site.

Here in the United Kingdom, the dry mixed recycling collected differs for each local authority. The main dry mixed recyclable fractions collected can include:

- paper and cardboard
- glass
- aluminium and steel
- plastics

Figure 2: delivery of dry mixed recycling.

The route of plastics

Figure 3: the route of plastics through the materials recovery facility.

Bag splitter

The first stage of the sorting process begins in the entrance hall, here the dry mixed recycling is delivered via refuse collection vehicles or transported from transfer stations.

The materials are loaded into a bag splitter, a large device which shreds any refuse sacks, without damaging any of the recyclables held inside.

The bag splitter also serves as a input management system, by regulating the rate at which materials enter the sorting process, to avoid the system becoming overloaded.

Pre-sort

During the pre-sort stage the materials entering the process are manually screened by negative pickers (negative picking is the process of removing unwanted materials from the stream). Waste materials, bulky, large, or electrical products, including batteries, are handpicked and segregated into the correct waste stream.

The pre-sort process helps to improve the effectiveness of the sorting equipment and also helps to prevent damage from incorrectly disposed items. It is not uncommon for pickers to remove wheel hubs from cars from streams which could cause damage to the screening equipment. Carelessly disposed batteries and electrical equipment, particularly containing lithium batteries have been blamed for costing the waste management industry £100 million a year in fire damages.

Glass breaker / fines

Figure 4: inside of a disc screen where materials are sorted for size, items smaller than 40 mm^2 fall between the oscilating discs.

The first automated stage in the sorting process is the size sort, here the material passes over a series of mechanical discs, called the OCC screen (old corrugated cardboard). Larger packaging items such as large brown cardboard boxes pass over the screen, while smaller items such as glass bottles, tins, and other rigid packaging fall through to another disc screen below.

Here at the second disc screen the glass packaging is smashed, and the glass pieces fall through onto the fines lines below. Larger rigid packaging passes over the osciliating disc screen and is carried over into the 2D and 3D packaging sorting process.

The initial size sort removes any small debris and contamination such as food waste through a series of openings which are between 40 - 50 mm^2, typically any items that are smaller than 40 - 50 mm in two dimensions will also be lost through the fines screen with the glass fragments.

This means that many small items such as bottle caps, toothbrushes, make-up packaging, batteries, coffee pods, and even disposable vapes are usually lost through the fines screen. This material then contaminates the glass stream, as can be seen in the image below, which was captured in the glass bunker at a material recovery facility.

In an earlier RECOUP report, it was estimated that a MRF collects 247 tons of fines including glass each month, of which around 70% is made up of glass fragments[1]. This means that there are 74 tons of mixed material fines collected on average at a MRF each month.

[1]https://www.recoup.org/wp-content/uploads/2023/09/recycling-of-small-plastic-items-1592562901.pdf

Figure 5: a selection of fines captured in the glass bunker at a materials recovery facility.

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The trouble with small items

In the materials recovery facility glass bunker it is common to find a wide variety of fines or residues mixed in with the glass. A lot of these items could be recycled via other means, while others are attachments which were became detached from the main packaging during transport or through the glass breaker phase.

Blister packs are one of the commonly found items in the fines bunker, usually constructed of mixed materials such as plastic with metalised foil.

Blister packs can vary in size but the small pile shown in the image was found to have a variety of sizes from 25 x 25 mm, to 100 x 65 mm in size.

Figure 8: used pharmaceutical blister packs.

Disposable lighters are typically around 80 mm long and 25 mm wide. This means that they are almost certain to fall through the glass breaker and into fines.

The nature of lighters containing flammable liquids means that they can pose a fire risk when disposed of incorrectly, such as through kerbside collections as they may be damaged suring compaction, and a spark may cause the fuel inside to ignite.

Figure 6: lighters collected from a fines bunker.

Bottle caps and other small attachments are too small to pass through fines sorting.

Guidance is always to keep caps on, so that they are captured with the container. The caps are then removed during the recycling process through density separation.

Figure 9: selection of small caps and closures.

Disposable vapes are often found in the fines bunker where consumers mistakenly believe that they are recyclable due to the polymer construction.

In fact, it is dangerous to dispose of vapes in general waste or kerbside recycling because they contain batteries which may cause a fire if damaged during the recycling process.

Figure 7: disposable vapes.

Toothbrushes are often found in the fines bunker. Despite their length their thin profile means that they are destined for the fines bunker if they are placed in kerbside recycling.

