NIR DETECTABILITY OF PLASTIC PACKAGING

A study to define NIR detectability for use in design guidelines

Research date: **January – May 2019**

Publication Date: **December 2019**

Project code: **PMP010-011**

About WRAP

WRAP is not-for-profit, working with governments, businesses and citizens to create a world in which we use resources sustainably. Our experts generate the evidence-based solutions we need to protect the environment, build stronger economies and support more sustainable societies. Our impact spans the entire life-cycle of the food we eat, the clothes we wear and the products we buy, from production to consumption and beyond.

This document provides the supporting evidence and analysis for defining Near Infrared (NIR) detectability of household packaging.

Document reference:
(please use this reference when citing WRAP's work):
[WRAP, 2019, Banbury, NIR Detectability of Packaging, Prepared by Axion]

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Front cover photography: PET thermoformed packaging with different pigments

Executive summary

A study has been carried out to define NIR detectability for household packaging based on desk-based studies and practical trials.

For packaging to be classed as recyclable, it must have the ability to be collected and sorted before being sold on to a reprocessor.

Sorting is carried out in Material Recovery Facilities (MRFs) into which packaging and other household recyclables are fed. The plastic packaging is then separated using Near Infrared (NIR) sorting technology; this uses infrared light to analyse the packaging at high speeds, detecting and ultimately separating the different polymers.

NIR is a very well-established technology and used by virtually all UK MRFs to sort packaging into different polymer fractions. In order for an item of packaging to be recycled, it must be identifiable using NIR technology. Otherwise, the packaging will be treated as residue and burnt in Energy from Waste plants or landfilled.

To provide guidance on the design of packaging, WRAP has commissioned this project to define NIR detectability, and determine what may prevent packaging from being detected.

The project has been carried out in two phases:

- Phase 1: A desk-based study focused on reviewing previous projects and holding interviews with the manufacturers of NIR sorting equipment, pigment suppliers and packaging converters; and,
- Phase 2: Practical trials to assess the feedback from the supply chain and provide evidence on what affects NIR detectability.

Four of the largest NIR machine manufacturers in Europe were interviewed with regards to NIR detectability of packaging. The main points raised prior to conducting the trials were:

- Detectability of packaging is only one element which leads to successful sorting. The way in which the NIR signal is interpreted and how the sorting facility is set up is also very important.
- The carbon black pigment can prevent detection, however there is thought to be an allowable limit. The limit was estimated to be between 2,000 ppm and 5,000 ppm, little testing had been undertaken to confirm this.
- Metallised packaging can distort the signal if the metallisation is on the outside. There is a question over whether metallisation on the inside may also distort the signal.
- NIR can see through thin sleeve material, even if a full body sleeve is used. The exact thickness hasn’t been stated, but is likely to be less than 0.05 mm.
- The age of the equipment should not be an issue, providing software is updated and the systems are regularly maintained in line with the manufacturer’s guidance.

Interviews were also held with a pigment supplier and converter. The pigment supplier confirmed the issue is with carbon black. Non-carbon black alternatives are more costly, and in some cases the pigment is less stable, which could lead to migration into food. Care must be taken to ensure any alternative pigment is shown to be food safe through migration testing.

The converter expressed that carbon black is the only suitable pigment that can completely mask a range of other colours. This allows for the use of mixed colour recyclate

from coloured PET bottles, while maintaining a uniformed output. Alternative pigments do not mask as well as carbon black, therefore the customer will have to accept a variable finish.

Using the feedback, an initial set of guidelines were drafted. This initial hypothesis on detectability was used to carry out a number of tests. A wide range of packaging was obtained for the testing, and can be grouped into the following categories:

- PET bottles with full body sleeves;
- PET thermoforms with different pigments, including colours with varying levels of carbon black and detectable black; and,
- PP injection moulded lids of different colours and control samples of PP with varying carbon black content.

Four different tests were carried out on the samples:

- Benchtop NIR tests: Axion Polymers uses an IOSYS SIRoGran for quality control purposes - a basic NIR analysis unit that was used as an initial assessment tool for the packaging samples;
- Machine manufacturer tests: Axion supplied samples to three of the four major NIR manufacturers for their feedback on whether a signal could be seen and how the packaging would be sorted;
- Static tests in two commercial sorting facilities: Samples were tested in a Plastics Recovery Facility (PRF) and PET recycling facility using their existing sorting programmes; and,
- Field test in a commercial sorting facility: A larger scale trial was carried out in the PRF to determine how the plant sorted the various samples in practice.

The results have been grouped into the following categories:

- Bottles with full body sleeves: Tests with the IOSYS and machine manufacturers showed that HDPE bottles with a PET full body sleeve can be detected without issue. For PET, no samples of bottles with a non-PET sleeve were identified. The PET bottle with a PET sleeve was identified as clear PET or coloured PET depending on the level of printing.
- PET in static tests: Tests on various colours of PET thermoforms showed that there was a variation in the ability of NIR machine manufacturers to identify samples with carbon black content. All manufactures were able to identify samples with up to 750 ppm carbon black. One manufacturer was able to identify a sample with 1800 ppm carbon black after optimisation of the settings.

  Static tests were also carried out in a PRF and PET recycler with the same results. However, one sample (a non-pigmented cPET tray) was unable to be identified from the inside at the PET recycler but was identified from the outside.
- PET in field tests: The field test showed that the setup of the process is very important. Interestingly, the coloured trays were identified as clear PET by one NIR in the process but not another, causing material to build up, re-entering the recycling loop.
- Coloured PP in static tests: PP with 1000 ppm carbon black was not able to be detected. Samples with lower levels of carbon black could be detected by an NIR machine manufacturer, but not in the lab using the IOSYS.

The results of the testing have enabled the guidance to be refined and is presented in Table 1.

Table 1 Finalised guidance

Property	Acceptable	Unacceptable
Colour	Any non-carbon black based pigment or masterbatch	>0 ppm carbon black masterbatch
Surface finish	Any matt or gloss finish	Metallised surface on the outside of the pack
Labels (PET bottles)	<60% coverage of packaging. Label to be made of material with density <1g/cm	PVC full body sleeve. Any sleeve >0.05mm thick
Labels (HDPE bottles)	Up to 100% coverage of any non-PVC polymer <0.05mm thick	>70% coverage of a label thicker than 0.05mm OR any size PVC sleeve

Regular testing would not be required providing the guidelines are adhered to. If further testing is needed over a questionable new product, for example one with a thick coating or with levels of carbon black greater than 750 ppm, it is recommended that it is tested and validated by two different NIR machine manufacturers.

