Good Practice Guidance

Near Infrared sorting of household plastic packaging

A practical guide aimed at helping recyclers and processors already using NIR technology to sort household plastic packaging.

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Foreword

The BPF Recycling Council (BPFRC) is very pleased to endorse this good practice guide on using Near Infrared technology to sort household plastic packaging waste.

The information and guidance provided in this document is very comprehensive and covers the essential topics associated with Near Infrared (NIR) sorting of plastic packaging waste. For recyclers and processors already using NIR technology it provides a valuable reference document and indicates many areas where improvements can be made to existing procedures and protocols to obtain better results.

The BPFRC strongly recommends that plastics recyclers and processors take the time to read, understand and adopt the guidance listed within this document. Recyclers and processors should have full control of their plant and BPFRC is pleased to see the guidance to NIR users to optimise their equipment for their specific needs and not treat NIR sorters as ‘black boxes’. Collaboration within the industry is necessary and the guidance for upstream and downstream suppliers to work together to ensure feed and product specifications can be achieved is also important.

It is clear that the implementation of good practice can bring a wide range of benefits, in particular, improved product quality which is a hot topic of discussion at the moment.

The BPFRC agrees with WRAPs’ intentions of improving the quality (purity) and quantity (yield) of plastics recycled in the UK and is keen to support the sustainability of UK plastics recycling operations using NIR technology. Therefore the publication of this guide is fully supported by the BPFRC and we hope users of NIR automated sorting systems find the guidance contained within useful and informative.

Mark Burstall
BPF Recycling Council Chairman
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Glossary

Availability
Actual plant running hours as a percentage of planned plant running hours

Capacity rate
Actual throughput for the entire processing plant as a percentage of rated throughput

Eject
The fraction removed from the main material stream by the air jets of the NIR sorter

HDPE
High density polyethylene

LDPE
Low density polyethylene

MRF
Materials Recovery Facility

NIR
Near Infrared

OEE
Overall Equipment Effectiveness

PET
Polyethylene terephthalate

PLC
Programmable logic controller

PP
Polypropylene

PRF
Plastics Recovery Facility (defined as a facility which takes plastic fractions from MRFs and separates the material by polymer type and/or colour)

PS
Polystyrene

Purity
The percentage of target polymer within a product fraction

PVC
Polyvinylchloride

Quality rate
Percentage of product which meets the product specification

Reject
Fraction not sorted by the NIR sorter

Separation efficiency
The probability that the target material is correctly separated into the desired product stream by the NIR sorter. A value of above 90% is considered to be very good, between 80-90% is good, between 70-80% is acceptable, whilst below 70% indicates a poor separation

Yield
The percentage of target polymer recovered from the feed stream to the product stream

Acknowledgements

WRAP and Axion Consulting would like to thank the various recycling and processing sites visited during the project for their help and assistance in developing this good practice guide and Mark Burstall from the BPF Recycling Council for providing the foreword for this guide.
Key good practice guidance

Feed materials
- Implement quality control procedures to monitor feed materials.
- Conduct regular compositional analysis of feed materials to understand supplier and seasonal variations.
- Use feed material specifications where practical to ensure a minimum quality is provided.

Output products
- Implement product specifications.
- Conduct regular quality control and product compositional analysis to assess the performance of the NIR sorters.
- Monitor and understand the relationship between the NIR sorters, any downstream hand sorting operations and the final product.
- Use hand sorting to further improve product purity (only considered to be good practice when used in conjunction with correctly configured and optimised NIRs).

Feed preparation processes
- The feed system to the NIR sorter(s) must create a single layer of material on the acceleration belt.
- There should be no overlapping or co-joined/clumped items.
- The full width of the acceleration belt should be utilised during operation.

Optimisation
- NIR sorters should not be treated as ‘black boxes’.
- Operators should make the most of the knowledge of their NIR technology providers.
- Operators should understand the process variables associated with NIR sorters and optimise these parameters beyond the initial configuration set by the technology providers.
- Implement methods of monitoring the performance of NIR sorters, for example the use of overall equipment effectiveness (OEE) and separation efficiency.