Recently bamboo and wooden toothbrushes have advertised their sustainable credentials, however they are still likely to contain plastics and are destined for residual waste.

Figure 10: variety of toothbrushes found in fines.

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Trommel

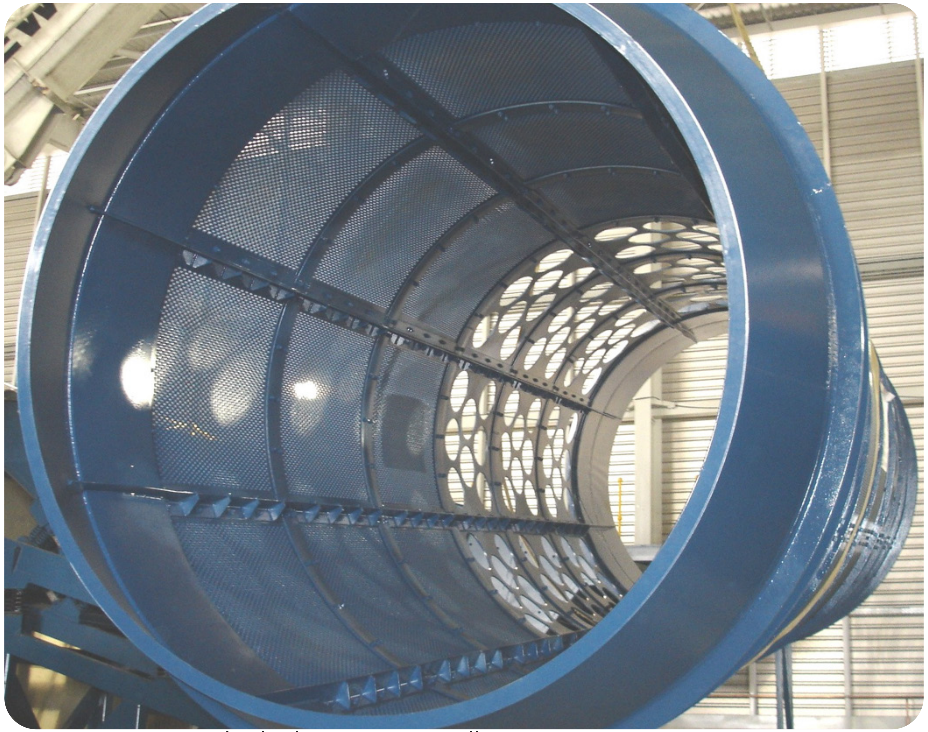

Figure 11: a trommel cylinder prior to installation.

In many MRFs currently the OCC or disc screens are commonly used for size sorting. However, in Europe and some MRFs in the UK, the trommel is used to separate materials by size.

The trommel, sometimes also known as a rotary screen, is a mechanical screen used to sort materials by size. Similar to the OCC screen it uses movements to agitate the materials through the sorting process and consists of a cylindrical drum which is normally elevated at the feed end. The size separation is facilitated as the material feeds down the trommel as the rotating drum spirals, the sides of the drum are perforated with a series of increasingly larger holes, with the finest holes near the feed end. As material feeds down the smallest objects fall through the perforations into the fines fraction along with any glass fragments, while the larger packaging continues further down the cylinder and any oversized items exit from the base of the drum.

2D / 3D
News screens and ballistic separators

Ballistic separators are widely used in Europe to separate the 2D and 3D materials at the MRF. They use a series of long paddles that undulate alternately, and this motion causes the flat 2D materials and the 3D packaging to move in opposite directions. Ballistic separators are sensitive to the proportion of materials that are fed onto them. For the most efficient operation they require a higher proportion of rigid materials over 2D materials. A proportion over 50% of 2D materials would likely decrease the efficiency and cause some of the 3D packages to be carried into the 2D lines.

News screens work in a similar way, except the motion of the materials is created by a series or rotating disks, which moves the 2D items up the screen, while heavier 3D items are tumbled down.

A benefit of ballistic separators over news screens is the lack of rotating shafts and discs. This means that there are no rotating parts for films to get caught up on, enabling the sorting of films without the frequent downtime caused by blockages and tangled films and flexible packaging.

Figure 12: mixed materials being agitated on a news screen.