The use of lab equipment may be suitable; however, the quality of detection may be lower or higher than that used by the machine manufacturers. If it can be shown that the laboratory equipment is consistent with the results of at least two NIR machine manufacturers, then it can be considered a viable alternative.

It can be concluded that NIR detectability is only one aspect of whether or not an item is recovered to the correct product stream. It is advised that WRAP undertakes work to fully map and understand the sorting infrastructure in the UK and how each material is handled.

Contents

Glossary

HDPE	High Density Polyethylene
MRF	Materials Recovery Facility
NIR	Near Infrared
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PPM	Parts Per Million
PRF	Plastics Recovery Facility

Tables and figures

Acknowledgements

Axion would like to acknowledge the support provided by the NIR equipment manufacturers Pellenc, Redwave, Steinert and TOMRA; BASF for providing feedback on pigments; Britvic, FAERCH and Quinn Packaging for providing samples; and Viridor for the use of its facilities for testing.

1.0 Introduction

In order for plastic packaging to be considered "recyclable" it is vital that the item of packaging is collected from the householder and then sorted into a product which is then reprocessed into a secondary raw material.

In the UK, packaging waste is predominately collected at the kerbside. Materials are often mixed together, and so the collected dry recycling is sorted using a Materials Recovery Facility (MRF). The purpose of the MRF is to take the mixed recycling and sort it into a product that can be sold. These products must typically be of a single material, and in the case of plastic packaging must be a single polymer type.

Sorting of polymer types is carried out using Near Infrared (NIR) technology. NIR works by shining infrared light onto the packaging while it is moving at a high speed. Different polymers absorb and reflect different wavelengths of light, due to their molecular chemistry. The reflected light is analysed by the NIR sorter, and algorithms are used to determine which polymer the packaging is made from.

Using this information, the NIR sorter will then either eject the item of packaging using an air jet or leave the packaging to fall under gravity. By ejecting material, it is separated into a different stream.

For this system to work, the packaging must be detectable using NIR. If the packaging reflects very weakly, or the signal is distorted, then the NIR sorter cannot determine the polymer type and thus cannot sort the material effectively.

There are some known issues with the detection of some kinds of packaging, such as that which uses a pigment containing carbon black. WRAP has therefore commissioned this project to establish guidance for NIR detectability based on quantitative tests.

Some of the known issues which can prevent the detection and identification of packaging include:

- The colour of the packaging: It is known that carbon black pigment absorbs a wide spectrum of light, including near infrared. This prevents a signal from being reflected by the packaging; therefore, there is no reflected light to analyse, making the polymer undetectable.
- The surface finish: A metallised surface can reflect too much light which prevents detection.
- Full body sleeves: It is believed that if there is not complete penetration of the packaging using NIR, only the polymer on the surface will be identified. This could be a problem with packaging that has a different sleeve material to the body of the pack, as the NIR may only identify the polymer that the label is made of. This would lead to either loss of material or an increase in contamination. For example, a PET bottle with a PP sleeve may be sorted to the PP stream. Not only is the PET bottle lost, but it also contaminates the PP stream.

2.0 Methodology

This project focuses on addressing the issue of NIR detectability. Whether a pack is NIR detectable is only one aspect of the recycling process, if an item of packaging is not detectable using NIR then it cannot be sorted. However, it may also be the case that an item is detectable and gives a signal to the NIR unit, but the sorting algorithm incorrectly characterises the material, leading to incorrect sorting. In addition, factors such as the shape and size of packaging will have an impact on the efficacy of the NIR machine to eject the packaging using air.

The project has been completed in two phases:

- Phase 1: Interviews with manufacturers of NIR equipment; and,
- Phase 2: Practical assessment of packaging at test centres and commercial sorting facilities.

The interviews were carried out with four of the largest suppliers of NIR sorting equipment in Europe. It is estimated they account for more than 80% of the market for UK installed machinery.

In addition to the NIR suppliers, interviews were held with a pigment supplier and PET thermoformer.

After the initial conversations, a hypothesis on NIR detectability was reached (see 3.4). This was then tested in Phase 2 of the project by carrying out practical trials.

For the second phase of the project, several packaging samples were obtained and tested in three ways:

1. A bench-top laboratory NIR spectrometer;
2. In the test centre of the three major NIR equipment manufacturers; and,
3. In an advanced Plastics Recovery Facility (PRF) and a PET bottle recycling facility.

3.0 Phase 1: Feedback from stakeholders

3.1 Feedback from NIR manufactures

Axion interviewed the following manufacturers of NIR sorting equipment, who cover the majority of UK infrastructure:

- Pellenc ST;
- REDWAVE;
- Steinert; and,
- TOMRA.

Nine questions were compiled by Axion and asked to each of the NIR sorting equipment manufacturers. These questions were aimed at understanding how each manufacturer defines NIR detectability. Similar responses to the questions were given by each of manufacturers – these are summarised below:

1. What has Pellenc/REDWAVE/Steinert/TOMRA done to understand NIR detectability?

   Each equipment manufacturer has built up an understanding of NIR detectability by regularly performing detectability trials at their facilities. These trials may be for internal research and development projects or for external clients, such as brand owners and packaging manufacturers.

2. Is an item either detectable or undetectable, or is detectability a spectrum? If detectability is a spectrum, how do weak signals affect the material separation?

   NIR detectability is a spectrum and the strength of signal can determine whether an item is seen and whether it is correctly ejected or not. With some exceptions, most items are detectable; incorrect sorting is often a result of how the signal is processed and what this means for the sorting decision. Items with a weak signal may not be sorted correctly if the NIR machine has not been programmed to do so.

3. How does colour affect detectability?

   The colour of an item does not affect its ability to be detected. If carbon black is used as a pigment, then the ability of the NIR to detect the item may be compromised. Two manufacturers said that, in order to be detected, items should contain no carbon black content. Trials previously performed by one of the NIR equipment manufacturers led them to conclude that items with a carbon black content greater than 2,000 ppm were undetectable, while a different NIR equipment manufacturer stated that they could see items with up to 5,000 ppm carbon black during dynamic trials on their machine. Later discussions with Viridor, however, suggested that the detectability of an item containing carbon black may depend on the type of polymer.