Planned maintenance
- Implement a structured cleaning and maintenance programme based on shift, daily, weekly and monthly activities.
- The programme should be audited to ensure it is being implemented correctly.
- Use NIR technology suppliers to provide regular detailed maintenance.
1.0 Introduction

This guidance document, for the Near Infrared (NIR) sorting of household plastic packaging, is a practical guide intended to provide advice and information to existing recyclers and processors using NIR technology to separate household plastic packaging.

NIR is an optical sorting technology that enables plastic packaging and other plastic wastes to be separated by polymer type. NIR technology allows the production of high quality materials which can substitute virgin polymers in the manufacture of new items.

Effective and reliable NIR sorting operations are fundamental to producing high purity segregated polymer streams and achieving maximum market value for products.

1.1 Purpose

The purpose of this guide is to convey good practice to existing users of NIR technology. The guidance is suitable for both material recovery facility (MRF) and plastic recovery facility (PRF) operators currently using NIR systems. In publishing this guide it is hoped that the quality and quantity of plastics recycled will improve and the sustainability of UK plastics recycling operations will be supported.

Some recyclers currently using NIR technology to separate plastic packaging may not be fully utilising their NIR equipment and as a result may be losing yield or product purity unnecessarily. This guide aims to show existing operators the key factors which affect NIR performance. The guide makes recommendations, which if implemented successfully, should result in improved yields, throughputs and product purities.

This guide assumes an operational level of knowledge of NIR automated sorting equipment.

1.2 Source of good practice guidance

This guidance is based on research undertaken between January and April 2010 to identify and assess NIR good practice in the UK and mainland Europe. Six sites were visited, including MRFs and PRFs currently using NIR technology to separate household plastic packaging.

The site visits involved collection of production data, assessment of each sites’ use and understanding of their NIR machines and the completion of demonstration trials to quantify the performance of the NIR sorters. A full technical report detailing the findings from each site is also available.

The information gathered from the research has been drawn together into this guide.

1.3 Structure of the guidance document

The structure covers five main topics relating to NIR sorters:

- Feed materials;
- Output products;
- Feed preparation processes;
- Optimising NIR operations; and
- Planned maintenance.
2.0 Feed materials

This section of the guide focuses on the typical feed materials processed, at both MRFs and PRFs, and the impact feed composition can have on product purity and NIR separation efficiency.

Feed composition will have a significant and direct impact on the product purity that can be achieved through any NIR sorter. Feed materials need to be considered in terms of both:

- The composition of the feed entering the plant; and
- The composition of the material entering the NIR sorters (i.e. the feed preparation utilised prior to NIR sorting).

Regular compositional analysis of the feed material is recommended to ensure that the actual content of the feed is known and that feed specifications are being met. If feed specifications do not exist, they should be established for suppliers wherever possible.

2.1 Typical feed into a MRF

MRF capacities can vary from smaller plants at 10,000 tonnes per annum up to large scale sites processing over 200,000 tonnes per annum.

The feedstock received by a MRF is entirely dependent on the collection schemes that the associated local authority has in place. It is recommended that compositional analysis is conducted to determine the potential variations in feed. For example a collection scheme taking mixed dry recyclables (paper, cardboard, metal and plastic) may have the following composition:\(^1\):

- 70-80% paper and cardboard;
- ~10% ferrous and non-ferrous metal;
- ~5% plastic (for bottle only collection of PET and HDPE); and
- ~10% residue.

However, without the paper and cardboard fractions, the plastic content is likely to be much higher, at 40-50% of the feed.

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\(^1\) Data taken in March 2010 from a UK based MRF processing mixed dry recyclables.
Near Infrared sorting of household plastic packaging

It is also important to recognise that feedstock composition is likely to vary between collection areas and can also fluctuate throughout the year (for example, it is common for there to be more PET present during the summer months than winter due to the increase in consumption of soft drinks/water).

The recommended good practice for feed materials is to conduct compositional analysis as frequently as necessary as determined by the data. The frequency of the analysis must be sufficient to take into account seasonal variations. Sampling frequency should be increased if there are indications of more frequent changes in composition.

In the case of MRFs it is recognised that feed specifications are not common and are often difficult, if not impossible, to implement due to inherent variations in the feed materials from household collections. In this case it is therefore even more important to have a good understanding of the feed composition via regular monitoring and analysis of the feed.