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Near infrared detection

Near infrared or NIR detection is the standard technology used by MRFs to detect materials during sorting. NIR operates by using the absorbance signatures of infrared wavelengths reflected from packaging as it travels on the sorting line.

In MRFs the infrared units are positioned high above the lines, with a clear unobstructed view of the materials below. After the materials have been filtered through the stages of the sorting process, only rigid plastic packaging should remain for sorting.

Each NIR station may be adjusted to target a specific polymer type, or a range of mixed polymers. The NIR unit scans each piece of packaging as it speeds along the belt and compares the infrared signature to a control standard for the polymer that is being targeted by that particular NIR unit.

In addition, the NIR units will sort based on the purity and uncertainty that a pack is of a certain target polymer. As a pack passes through the NIR detection point the detector reads a point on the pack, known as a pixel. The signature recorded from the pixel is analysed by the detector unit and compared to the reference spectra being targeted.

When an NIR is targeting a specific polymer, it does not matter if it sees any other polymers, in fact it won't, the system will only register an identification when it sees the polymer that the unit is targeting, this means that non-target materials should not be captured and contaminate the stream.

This ability to single mindedly target only the desirable material signatures, and the speed at which an identification can be made, makes NIR the ideal technology to be used in sorting. A further advantage of NIR detection is that it is non-destructive and is able to identify a wide range of materials with no preparation required.

NIR is not without a handful or flaws. NIR is not able to distinguish colour, by the nature of the infrared spectrum, the infrared wavelengths sit outside the visible spectrum, meaning that there are no colours visible to the NIR. NIR is also unable to detect dark or black plastics. These materials by their nature do not reflect well, and as NIR is reliant on good reflectance. If colour separation is required, this can be achieved with the addition of visible spectroscopy, an RGB camera or some other AI detection equipment in addition to the NIR.

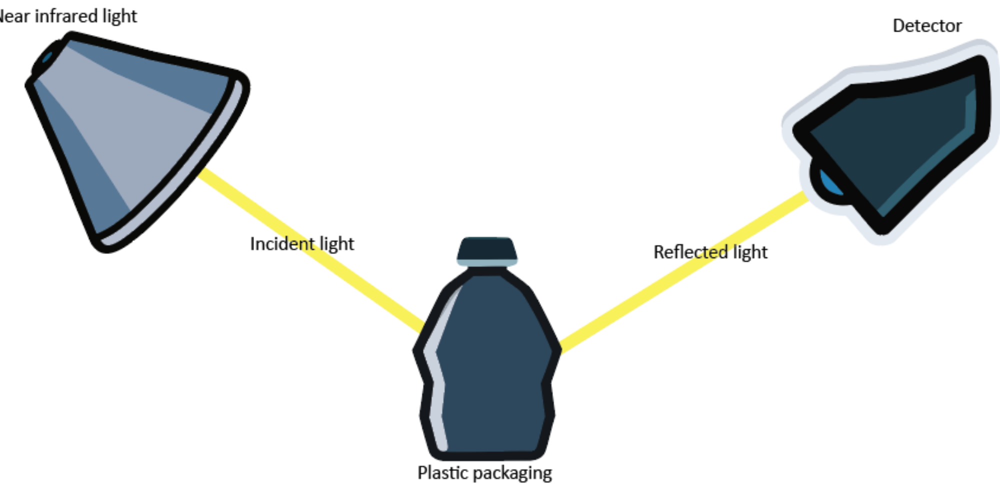
Figure 13: The latest generation TOMRA AUTOSORT™ in action.

NIR detection - how does it work?

1. The near infrared light source is positioned high above the moving belt, providing a clear and unobstructed view of the materials passing below.

2. The packaging moves along the belts at high speed and is irradiated with infrared energy from the infrared unit above.

3. This light is called incident light, and some of the energy is absorbed by the packaging, with the rest being reflected.



4. Near infrared light is reflected from the sample towards a detector, which reads the intensity of the reflected incident light.

5. The signature of the reflected light is unique to the material of the packaging, enabling the packaging to be separated by polymer type.

6. The identified packaging is then positively ejected by air jets and is able to be recycled.

Figure 14: interpretation of how infrared light is reflected and detected.

What can be detected by NIR

- Polyethylene (PE)
- Polypropylene (PP)
- Polyethylene terephthalate(PET)
- Paper

Limitations of NIR

- Extremely thin materials
- Black plastics
- Metalised surfaces
- Shiny materials
- Glass
- Aluminium
- Steel

Near infrared detection is a form of vibrational spectroscopy and is a non-destructive procedure, meaning that packaging does not need any preparation to use it.