4. How do packaging labels affect detectability? (Including full body sleeve, wrap around and self-adhesive.)

   The label material, label coverage and label thickness can all affect how an item is seen by the NIR machine. PE labels, which are often thin[1], can normally be seen through and therefore do not normally affect the separation. On the other hand, paper labels are often much thicker and so do not normally allow any material underneath to be detected. As such, generally labels do not affect the detectability of an item, they may however affect what an item is detected as.

5. How does the shape of an item affect detectability?

   The shape of an item does not affect the ability of the NIR machine to detect an object. It may however affect what the NIR machine sees. For example, if a PP/PET multi-material object is crushed, the object may be detected as being predominately PP or predominately PET – how this signal is interpreted may therefore cause the object to be processed into the wrong material stream. Again, this will depend on the programming.

6. How does an item's surface finish affect detectability?

   Very shiny finishes, such as metallised objects, will result in an undetectable object. These mirror-like finishes cause the intensity of the returned light to be too high.

7. Does the age of an installed NIR machine affect detectability?

   The age of an NIR machine may affect its performance in some cases. Newer machines may have better hardware or software which may improve performance. In most cases however, so long as an installed machine has been well maintained and its software updated, it should have sufficient capability to detect any detectable items of packaging.

8. How would Pellenc/REDWAVE/Steinert/TOMRA define detectability?

   Carbon black content and reflective surfaces (such as metallised objects) will affect the detectability of an object. So long as an object can be detected then the problem becomes how the signal is interpreted and whether an object should be ejected or not.

9. How could you test for detectability on a new item of packaging?

   All manufacturers perform both stat3.3ic and dynamic detectability trials.

3.2 Feedback from pigment suppliers

Axion held a meeting with BASF to discuss the use of detectable black pigments. BASF is a major supplier of pigments into the plastics industry.

[1] An exact thickness was not given, although a figure of 0.05 mm could be assumed

It was confirmed that carbon black was believed to be the issue with detectability. BASF understands that any level of carbon black is problematic for detection.

Carbon black is a popular choice not only because it is lower in cost than alternative pigments, but also because it has a strong masking ability. The opacity of carbon black means many other colours can be included into the polymer from a recycled source, and the resulting product would still maintain a uniform black appearance.

The alternative pigments to carbon black are all metal based. There are two potential issues with this:

1. A significantly higher cost; and,
2. The metal compounds are more mobile than carbon black within the polymer and present a potential issue with migration into food.

BASF commented that some of the lower cost alternative black pigments may not be food safe when subjected to rigorous testing.

3.3 Feedback from thermoformers

Axion interviewed two major thermoformers supplying black PET into the UK market:

- Quinn Packaging; and,
- Faerch.

Quinn Packaging has released a detectable black tray after testing was carried out in Ireland. During testing, it was found that the black tray reported to the coloured PET stream at the Materials Recovery Facility. Quinn Packaging provided samples for testing.

Faerch has a detectable black tray, and has released “Evolve by Faerch”, a “natural” cPET tray which contains no additional pigment, other than that already in the recycled PET.

Faerch stressed the ability for carbon black to mask other colours, and without it the customer will not receive a uniform colour. As alternative pigments are a high cost, the “natural” cPET tray provides an alternative for retailers that are fully detectable.

A wide range of samples were provided by Faerch for testing to validate the hypothesis.

3.4 Initial hypothesis

The feedback from the supply chain demonstrated that NIR detectability is only one issue when considering if an item of packaging can be sorted to the correct stream in a Materials Recovery Facility.

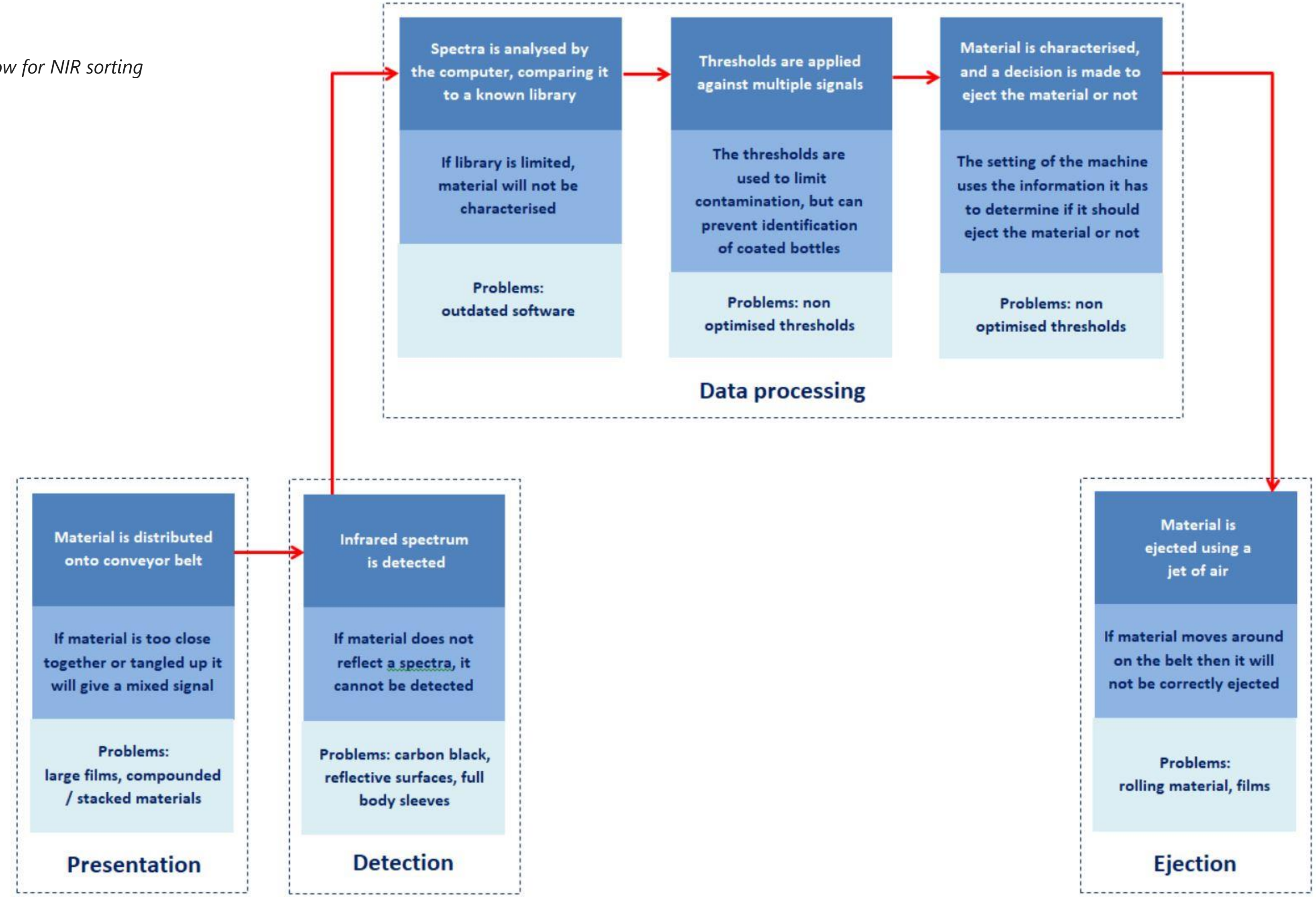
The ability to recover material using an NIR sorter depends on four factors:

1. The distribution of material on the NIR conveyor – “Presentation”;
2. The ability of the machine to detect the polymer – “Detection”;

3. The algorithm and thresholds used by each individual machine to determine what to eject – “Data processing”; and,
4. The ability of the machine to use that signal and effectively eject the material – “Ejection”.

Error! Reference source not found. shows how the NIR sorting process works for an item of p ackaging.

Figure 1. Process Flow for NIR sorting



The conversations with the supply chain were used to develop draft guidelines, presented in Table 2 below. These guidelines were only for detectability of packaging and are not general design guidance. This is the initial hypothesis developed from conversations with the supply chain and is not the final guidance. This was used to develop the tests conducted to determine NIR detectability.

Table 2 Draft guidelines

Property	Acceptable	Conditional	Unacceptable
Colour	Any non-carbon black based pigment or masterbatch	0 – 5,000 ppm carbon black masterbatch	>5,000 ppm carbon black
Surface finish	Any matt or gloss finish	Metallised surface on the inside of pack	Metallised surface on the outside of pack
Labels	<70% coverage of packaging	Any non-PVC full body sleeve <0.05mm thick[2]	PVC full body sleeve, any sleeve >0.05 mm thick

Following the feedback, it has been concluded that a metallised surface finish would not be detectable. This is present primarily in flexible packaging, which is currently not commercially sorted in the UK, therefore testing this hypothesis further in commercial installations is not possible.

Testing during the REFLeX[*] project showed no issues with sorting metallised flexible packaging when metallisation was on the inside. However, optimisation of the NIR was required as the metallised surface did distort the signal. When a dedicated film sorting plant is established, this should be revisited and placed in the conditional category.

In order to test the assumptions used to develop these guidelines, Axion sourced a range of samples to be tested with NIR machine manufacturers and in a commercial sorting facility.

[2] This was found to be the thickness at which material behaved as a film and is removed by air separation at the PET recycling plant.
* https://ceflex.eu/public_downloads/REFLEX-Summary-report-Final-report-November2016.pdf

4.0 Phase 2: Practical assessment

Various samples were analysed for NIR detectability in four ways:

1. Benchtop NIR tests;
2. Machine manufacturer tests;
3. Static tests in two commercial sorting facilities; and,
4. Field test in a commercial sorting facility.

The method for each test is detailed below.

4.1.1 Benchtop NIR

A basic set of static tests was carried out on each item of packaging investigated. The tests were carried out in the Axion Polymers Quality Control and Material Characterisation Laboratory. The unit used was the IOSYS sIRoGran.

The NIR reflectance from both the inside and outside of the packaging was measured, and whether or not the polymer type was identified. The spectrometer is not as sophisticated as ones in commercial NIR machines but is a very low cost method for initial analysis.

4.1.2 Machine manufacturer test centre

Samples were sent to three of the largest European suppliers of NIR sorting technology. The report will refer to them as Manufacturer A, B and C. Samples were tested using the trial NIR units with up-to-date software.

Axion was present for the trial carried out with Manufacturer A while Manufacturers B and C provided results via a report.

There are differences in the way that each manufacturer has developed their machines. Manufacturer A uses two spectrometers to analyse items; one is used to detect the NIR signal and determine the polymer type while the other analyses visible light to determine the item's colour and transparency. Manufacturer B and C, however, use a single spectrometer to analyse the NIR signal to determine the polymer type, complemented by an optical camera to detect colour and transparency. There are also differences in the type of spectrometer used by each manufacturer. For example, Manufacturer C uses hyperspectral imaging; a technique in which increased spatial resolution (more pixels per belt width) and spectral resolution (more data points on the NIR spectrum for each item analysed) are used to provide the sorting system with more data.

Static tests were carried out in two commercial facilities:

1. An advanced Plastics Recovery Facility (PRF) sorting mixed plastics into different products. The PRF uses machines from Manufacturer B; and

2. A PET recycling facility using machines from Manufacturer A.

A selection of samples was taken to one of the most advanced Plastics Recovery Facilities (PRFs) in the UK. The facility is designed to sort mixed plastics from Materials Recovery Facilities (MRFs). The tests at the PRF focused on PET as the greatest range of samples was obtained in this material and this is the material of most concern when discussing NIR detectability.