2.2 Typical feed into MRF NIR separators

The feed material arriving at the NIR separators at a MRF is typically very different to the feed into the front end of the plant. Variations can exist depending on the feed preparation process route (feed preparation is covered below). If the majority of the non-polymer feed components are removed prior to the NIR sorters, then the polymer content in the feed to the NIRs can range from 70-90%. Compositional analysis of the feed into the NIR separators should be conducted, again on a similar basis to the feedstock analysis.

As NIR sorters are typically positioned towards the end of a MRF process the throughput tends to be significantly lower than the feed rates into the plant. For example a plant with a 15 tonnes per hour feed rate may have NIR separators with throughputs of 2 tonnes per hour or less.

2.3 Typical feed into a PRF

PRF capacities also vary but are typically in the region of 30,000 - 80,000 tonnes per annum.

Mixed plastic bottle fractions can have some variation depending on the source. In the UK a mixed bottle fraction may have the following typical composition:

- 45-55% clear/light blue PET;
- 30-40% natural HDPE;
- 0-15% coloured HDPE, PET and PP; and
- Remainder is minor levels of contaminants (for example PVC, paper, cardboard, metal, films, etc).

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2 Data sourced from a UK PRF processing mixed polymer bottle fractions in November 2009.
The use of feed specifications, set in association with the feed material suppliers, can help ensure a consistent high quality feedstock and are therefore highly recommended. Feed specifications should not be used as an alternative to compositional analysis of the feedstock. Quality control systems to regularly check feedstock composition should be defined and implemented. For a new supplier it is recommended that every batch of feed is tested until the supplier can demonstrate that the feed material is consistently meeting the specification. After this it would be acceptable to decrease the frequency of sampling and analysis, for example, to every fifth batch.

There should be a willingness and effort to work with upstream suppliers to ensure that the feed specification is achieved but also to provide assistance if there are problems in meeting the agreed specifications.

2.4 Typical feed into PRF NIR separators

It is estimated that typically 90-95% of the feed tonnage reaches the NIR sorters in a PRF and usually with a plastic content of over 90%.

The composition, by polymer type, will be dependent on the feedstock source.

The NIR sorters in a PRF typically have higher throughputs (and therefore wider belts) than NIR sorters used in MRFs. The throughput rate is likely to be in the range of 5-10 tonnes per hour for the first couple of NIRs, with subsequent downstream NIRs requiring lower throughput.

It is important to understand feedstock composition and variability and the impact it can have on overall product purity and NIR sorting efficiency.

Refer to Appendix 1 for more information about how to conduct compositional analysis of feed material and Appendix 2 for example feed stock specification sheets.

2.5 Key good practice - feed materials

- Implementation of quality control procedures to monitor feed materials;
- Regular compositional analysis of the feed materials should be conducted to understand supplier and seasonal variations; and
- Use of feed material specifications where practical to ensure a minimum quality is provided.
3.0 Output products

This section of the guide provides information about output products and explains the importance of establishing product specifications. Typical product purities and yields, for both MRFs and PRFs, are also given.

Analysis of the product fractions is one of the key ways to measure the operating success of NIR sorters. A system to measure and record output product composition and compare this to target values should be developed and implemented by all NIR operators, in order to monitor product quality, measure separation performance and drive process improvements.

3.1 Typical product data

MRFs and PRFs should both be capable of achieving similar product purities when using NIR technology to sort plastic packaging.

Polymer stream purities achieved by NIR sorters are typically in the range of 80-95%. High performing and well configured systems can achieve in excess of 95% purity.

Product specifications should be used. These give a benchmark level against which production results can be compared. Along with demonstration of regular compositional analysis, product specifications give customers confidence in the products. Typical product specifications include a minimum percentage of specified polymer (for example 90% PET) and a maximum allowable contamination level (for example 5% non-polymer).

Refer to Appendix 2 for example product specifications.

Figure 3 HDPE product bales

Manual hand sorting by well trained, experienced operators should be considered as an integral part of the sorting system. It is important to understand the relationship between the NIR sorters, any downstream hand sorting operations and the final product. The two sorting processes should be viewed independently and the sorting efficiency calculated separately for each.