Materials are comprised of different chemical compounds, and vibrational spectroscopy measures the vibrational energy in the material. Each chemical bond within a material corresponds to a unique wavelength of infrared energy, which is as distinctive as a fingerprint.

As the material is irradiated with energy, the molecule enters an excited state and will stretch or vibrate, which absorbs the energy on that particular wavelength. The remaining energy is reflected and detected by the infrared sensors, which then calculates the absorbed energy to generate a spectrum.

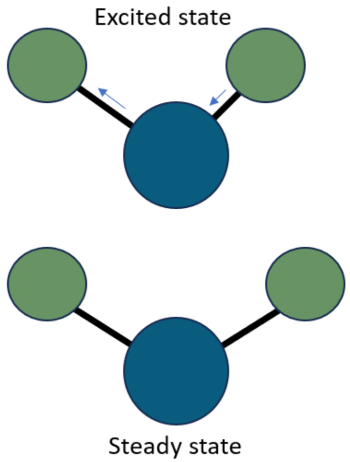


Figure 15: a molecule stretching in excited state compared to steady state.

Using the spectrum, it is then possible to determine which material has been scanned based on the interactions of the molecules and the infrared energy.

Understanding colour maps

A colour map shows how a package is seen by the near infrared systems at the materials recovery facility. Near infrared technology uses the wavelength of infrared light reflected from the material surface to distinguish between different material and polymer types.

Each material has a unique signature which may be represented as a specific colour on the colour map. For example, polyethylene terephthalate may be represented as blue in a colour map, while polypropylene may be shown as green, enabling the human eye to visualise how the materials are seen by the near infrared.

It is important to emphasise that near infrared cannot distinguish the colour of individual materials, near infrared does not visualise objects in the same way as the human eye, instead it interprets the reflected light as data and uses library standards to identify materials by matching the packaging spectra to known spectra stored in the database.

Key

- PET
- PE
- PP
- Mixed
- Low reflectance
- High reflectance

Figure 16: bottles shown in grey scale and colour mapped.

The images above show how an object would be seen by near infrared, the image on the left is in greyscale because there is no visible colour on the infrared wavelength of the electromagnetic spectrum. The image on the right is a false colour image created using the greyscale as a base.

Using the colours in the key provided, it is possible to indicate which material each of the components has been identified as. The colour map shows the bottle as PET (blue), with a PE cap (yellow). The label area shows as mixed (orange) because the near infrared penetrates the label and returns data from both materials.

Understanding near infrared spectra

The near infrared spectra use a graph format to visualise the data being received by the infrared detector. The graph shows the reflectance from 0-100% on the vertical axis. The horizontal axis is shown in pixels, each pixel corresponding to a specific wavelength on the infrared spectrum.

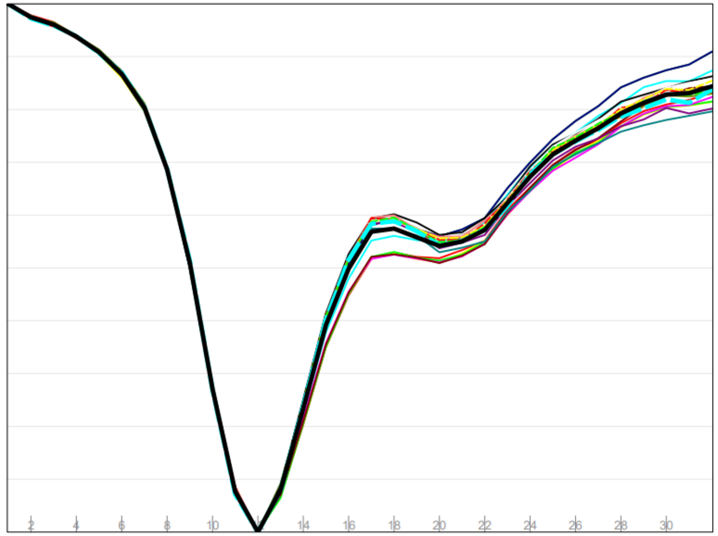


Figure 17: an example near infrared spectra.

Using near infrared spectra it is possible to identify material types based on where the spectra contact the horizontal axis. This indicates the point at which the highest absorbance of infrared energy occurred.