Figure 1 shows a basic flow of the PRF with respect to PET. In the diagram the following notation is used:

- +VE – a positive sort where air is used to eject the target material.
- -VE – a negative sort where all materials other than the target material is ejected.
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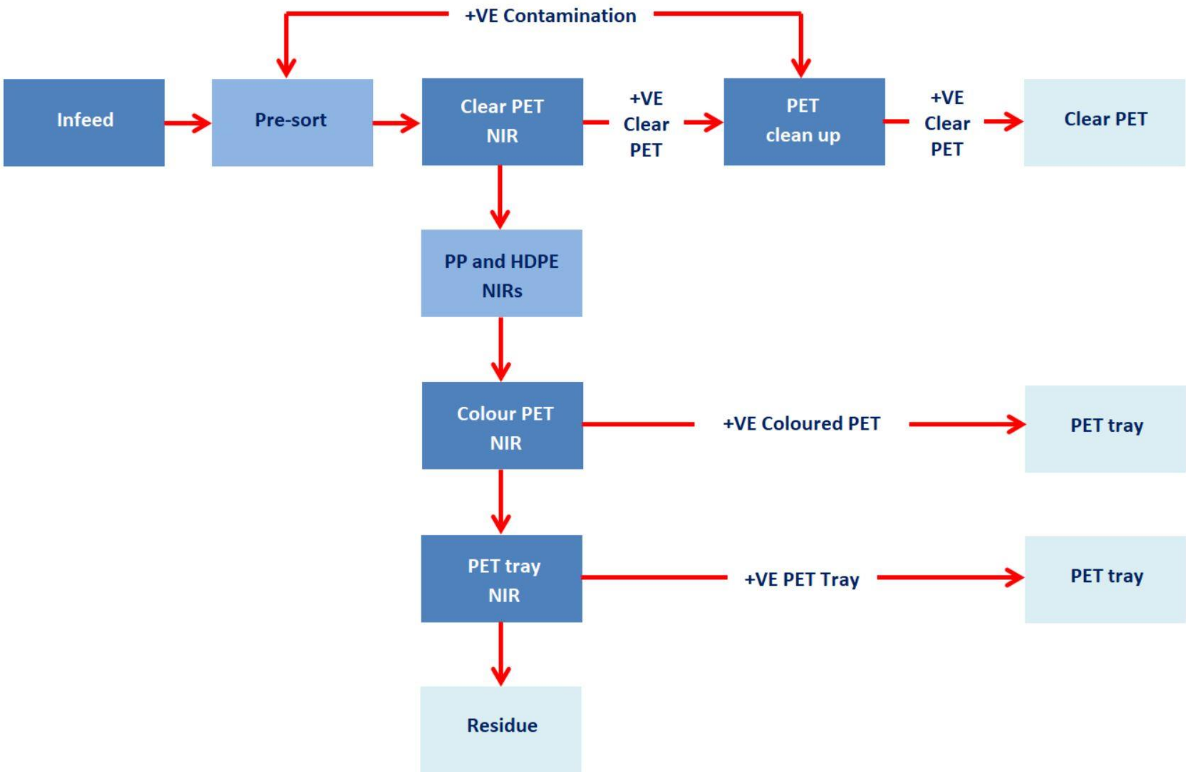
Figure 1 Basic PRF flow:



The first NIR positively ejects clear PET. This is quite an aggressive sort to give maximum recovery. After ejecting, the clear PET goes through a second "clean up" NIR. This NIR positively ejects any material that is not "clear PET".

The drops from the first NIR go through various NIRs to recover HDPE and PP, and then through an NIR that positively ejects "coloured PET". The drops from this NIR are then fed onto a final NIR that is programmed to eject all remaining PET material, which is largely PET trays.

For the static tests, the feed to the facility was stopped. The samples were then individually tested on the top and bottom of the packaging to see if the NIR air jets were activated, showing that the NIR could detect the material and that the NIR would eject it.

It was only possible to access the first NIR (ejecting clear PET) and the coloured PET NIR for the static test.

At the second facility, items were fed onto a single NIR which ejected “all PET”. The PET fraction is then manually sorted to remove any coloured PET. Samples were put on the belt with no other waste present.

The reason given by the site for ejecting all PET and then manually sorting is because the yield loss when ejecting clear PET only was too high, and it was more effective to recover more material and manually sort it.

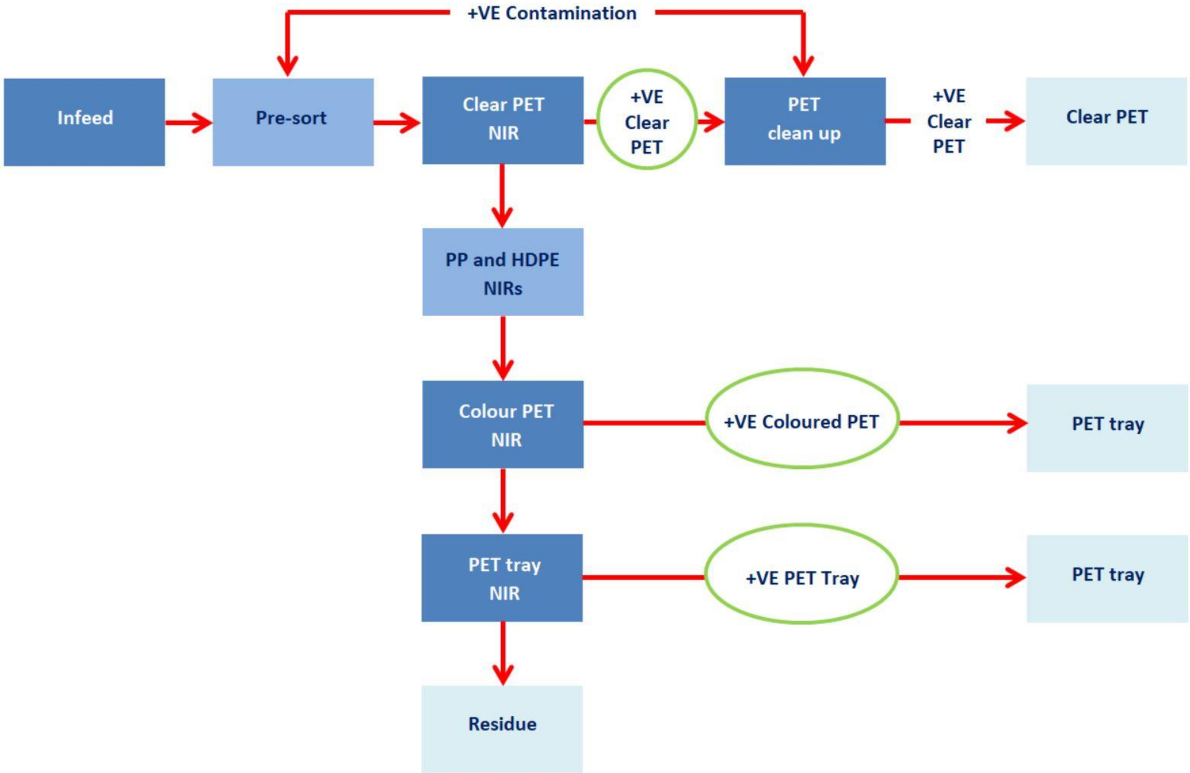
4.1.3 Field test in commercial facility

Using the same PRF, a more representative test was carried out to demonstrate how the packaging would behave in practice.