Hand sorting is a key activity to improve product purity, and in some cases, should be considered as good practice. Hand sorting can have a significant positive impact on purity and typically results in products with purities in the range 95-99%.
For NIR sorters which are operating efficiently, hand sorting can be utilised as a final stage to further improve the product purity by removing any mis-sorted items and produce a product with a purity level above what could be achieved by the NIR technology alone. In this scenario hand sorting is more than acceptable and should be considered as good practice.

If the NIR sorters are performing below standard and hand sorting is being used to improve the product purity to an acceptable level, then the NIR sorters require optimisation and in this scenario hand sorting cannot be considered as good practice.

The performance of both the NIR sorters and the hand sorting operations need to be considered when assessing output fractions. Efficient hand sorting can mask a drop in efficiency of the NIR sorters and so continual monitoring and assessment of the quantity and composition of the material removed by hand sorters should be conducted. Simple assessment of the manually removed material can help determine if the NIR sorters are performing well or if there are possible problems. This can be easily carried out by measuring the mass of hand sorted non-target material picked from the product stream. If there is a significant increase in the amount removed in a fixed time, this would indicate an upstream problem; either with the NIR sorter, or with one of the pre-treatment operations.

By spending time and effort to optimise NIR sorting operations, purity can be improved up to around 95%. However, if purer fractions are required, post NIR hand sorting should still be considered and can be recommended as good practice.

<table>
<thead>
<tr>
<th>Typical results</th>
<th>Product purities</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants with hand sorting</td>
<td>Post NIR/ pre-hand sort Typically 80-90%</td>
<td>Post-hand sort Typically +95% and in some cases as high as 99%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants without hand sorting</td>
<td>Likely to be around 90% but can be as high as 95% for well configured systems</td>
<td>Sites which can achieve very high purities without hand sorting have usually conducted detailed optimisation of the NIR sorters. It will often take time for the site to be confident that the high purity levels can be repeatedly achieved and for hand sorting to be eliminated entirely.</td>
</tr>
</tbody>
</table>
The following tables give examples of actual purities and yields that were observed at sites in the UK and mainland Europe during this project.

**Table 2** Examples of MRF product purity & yields

<table>
<thead>
<tr>
<th>Example</th>
<th>Product purity from NIR sorters (before hand sorting)</th>
<th>Product purity (after hand sorting)</th>
<th>Separation efficiency of NIR sorter</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1³</td>
<td>PET 88%</td>
<td>97%</td>
<td>74%</td>
<td>99.9%</td>
</tr>
<tr>
<td></td>
<td>HDPE 92%</td>
<td>99.9%</td>
<td>90%</td>
<td>96%</td>
</tr>
<tr>
<td>2⁴</td>
<td>PET 65%</td>
<td>93%</td>
<td>93%</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td>PP 91%</td>
<td>No hand sorting</td>
<td>58%</td>
<td>59%</td>
</tr>
<tr>
<td>3</td>
<td>PET 73%</td>
<td>99%</td>
<td>73%</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>HDPE 89%</td>
<td>96%</td>
<td>89%</td>
<td>95%</td>
</tr>
</tbody>
</table>

³ An additional third recirculation NIR is used to increase the yield in this example. The separation efficiencies refer to the initial PET and HDPE NIR sorters only but the yield includes the effect of the third NIR.

⁴ The two product fractions in example 2 were created by a single three way NIR sorter.
Table 3 Examples of PRF product performances and yields

<table>
<thead>
<tr>
<th>Example</th>
<th>Product purity after NIR sorters</th>
<th>Yields</th>
<th>Separation efficiency of NIR sorters</th>
<th>Hand sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(^5) Coloured HDPE</td>
<td>59% coloured HDPE 37% natural HDPE Total HDPE purity 96%</td>
<td></td>
<td>70%-83%</td>
<td>Data not available</td>
</tr>
<tr>
<td>Natural HDPE</td>
<td>83% natural HDPE 15% coloured HDPE Total HDPE purity 98%</td>
<td></td>
<td>72%-86%</td>
<td>Material is hand sorted after NIRs but data not provided</td>
</tr>
<tr>
<td>Clear/light blue PET</td>
<td>72% clear PET 10% light blue PET Total PET purity 82%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2(^6) Coloured PET</td>
<td>53% coloured PET 40% clear PET Total PET purity 93%</td>
<td></td>
<td></td>
<td>Not hand sorted</td>
</tr>
<tr>
<td>HDPE</td>
<td>89%</td>
<td>94%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>Clear PET</td>
<td>95%</td>
<td>53%</td>
<td>55%</td>
<td></td>
</tr>
<tr>
<td>Coloured PET</td>
<td>33% coloured PET 62% clear PET Total PET purity 85%</td>
<td></td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>95%</td>
<td>76%</td>
<td>82%</td>
<td></td>
</tr>
</tbody>
</table>