In the spectra shown above the contact point on the horizontal axis happens at 12 pixels. This is consistent with a match of polyethylene terephthalate (PET). In this instance there is a slight dip again where the absorbance increases around 20 pixels. This means that there may potentially have been a thin polyethylene label or as happened in this case a thin polyethylene barrier layer on a clear PET tray.

The contact points for different materials are:

- 12/13 pixels = PET
- 18/19 pixels = PP
- 20/21 pixels = PE

NIR detection - Clear PET bottles

Key

- PET
- PE
- PP
- Mixed
- Low reflectance
- High reflectance

Figure 18: colour map showing a PET bottle and label (top) and how the pack is seen through NIR spectroscopy.

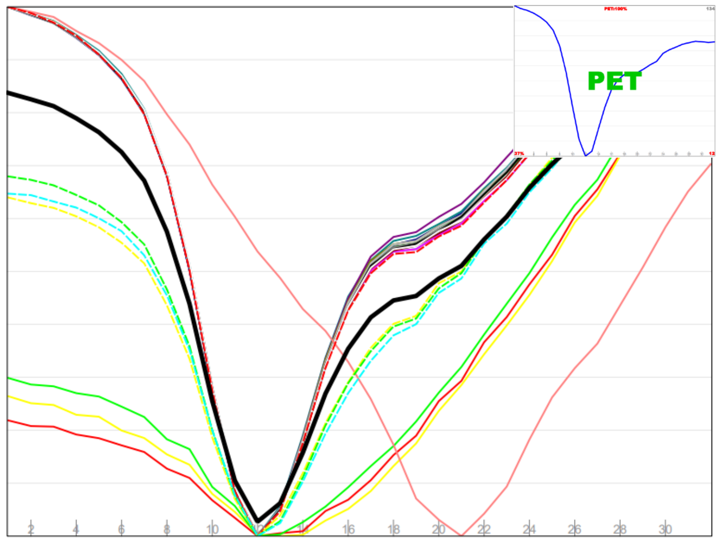


Figure 19: near infrared spectra taken from the PET bottle and label, with reference spectra inserted.

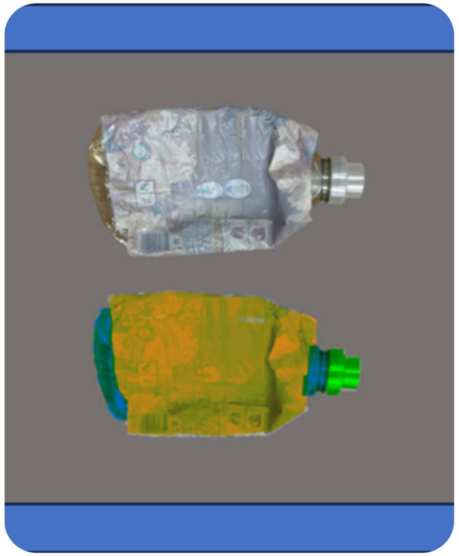
The image above shows a clear PET plastic bottle, with a PP label covering around 50% of the bottle surface. The colour map illustrates how the materials are being detected as the bottle is scanned by an NIR spectrometer on the MRF sorting line.

The cap is shown in yellow (which is not clear due to the green colour of the cap in the image), the bottle is shown in blue, where the PET material is visible at the top and bottom of the bottle. The label covered area in the middle of the bottle shows as orange, this is where the label interferes with the material identification by the NIR, which is shown and described in the image on the right.

The image above shows the NIR spectra collected from the clear PET bottle. The average scan is shown as a black line and indicates a strong absorption peak at 12 pixels on the baseline. This indicates where the PET was detected. There is also a peak around 21 pixels on the baseline, which is an outlier from where the cap material was detected.

The average spectra shown in black when compared to the reference spectra for PET (inset) shows that there is a strong match to the scanned bottle and the reference spectra, this means that there is a strong probability that the clear PET bottle will be captured as clear PET during MRF sorting.

NIR detection - Full sleeves



Key

- PET
- PE
- PP
- Mixed
- Low reflectance
- High reflectance

Figure 20: colour map showing a full sleeved PET bottle (top) and how the pack is seen through NIR spectroscopy.