For this test, 40 samples of each tray were fed onto the conveyor belt feeding the first NIR while the PRF was processing material as usual. Staff were then positioned at different points in the PRF to observe the outputs from the first clear PET NIR, coloured PET NIR and PET tray NIR. It was not possible to observe the product or residue.

Error! Reference source not found. below shows the three observation points highlighted in g reen circles.

Figure 3 observation points:



The number of items of packaging were counted by the staff at each observation point.

4.2 Samples

Axion obtained samples directly from four packaging converters. In addition, control samples of PP with different levels of masterbatch were formulated with levels of carbon black ranging from 0 to 5,000 ppm in 1,000 ppm increments.

Table 3 details the different samples analysed in the project. Due to the wide range of samples, they have been grouped. Not all samples were used in all tests. This was either due to availability of samples, or because it was clear from the test centre trials that the material was not detectable.

Sample(s)	Description	Benchtop	Machine manufacturer	Static PRF test	PRF field test
Detectable black PET trays	Two types of detectable black trays from different converters	Yes	Yes	Yes	Yes
Coloured PET trays using carbon black	Three different colours (blue, green and brown)	Yes	Yes	Yes	Yes
Coloured PET trays made without carbon black	A range of different cPET and aPET trays	Yes	Yes	Yes	Yes
HDPE bottles with PET body sleeve	Range of bottles with full PET body sleeves	Yes	Yes	No	No
PET bottle with full body sleeve	Range of bottles with full PET body sleeves	Yes	Yes	Yes	No
PP samples with various carbon black content	Levels of carbon black from 1,000 to 5,000 ppm	Yes	Yes	No	No
Injection moulded PP lids	Various colours of carbon black and non-carbon black PP lids	Yes	Limited	No	No

Table 3 Samples tested

Sample(s)	Description	Benchtop	Machine manufacturer	Static PRF test	PRF field test
Detectable black PET trays	Two types of detectable black trays from different converters	Yes	Yes	Yes	Yes
Coloured PET trays using carbon black	Three different colours (blue, green and brown)	Yes	Yes	Yes	Yes
Coloured PET trays made without carbon black	A range of different cPET and aPET trays	Yes	Yes	Yes	Yes
HDPE bottles with PET body sleeve	Range of bottles with full PET body sleeves	Yes	Yes	No	No
PET bottle with full body sleeve	Range of bottles with full PET body sleeves	Yes	Yes	Yes	No
PP samples with various carbon black content	Levels of carbon black from 1,000 to 5,000 ppm	Yes	Yes	No	No
Injection moulded PP lids	Various colours of carbon black and non-carbon black PP lids	Yes	Limited	No	No

All samples tested can be seen in Table 4 and Table 5. Some additional samples of PP injection moulded lids were received after the planned testing and were only subjected to benchtop NIR analysis.

4.3 Results

The results will be discussed in four sections:

1. Bottles with full body sleeves;
2. PET in static tests;
3. PET in field tests; and,

4. Coloured PP in static tests.

4.3.1 Bottles with full body sleeves

Axion set out to determine if bottles with full body sleeves could be effectively detected by NIR, even where the sleeve is a different material to the body of the bottle. Several samples of PET bottles were obtained, however they all had PET body sleeves. This means that the bottles would likely be detected as coloured PET. No PET bottles were found to have PP, PS or PVC sleeves so further testing was not worthwhile.

One sample of a PET bottle with a clear PET sleeve with printing on was tested statically. The results show that the bottle is effectively detected as PET, but is sometimes detected as coloured and other times not. The downside to this is the PET sleeve material will contaminate the clear PET bottle stream, although the sleeve will most likely be removed using air separation before flake sorting.

Two samples of HDPE packaging with PET sleeves were obtained. The analysis showed that the NIR detects the HDPE bottle under the PET sleeve, meaning it can be correctly sorted.

Table 4 shows the results of the testing.

+VE denotes the packaging was positively identified.

-VE denotes the packaging was not identified with NIR.

Table 4 Results for full body sleeve bottles

Item	Description	IOSYS	Manufacturer A	Manufacturer B	Manufacturer C	PRF (Clear PET NIR)	PRF (Jazz NIR)	Notes
	Clear PET bottle Clear PET sleeve with printing	+VE PET	+VE PET Sometimes detected as coloured	+VE PET	N/A	+VE PET clear	-VE Not identified by colour PET NIR	
	Opaque white HDPE bottle Blue PET sleeve	+VE HDPE	+VE HDPE with PET label	+VE HDPE	+VE HDPE	Not tested	Not tested	
	Natural HDPE bottle PET sleeve	-VE Too transparent	+VE HDPE with PET label	+VE HDPE with PET label	+VE HDPE	Not tested	Not tested	IOSYS system couldn't see item due to transparency. Not an issue in practice.

The testing on the sleeves shows that for HDPE, a PET sleeve can be used without affecting detectability.

There is still a question over whether a non-PET sleeve can or should be used on a PET bottle. The feedback from the machine manufacturers suggests that providing the NIR is set up correctly, then the PET bottle will be detected regardless of the sleeve material.

If this is the case, the use of a PP full body sleeve would be preferential, as during the PET bottle washing process the sleeve material will float and can be removed. In many cases this floating fraction can be recycled into a polyolefin blend for injection moulding.

In reality however, it depends on how each NIR is set up in each sorting facility. The advice on sleeves should remain aligned with advice from the European PET Bottle Platform (EPBP), suggesting no more than 70% of the bottle is covered using a sleeve material that has a density lower than water.

4.3.2 Static tests on PET and carbon black PP

Table 5 shows the results from the static and machine manufacturer tests for the PET trays and PP samples with varying carbon black content. Unless stated otherwise, the result obtained refers to both the inside and outside of the packaging.