It is recommended that operators put in place systems to measure, on a regular basis, product purities and yield after both the NIR sorters and the hand sorting, together with the yield and separation efficiency for each of the sorting steps. The data can be used to drive process improvements.

Refer to Appendix 1 for more information about how to conduct compositional analysis, measure purity and calculate yields and separation efficiencies.

3.2 Key good practice – output products

- Implementation of product specifications;
- Regular quality control and product compositional analysis to assess the performance of the NIR sorters;
- Monitoring and understanding the relationship between the NIR sorters, any downstream hand sorting operations and the final product; and
- Use of hand sorting to further improve product purity (only considered good practice when used in conjunction with correctly configured and optimised NIRs).

\(^5\) Data provided by site, the typical yield range achieved is indicated.

\(^6\) Data collected from performance trial, actual results given.
4.0 Pre-treatment processes

As this guide is aimed at existing NIR operators, it has been assumed that feed preparation processes are already in place. Therefore this section focuses on giving advice to ensure the pre-treatment processes are utilised correctly so that the feed material is presented to the NIR sorters in the most efficient way.

In general, upstream pre-treatment operations in both MRFs and PRFs, remove films and non-polymer material (i.e. lights, for example paper and labels, and metals, both ferrous and non-ferrous) prior to the NIR sorters. This reduces the mass feed rate through the NIR sorters, reducing the load through this expensive plant area and potentially reducing operational costs.

The following upstream pre-treatments should be used, as a minimum, prior to NIR sorting:

- A bale breaker or disentangler;
- A size segregation screen such as a rotating trommel or ballistic separator;
- An overband magnet to remove ferrous metal;
- Non-ferrous metal removal using an eddy current separator; and
- An air classification system to remove ‘lights’ (loose paper and film).

Separation of items to create a single layer of feed material on the acceleration belt prior to the NIR sorter is vitally important to ensure that each piece of material can be identified and scanned separately by the NIR sorter. Overlapping material on the belt can result in mis-fires which will adversely affect the product purity. Co-joined or comingled material, where two or more items are attached together, must also be avoided.

The feed mechanism to the acceleration belt should also ensure that the full width of the belt is utilised during operation.

Additionally no material should move on the acceleration belt as it passes between the detection unit and ejection nozzles, for example uncrushed bottles which are free to roll. The NIR sorters should be observed during operation to ensure this does not happen.
Pre-treatment operations should be regularly checked to ensure the feed to the NIR sorter is a loose single layer of material and only contains the fractions intended in the original design. Failure of any upstream pre-treatment equipment can lead to throughput reductions, yield losses and NIR malfunction.

Figure 6 Example of a vibrating feeder with grate bars feeding material uniformly onto the acceleration belt

4.1 Key good practice - feed preparation processes

- The feed system to the NIR sorter(s) must create a single mono layer of material on the acceleration belt;
- There should be no overlapping or co-joined items; and
- The full width of the acceleration belt should be utilised during operation.
5.0 Optimising NIR operations

This section of the guide covers the optimisation of NIR sorting operations. It includes topics such as advice on how to get the most out of the expertise of the NIR technology suppliers, helping staff to fully understand the technology, optimisation of NIR sorter process parameters and using Overall Equipment Effectiveness (OEE) to assess performance.

5.1 Making the most of the NIR technology supplier

NIR sorting optimisation should be carried out through the lifetime of the equipment. During the installation and commissioning phase, the NIR technology suppliers do a good job of setting up the machines, based on the initial design parameters. However, the expertise of the technology supplier during the set up stages is often not fully utilised and a potentially vital opportunity for operational staff to gain a detailed understanding of the machines can be missed.