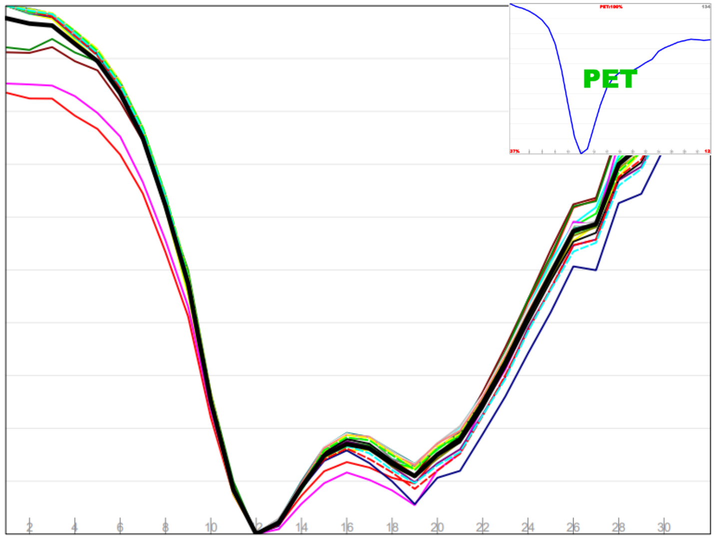


Figure 21: near infrared spectra collected from the full sleeved bottle, with reference spectra inserted.

The bottle pictured in the image above is a clear PET bottle, with a full PP sleeve and cap. The colour map illustrates how the materials are seen by an NIR spectrometer during the MRF sorting process.

The cap is shown in green, which indicates that it was seen as PP, while there is some blue visible at the neck and base of the bottle. The sleeve is shown in orange, which indicates that there was a mixed spectra detected which has properties of both the PET and PP spectra.

The NIR spectra shown above represents the NIR scans collected from the full sleeved PET bottle. The average spectra is shown as a black line and indicates that there was a strong absorption band at 12 pixels on the baseline, which would normally indicate PET. However, there is also a strong absorption band at 19 pixels at around 90%, which is consistent with a result for PP.

The two combined spectra mean that no definitive identification is possible as the spectra registers peaks consistent with both of the materials present. Because of the high levels of absorption of both of the materials, they are in conflict with one another and neither match the reference spectra for the target material, this means that it is highly unlikely that the pack will be captured for recycling in the correct stream.

NIR detection - HDPE bottles with triggers

Key

- PET
- PE
- PP
- Mixed
- Low reflectance
- High reflectance

Figure 22: colour map showing a HDPE full sleeved spray bottle (top) and how the pack is seen through NIR spectroscopy.

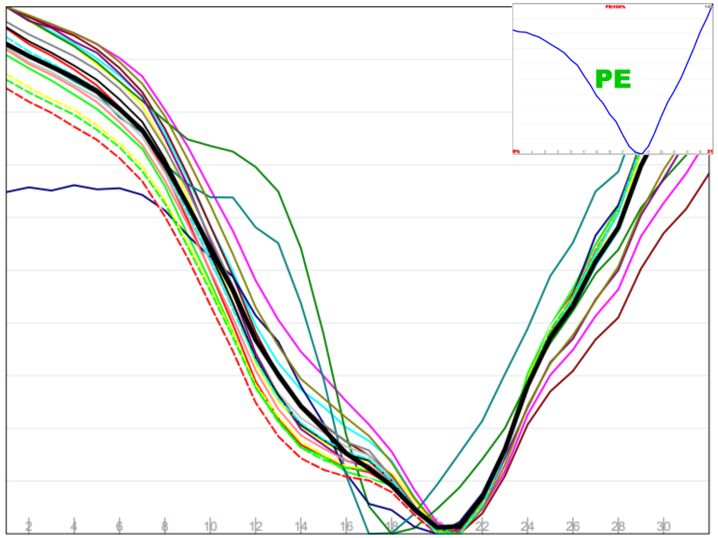


Figure 23: near infrared spectra showing the results collected from the HDPE full sleeved bottle, with reference spectra inserted.

The bottle pictured above is a white HDPE bottle, with a full polyolefin sleeve and a mixed PE/PP trigger. The colour map image illustrates the materials that are being detected as the pack is scanned using NIR spectroscopy.

The trigger is shown in green, showing that it has been seen as PP apart from the nozzle, which should be yellow, but this is hidden in the image by the nozzle colour.

The bottle is shown as yellow, where the bottle materials are seen through the sleeve and the sleeve materials do not adversely affect the detection.