Table 5 PET tray results, static

Item	Description	IOSYS	Manufacturer A	Manufacturer B	Manufacturer C	PRF (Clear PET NIR)	PRF (Jazz NIR)	PET bottle recycler
	Red PET tray	+VE PET Light reflection: Inside: 33% Outside: 29%	+VE PET (blue)	+VE PET	+VE PET	+VE PET clear	+VE PET colour	+VE PET
	"Natural" cPET tray	+VE PET Light reflection: Inside: 21% Outside: 13%	+VE PET (grey)	+VE PET and PET opaque	+VE PET	+VE PET clear	+VE PET colour	-VE from the inside +VE PET from outside
	Detectable black PET tray (Faerch)	+VE PET Light reflection: Inside: 37% Outside: 22%	+VE PET (black)	+VE PET	+VE PET	+VE PET clear	-VE Not picked up by colour NIR sort	+VE PET
	Detectable black PET tray (Quin)	+VE PET Light reflection: Inside: 32% Outside: 20%	+VE PET (black)	+VE PET	+VE PET	+VE PET clear	-VE Not picked up by colour NIR sort	+VE PET

	Cream tray	+VE PET Light reflection: Inside: 31% Outside: 26%	+VE PET (cream)	+VE PET	+VE PET	+VE PET clear	+VE PET colour	+VE PET
	Blue tray 169 ppm carbon black	+VE PET from inside Not detected from outside Light reflection: Inside: 9% Outside: 5%	+VE PET (blue)	+VE PET opaque	Unknown Strong signal but did not match library but shows tendency to PET signal. Would need optimising	+VE PET clear	+VE PET colour	+VE PET
	Brown pot 1,800 ppm carbon black	Not detected Light reflection: Inside: 3% Outside: 4%	+VE PET Weak signal but detectable	-VE Signal too weak	-VE Weak signal	-VE	-VE	-VE
	Green tray 750 ppm carbon black	Not detected Light reflection: Inside: 5% Outside: 5%	+VE PET (green)	+VE PET opaque	Unknown Gave a noisy signal but a tendency to PET	+VE PET clear	+VE PET colour	+VE PET from inside -VE from the outside

	PP dog-bone 1,000 ppm carbon black	Not detected •	Not detected •	Not detected •	Not detected •	Not tested	Not tested	Not tested
	PP dog-bone 2,000 ppm carbon black	Not detected •	Not detected •	Not detected •	Not detected •	Not tested	Not tested	Not tested

The results of the static test are varied.

For the benchtop NIR, there was no consistent detection of the packaging with any level of carbon black. All other samples were detected correctly as PET.

Manufacturer A uses NIR to detect both polymer and colour. The NIR was unable to see the PP samples with 1,000 ppm carbon black; however, it was able to correctly identify all other samples, including the PET pot with 1,800 ppm of carbon black. The only sample which was not detected completely accurately was the red tray, which was detected as blue. This is unlikely to be a concern, as sorting PET into individual colours would be very unlikely, providing it is identified as "coloured" the result is positive.

Manufacturer B on the other hand does not detect colour, and instead classifies the material as "PET" or "Opaque PET". Manufacturer B was able to detect all samples aside from the PET with 1,800 ppm carbon black or any of the PP samples.

Manufacturer C could not correctly detect any of the PET samples with carbon black using existing libraries. However, a signal was obtained from the samples with 750 ppm carbon black or less, and so it would be feasible to optimise the equipment.

This means there is a clear difference between NIR manufacturers. Testing packaging with only one supplier is not sufficient to draw a conclusion. It can be concluded that the NIR units receive a signal from PET samples with 750 ppm or less of carbon black. For PP, no signal was achieved at 1,000 ppm carbon black.

In the PRF, the detectable black packaging was not detected by the colour PET sorter. This is not a problem with detection as the detectable black was seen by the clear PET sorter. Therefore, the settings of the equipment would need to be adjusted.

Additionally, there were some differences in the MRF tests with regard to the signal from the outside and inside of the PET trays. PET trays often have a layer of clear aPET on the inside surface which makes it shiny. This is why more light is reflected as shown by the IOSYS results. This was seen for the green tray and natural cPET tray using the PET recycling facility's NIR, where both the outside of the green tray and the inside of the natural cPET tray was not detected. Due to the results obtained from the other testing, this is most likely an optimisation issue.

Field test on PET

Table 6 Results from field test on PET

	Number ejected by Clear PET NIR	Number ejected by coloured PET NIR	Number ejected by PET tray NIR	Comments
	39	0	0	Stuck in recycle loop – packaging ejected by "clean up" NIR and fed back to "clear PET" NIR
	39	6	0	Stuck in recycle loop – packaging ejected by "clean up" NIR and fed back to "clear PET" NIR
	34	1	1	Stuck in recycle loop – packaging ejected by "clean up" NIR and fed back to "clear PET" NIR
	40	0	1	Stuck in recycle loop – packaging ejected by "clean up" NIR and fed back to "clear PET" NIR
	39	1	0	Stuck in recycle loop – packaging ejected by "clean up" NIR and fed back to "clear PET" NIR
	40	30	0	Mostly sorted to coloured PET stream without issue
	0	0	0	Not detected (high level of carbon black)

	36	2	0	Stuck in recycle loop – packaging ejected by “clean up” NIR and fed back to “clear PET” NIR

shows the results from the field test carried out at the PRF using NIRs from Manufacturer B. The number of items reporting to each stream was recorded.

Table 6 Results from field test on PET

	Number ejected by Clear PET NIR	Number ejected by coloured PET NIR	Number ejected by PET tray NIR	Comments
	39	0	0	Stuck in recycle loop – packaging ejected by “clean up” NIR and fed back to “clear PET” NIR
	39	6	0	Stuck in recycle loop – packaging ejected by “clean up” NIR and fed back to “clear PET” NIR
	34	1	1	Stuck in recycle loop – packaging ejected by “clean up” NIR and fed back to “clear PET” NIR
	40	0	1	Stuck in recycle loop – packaging ejected by “clean up” NIR and fed back to “clear PET” NIR
	39	1	0	Stuck in recycle loop – packaging ejected by “clean up” NIR and fed back to “clear PET” NIR
	40	30	0	Mostly sorted to coloured PET stream without issue

	0	0	0	Not detected (high level of carbon black)
	36	2	0	Stuck in recycle loop – packaging ejected by "clean up" NIR and fed back to "clear PET" NIR

The results from the field test were surprising. All samples, aside from the pot with 1800 ppm carbon black, were initially identified as clear PET. The packaging was therefore ejected into the "clear PET" stream and fed into the "clean up" NIR. This NIR is in place to then eject any material that is not clear PET.