For existing NIR operators, although the installation phase has passed, the NIR technology providers are still a useful resource.

During any site visits by NIR technology providers, the opportunity for operators to gain an understanding about the NIR sorters should be seized.

NIR operators could for example, consider selecting a number of key personnel (for example production manager, technicians, key operators) to work with the technology supplier to gain a more detailed understanding of the operation of the NIR sorters. For example, this could be in the form of an in-house training course. The knowledge gained from any form of training needs to be captured to ensure it is retained within the company and not lost if personnel move on.

5.2 Operator responsibility

The key message is that it is vital that the plant operator takes responsibility for the optimisation of the process. The NIR sorter(s) should not be treated as ‘black boxes’ that require once a year/contractual maintenance from the technology provider. The ‘black box’ approach potentially results in a lack of understanding of the NIR sorters, resulting in under performance and lower quality products.

Figure 7 View underneath an NIR sorter
5.3 NIR sorter optimisation

Each technology supplier’s NIR sorters will have slightly different functionality. Time needs to be spent understanding how the NIR process parameters can be adjusted and what effect they have on the process in terms of product purities and yields.

Three operating parameters which can be optimised are:

- Belt speed;
- Splitter plate position; and
- Software settings and sensitivity levels.

It should be noted that the above list is not exhaustive and there may be other operating parameters and variables not discussed in this guide which can be optimised.

One way of understanding the NIR sorters is to conduct trials with the plant’s normal feedstock material whilst changing the operating parameters. Product analysis should then be conducted to determine the effects of changing the settings on the product quality and yields. Where necessary the technology suppliers should be consulted for assistance and guidance.

5.4 Belt speed

Belt speed is an important process variable which should be investigated. For example, as the mass flow rate decreases through a system the belt speed of each NIR sorter may need adjusting to cope with this. During operation the belt speed must be kept constant as small fluctuations in speed can have a direct impact on sorting accuracy and efficiency.

5.5 Splitter plate position

The position of the splitter plate dividing the ejected and rejected material is another process parameter which can be changed. The splitter plate is typically set in position during commissioning of the NIR sorter by the technology provider. The positioning of the splitter plate has a direct impact on the efficiency of any separation achieved.

Incorrect positioning of a splitter plate could result in material ending up in the wrong fraction. For example, if the splitter plate angle is too steep the ejected material may not be able to clear it or may hit the plate and bounce into the wrong fraction. Whilst a splitter plate that is positioned with an angle which is too low, may mean the trajectory of the reject material is sufficient to clear the plate too.

Whilst it is important to record the initial positioning of the splitter plate, sites should be encouraged to further optimise the position and height in order to gain improved performance. The splitter plate can always be returned to its original position if the trials are unsuccessful.
5.6 Software settings and sensitivity levels

The software settings and sensitivity levels of NIR sorters can usually be modified. NIR sorters from different technology suppliers have different features and therefore exact software details cannot be listed here, as what is relevant for one machine may not apply to another. Therefore the user manuals and technology suppliers should be consulted.

For example it may be possible to adjust the sensitivity of the NIR sensors. A higher sensitivity can mean material detection is increased which results in a higher yield but this can cause the product purity to decrease. Therefore the sensitivity needs to be established for each sorting task in which the yield and purity are at an acceptable balance.

Where different polymer types are identified within the same item, such as a PET bottle and a PP screw cap or items are not separated from each other correctly on the belt, various levels of filtering can be set up in the NIR software to adjust the sensitivity for firing. Whilst these variables are set up by the technology supplier during initial commissioning, they can be optimised further, depending on each operator’s specific requirements and experience.

There are many further process variables and parameters which could be assessed. Therefore it is recommended that the complete NIR sorting process is assessed to identify any parameters which can be changed. A programme to assess the effect of changing the variables should then be implemented to determine the optimal settings for each parameter. Again, NIR technology suppliers should be consulted where required.