The image above shows the scans from the bottle as it was scanned using the NIR spectrometer. The average scan is shown in black and indicates that there is a strong peak at 21 pixels.

This indicates where the PE was detected. There is also a peak around 18 pixels, which is where the PP was detected from the trigger. The two peaks do not conflict with each other because the average spectra closely resemble the reference spectra (inset), meaning that a positive identification as PE is possible and the bottle can be captured by the NIR sorting process.

NIR detection - Dark colours

Key

- PET
- PE
- PP
- Mixed
- Low reflectance
- High reflectance

Figure 24: colour map showing a dark pack (top) and how the pack is seen through NIR spectroscopy.

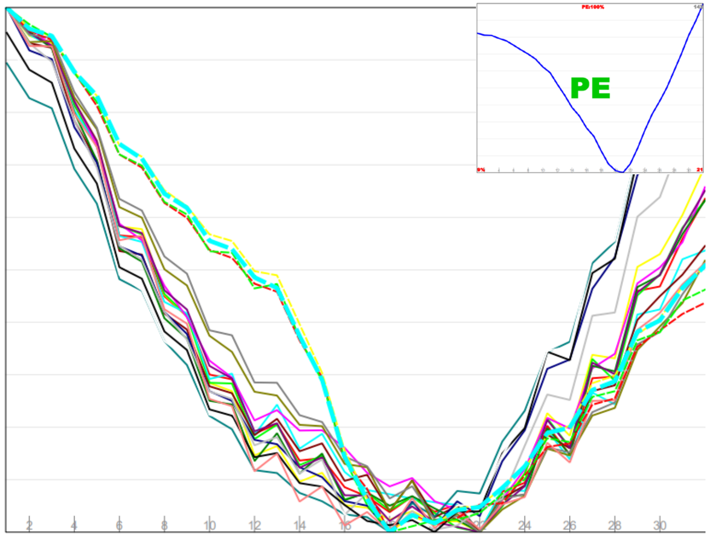


Figure 25: near infrared spectra showing how dark materials affect the reflectance of the infrared light, with reference spectra inserted.

The bottle pictured above is a detectable black HDPE bottle with a PP label. The colour map should show the polymer being detected through NIR spectroscopy.

The colour map is black because there is insufficient reflection being emitted by the dark plastic.

One of the weaknesses of NIR spectroscopy is the reliance on reflected infrared radiation. Often black or dark plastics contain carbon black, which absorbs highly on the infrared spectrum making an identification nearly impossible in all applications using carbon black.

Even in dark plastics where carbon black is not used, the nature of dark colours offering reduced reflectance and absorbing heavier levels of infrared will mean that an identification is more difficult when compared to lighter coloured or clear/ natural polymers.

The image above shows the scans from the bottle as it was scanned using the NIR spectrometer. The average scan is shown in black and indicates that there are no consistent peaks being registered.

The wavy nature of the spectra shows that there is a lot of noise, and the peaks are registering from 16 to 22 pixels.

This means that there is not enough consistent data to enable an identification through NIR sorting as the spectra do not match the reference spectra for PE (inset), or any other polymer, so the pack would be rejected.

Conclusion

This document set out to highlight some of the key commitments RECOUP supports along with our members, such as our commitment to lead, advise, challenge, and educate stakeholders in the plastics and packaging industry about the importance of design for recyclability and the sustainable use of plastics in packaging.

Plastics were introduced to improve sustainability and they have become vital materials for everyday life. Without plastics many of the things we take for granted wouldn't be possible, from life saving medical devices, to transport and electonics, almost every aspect of our lives is impacted by plastics in some way. Plastic packaging is used to contain, protect, transport, and communicate. It has many unique properties, that cannot be replicated by other materials, leading to numerous green washing claims due to hidden plastic content in new sustainable packaging switches.

Plastic packaging has become a polarising topic across multiple facets of every day life. It is hard to find someone who doesn't have a strong opinion about plastics, whether it is from a positive or negative perspective. Plastic has become the go to material for companies, environmentalists, and the media to collectively deride in favour of supposedly more sustainable materials, some of which have questionable sustainability credentials in their own right.