The "clean up" NIR also ejected all of the trays, aside from the blue tray. This meant that the packaging was "stuck in recycle loop" as it was being identified by the first NIR as clear PET but by the second as "not clear PET".

The blue tray was originally detected as clear PET but eventually the majority was sorted to the coloured PET stream.

The site uses machines from Manufacturer B, and so the NIR does not detect colour, however the operator claims a camera is used in conjunction with the NIR to sort based on colour also. If this is the case, the trays should not have been identified as clear, and should have immediately been sorted to the coloured PET stream.

The second field test was carried out at a PET recycling plant using machines from Manufacturer A. For this test, packaging was fed onto the belt of an NIR sensor that would eject clear PET.

This field trial shows that the coloured PET trays, including the detectable black, can be detected using NIR providing the level of carbon black is less than 750 ppm. However, because of the configuration of the plant, it cannot be concluded that they would be sorted into the correct product fraction.

4.3.3 Static tests on coloured PP

Axion was also provided with a range of injection moulded coloured PP lids. Static tests using the IOSYS in the Axion laboratory were carried out, and a test with NIR Manufacturer B was also carried out on two samples which contained carbon black.

Table 7 Results on coloured PP samples using the IOSYS

Colour	% light reflected	Detected
Dark blue (unspecified level of carbon black)	2%	No
Brown (<500 ppm carbon black)	3%	No
Red	15%	Yes
Blue	9%	Yes
Yellow	17%	Yes
White	29%	Yes
Silver	12%	Yes

As shown with the PET, the IOSYS is not able to detect samples with carbon black.

Two PP lids (one dark blue lid and one brown lid) were subjected to NIR detectability trials at Manufacturer B's test facility. Axion was present for this trial. The detectability trial was performed on their commercialised NIR machine installed within their test centre using NIR only. The detection and sorting settings used by the machine are highly customisable. Two different settings were used.

1. Standard German MRF setting; and,
2. Black plastic setting.

The standard German MRF setting replicates a typical setup of an NIR machine installed within a German MRF. The black plastic setting has been programmed to try to obtain as much signal as possible from black items.

Using the standard German MRF setting, the dark blue lid gave a very noisy signal and the item was partially detected as PP film. In a real-world scenario, it is unlikely that this item would be sufficiently detected and sorted.

The brown lid however gave a good quality signal but was detected as PP film. Further discussion on this item led to the conclusion that it gave a sufficiently strong signal to be sorted in a real-world situation. It was also evident that the output it would end up in would be totally dependent on how a facility's NIR machines were set up and what additional equipment was installed.

Using the black plastic setting, the dark blue lid was seen as PP (this setting does not distinguish between PP and PP film), however the signal obtained was weak. The brown lid was detected as PP with a good strong signal.

The level of carbon black in the dark blue lid was not specified, however it would be reasonable to use the same (less than 750 ppm) threshold for PP as for PET.

5.0 Guidelines

The tests with the machine manufacturers and at the PRF have shown that detection and sorting are two very different things.

In order for an item to be NIR detectable, a clear conclusion can be reached and guidelines created. The caveat is that, although an item can be detected, how each individual sorting facility handles the material will differ.

5.1 Guidelines

Table 8 gives the suggested final guidelines to determine whether packaging is NIR detectable.

Table 8 Final suggested guidelines

Property	Acceptable	Conditional	Unacceptable
Colour	Any non-carbon black based pigment or masterbatch		>0 ppm carbon black
Surface finish	Any matt or gloss finish	Metallised surface on the inside of pack	Metallised surface on the outside of pack
Labels (PET bottles)	<60% coverage of packaging. Label to be made of material with density <1g/cm	Any non-PVC full body sleeve <0.05mm thick	PVC full body sleeve, any sleeve >0.05 mm thick
Labels (HDPE bottles)	Up to 100% coverage of any non-PVC polymer <0.05mm thick		>70% coverage of a label thicker than 0.05 mm OR any sized PVC sleeve

There is still a question around the use of full body sleeves made from a polymer different to the main pack. For HDPE, it is clear the NIR sorting technology can detect the HDPE under a PET sleeve.

For PET, the industry appears to have moved to full body PET sleeves. This means detection as PET is guaranteed, and the sleeve material will be removed using air separation once material is washed. Axion recommends that EPBP guidance be followed for PET bottles and labels to ensure consistency with Europe.

5.2 Testing of new products

If further testing is needed over a questionable new product, for example one with a thick coating or with levels of carbon black greater than 750 ppm, it is recommended that it is tested and validated by two different NIR machine manufacturers.

The use of lab equipment may be suitable, however the quality of detection may be lower, or higher, than that used by the machine manufacturers. If it can be shown that the laboratory equipment is consistent with the results of at least two NIR machine manufacturers, then it can be considered a viable alternative.

Regular testing would not be required, providing that the guidelines are adhered to.

6.0 Conclusion and recommendations

The project has provided some clear evidence on the detectability of packaging, most notably on the allowable level of carbon black and the use of sleeves on bottles.

Although packaging may be detectable, this does not mean it will be recovered and sorted into the “correct” product stream. Many Materials Recovery Facilities (MRFs) were not designed to separate out the kinds of materials that now need to be recycled. These are primarily pots, tubs and trays that have been introduced to kerbside collection in recent years without the proper change in infrastructure and development of end markets to make the system sustainable.

The demand for rPET and rPP is growing, but there is an inability to recover enough material to a high enough quality with existing infrastructure. MRFs have been designed primarily to recover clear PET bottles and HDPE as there has always been a good market for this material.

Understanding the composition of what MRFs are and are not recovering is vital. It is still the case that an item may be detectable but not recovered. In some instances, such as the coloured PET thermoforms, it is possible they could be recovered with other coloured PET bottles. WRAP is undertaking further work to determine how sorting more of this material will affect the quality of the coloured PET bottle stream.

An additional study could gain a better understanding of the current MRF infrastructure with details on infeed specification, what materials are being produced and where the materials are being sold (e.g. domestic recycler, export, energy recovery). This would rely on MRF operators sharing a lot of data and may not be feasible, but it is vital to gain a more in depth understanding to ensure the UK Plastic Pact targets can be met.

WRAP's vision is a world in which resources are used sustainably.

Our mission is to accelerate the move to a sustainable resource-efficient economy through re-inventing how we design, produce and sell products; re-thinking how we use and consume products; and re-defining what is possible through re-use and recycling.

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