5.7 Data monitoring and reliability

Leading NIR technology suppliers can provide real-time monitoring reports of the sorting operations in electronic format, showing information such as average number of objects sorted per hour and split ratios between sorted and non-sorted material. Monitoring and recording of these figures will highlight operational problems early on. An historical record, stored electronically and related to batch code, can also prove useful if, for example, a batch
of material is below specification. Analysis of the NIR settings and sorting records may yield clues as to why the batch failed.

Evidence from sites using NIR technology indicates that NIR sorters are reliable pieces of equipment with few reported plant stoppages due to breakdowns and blockages. However, separation efficiency and product purity across each unit should be measured regularly to ensure performance is maintained. Benchmark production levels should be established and regularly checked as a minimum requirement.

**Figure 9** Two parallel NIR sorters

5.8 Overall Equipment Effectiveness (OEE)

OEE is a well recognised operational metric used in lean manufacturing plants. It evaluates three key aspects of equipment performance allowing direct comparison between different processes and machines. In lean manufacturing, an OEE of greater than 85% would be considered as ‘World Class Performance’ and therefore demonstrates ‘good practice’. OEE relates to running time, throughput rates and quality achieved and is defined as follows:

\[
\text{OEE} = \text{capacity rate} \times \text{quality rate} \times \text{availability}
\]

Capacity rate (\%) = \frac{\text{actual measured throughput}}{\text{rated throughput}}

Quality rate (\%) = \% \text{ of product meeting the product specification}

Availability (\%) = \frac{\text{actual plant running hours}}{\text{planned plant running hours}}

Normally OEE is calculated for a single machine. However, in some cases it may not be possible to measure one machine independently from the rest of the process and the OEE calculation methodology can be applied to a series of in-line machines. In simple terms, the ‘machine’ can be taken to mean the entire process rather than individual unit operations.

From the sites studied during the research phase of the project the following results are typical.
Table 4 Typical research phase results

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Quality</th>
<th>Availability</th>
<th>OEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typically capacities in the range of 70-90% can be achieved</td>
<td>Typically 100% Sites studied did not rework material and as compositional analysis is often limited sites tend to assume the material meets the specification</td>
<td>Typically in the range of 75-95% Often lower than other types of manufacturing plants due to high cleaning requirements</td>
<td>Calculated OEEs tend to be in the range of 60-75%</td>
</tr>
</tbody>
</table>

**Capacity rate**

The capacity rate is typically based on the throughput for the entire processing plant including the NIR sorters, rather than for each individual NIR sorter.

**Quality rate**

The quality rate is based on the percentage of product achieving the product specification from the processing plant and includes any manual hand sorting, conducted downstream of the NIRS. The quality metric therefore applies to the overall separation process including any manual hand sorting after the NIRS and is not ascribed to individual NIRS.

Reworking means the final product, after all processing stages, requires reprocessing because it does not meet the product specification. Manual hand sorting, conducted after the NIRS, as part of the normal operating process is not considered to be rework.

It should be noted that care needs to be taken with the quality parameter. There tends to be a lack of product compositional analysis and/or product quality specifications at most sites using NIR sorting technology, and therefore proving the product is acceptable can be difficult. This does not automatically mean that an assumption of 100% is correct but the fact that most sites do not rework the products is a simple way of indicating the quality rate is high.

It is preferable for sites to have an output quality specification and assess quality against this, so that actual performance can be measured and monitored over time against an agreed specification.

**Availability rate**

Availability is a measure of the actual ‘machine’ operating time as a ratio of the planned operating time. Typically the ‘machine’ is defined as the processing plant, from in feed to products after hand sorting downstream of the NIRS. Unplanned downtime may be a result of mechanical failure within the ‘machine’, no feed material being available, full bunkers/silos or operator issues.

To ensure OEE is representative of normal operations it should be calculated using reliable data covering a reasonable time period. Typically, data for at least one month’s normal production would be required in order to accurately measure the system OEE. Whilst it is possible to measure the OEE of an individual NIR unit, it is most unlikely that existing sites will measure at this level and are far more likely to record data across the full separation process from in feed to bunkers downstream of the NIR sorters.

Based on the above information NIR sorter(s) with an OEE of 75% and above can be considered to be operating efficiently. OEEs of greater than 85% are fairly unlikely to be achieved in recycling plants and therefore, for the purpose of this guide, a good practice OEE is proposed at 75% or above.