One key example being the switch from plastic milk bottles to cartons. The UK is unique in that it is the only country across the European markets that uses high density polyethylene for milk bottles. Across Europe it is common to find milk sold in cartons. In the UK, HDPE milk bottles are considered a food grade material, widely collected and sorted across all of the local authorities for recycling back into milk bottles. In the UK the same cannot be said about cartons. The multi-layer laminated construction of cartons makes them difficult to recycle, with the materials not being used to make new cartons, unlike the HDPE milk bottles.

The recycling chain is crucial in ensuring that any packaging placed on the market is able to find its way into the hands of dedicated recyclers, who are able to reprocess the material so that it can be recycled and placed back on the market. Design plays an important part in the recycling chain, if a pack is not designed to be easily sorted and recycled, the chain will be broken, and the valuable materials lost to landfill or incinceration.

Designing for recyclability has become a focus for many companies across the world, some of the design features have been well received, while some have struggled to capture the enthusiasm of consumers. An example being tethered caps for drinks bottles, an important design choice that should stop small plastics such as caps and closures from being lost into fines and residual waste during the sorting process.

A key piece of technology used for the sorting of plastic packaging is near infrared spectroscopy. Able to make near instantaneous identifications of materials, it is able to sort high volumes of materials quickly and accurately. However, it is not infallible and does have some weaknesses, as have been pointed out in this document. NIR is not able to detect black, extremely thin, or shiny plastics. It also struggles to identify mixed or multiple components in packaging formats.

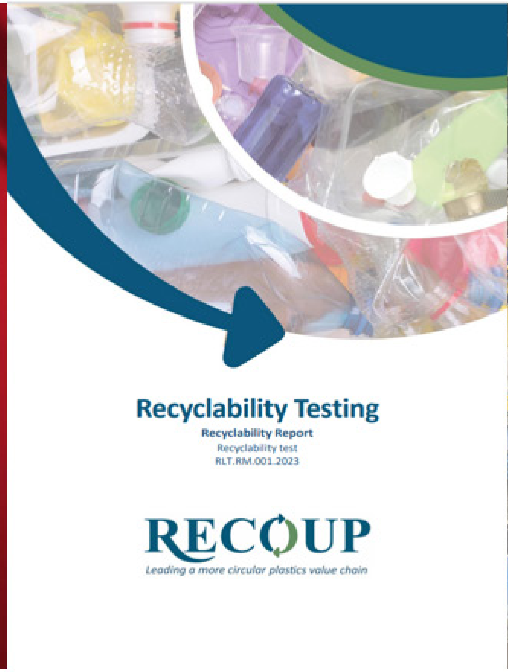
From the colour maps presented in this document we have seen how design choices can affect how a pack is seen by NIR detectors, or in some case how it is not seen (page 19). Packaging designers play a key role in determining whether packs are recyclable, or not. By placing the emphasis on design for recycling and following guidelines set out to optimise sorting potential, designers have the ability to increase rescycling rates across all packing formats.

Citizen messaging is another key factor in the recycling chain that is often overlooked. Confusion about what can be recycled and in which bin is often amongst the comments on consumer recycling surveys. By ensuring that the messaging on packaging is clear, consistent, and easy to understand, consumers can know with confidence that their packaging is going to be recycled, which means that more recyclable materials will find their way into the recycling chain. Combined with recyclable design principles packaging has a better chance of making it through to recyclers and having a second life.

How can RECOUP help?

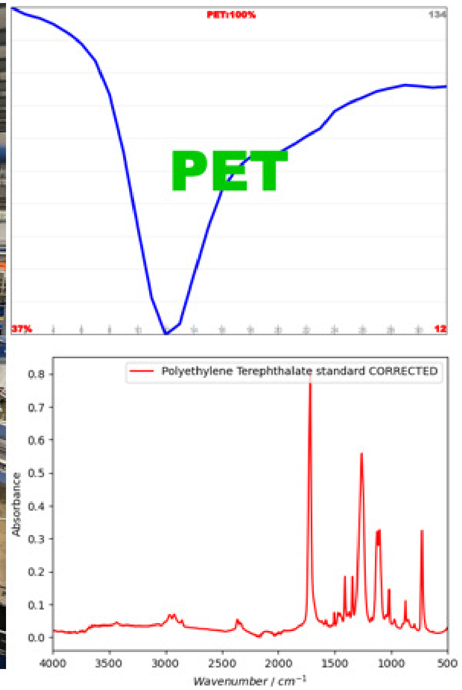
RECOUP Recyclability Testing Services

Guidelines



Recyclability Reports

Sorting Trials



Laboratory Analysis

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