The OEE result should be used in conjunction with product purities, yield and NIR separation efficiencies to give an overall assessment of the NIR sorting performance.
5.9 Key good practice – optimisation

- NIR sorters should not be treated as ‘black boxes’ that don’t require attention;
- Operators should make the most of the knowledge of their NIR technology provider;
- Operators should understand the process variables associated with NIR sorters, for example belt speed, splitter plate position, software settings and sensitivity levels, and optimise these parameters beyond the initial configuration set by the technology providers; and
- Methods of monitoring the performance of NIR sorters should be implemented, for example the use of overall equipment effectiveness (OEE) and separation efficiencies.
6.0 Planned maintenance

This final section provides advice on cleaning and maintenance and includes recommended regular cleaning and maintenance schedules and the benefits of following them.

Regular cleaning is essential to ensure NIR sorters operate efficiently. Downtime should be built into the production schedule to allow for regular cleaning. A minimum of once per day is advised.

There are a number of cleaning activities that are required, dependent on the NIR technology used by a site. Each NIR technology supplier should provide detailed information on the type and frequency of maintenance required for their equipment. However the operational environment (for example dust, dirty materials) of the NIR sorters and its use are critical to the required maintenance and cleaning. Each site should take on board the cleaning/maintenance activities and frequencies recommended by their NIR technology supplier and adjust accordingly to reflect the machine’s use and environment. In the event of any uncertainty the technology supplier should be consulted.

The following are common parts of NIR sorters which require regular cleaning and maintenance:

- Air nozzles;
- Valve block;
- Glass/optical covers;
- Acceleration belts;
- Halogen lights; and
- Outlet chutes.

6.1 Air nozzles

The air nozzles in the valve block need to be cleaned on a daily basis to prevent blockages. The nozzles can typically be cleaned by a sequence in the programmable logic controller (PLC) of the NIR sorter. Some models of NIR sorters also include a facility that automatically checks the functionality of each nozzle via a cleaning sequence in the PLC. This should be used if available as regular cleaning using this sequence can prevent blockages and also identify blockages down to a specific nozzle.

Running a small air flow through the air jets when they are not activated can be useful in preventing the build up of material on the nozzles, although it will increase costs in terms of air consumption.

6.2 Valve block

The valve block containing the air nozzles should be cleaned regularly; at least once per day but more frequently if the material is very dirty and valves block easily. After cleaning the valve block with a scraper, the nozzle cleaning sequence should be run to flush out all the dirt. Water must not be used to clean the valve block.

The position of the valve block should also be checked weekly to ensure it is not out of alignment. The air pressure should be checked daily to ensure it is within the recommended range and the compressor purge valve tested weekly. The air quality should also be checked regularly.

6.3 Glass/optical covers

The glass/optical covers can easily become covered with dirt. Both should be regularly cleaned with a soft damp cloth, a scraper and non-greasy window type cleaner. The sensors/detectors should be cleaned with a soft wet cloth. The frequency of the cleaning will depend on how dirty they become, but cleaning at least once per day, after the unit has cooled down, is highly recommended. A monthly thorough clean of the glass covers with hot soapy water is also recommended.
6.4 Acceleration belts

An NIR sorter needs a defined and consistent background colour against which to measure the NIR spectrum of individual items. However it is common for the acceleration belts to become dirty and therefore regular cleaning of the belts with a soft damp sponge or cloth is required to ensure good operation. The belts should be cleaned at the end of each shift, with monthly detailed checks to inspect the belts for any damage. Additionally the speed of the belt should be checked with a tachometer on a monthly basis.

6.5 Halogen lights

The halogen lights will dull over time and need checking by performing a halogen brightness test. Wavelength and brightness across the full width of the belt must remain constant to ensure efficient operation. The light bulbs require replacing once they start generating light below the minimum acceptable level of brightness. It is recommended that the brightness tested is performed daily. The position of the light bar should be checked weekly.
Outlet chutes can become blocked leading to machine malfunction. Regular cleaning of the chutes and blockage protection sensors is required. Blockage sensors should be cleaned daily to ensure they function correctly. Engagement with NIR technology suppliers should determine if additional automatic blockage prevention sensors are required. Blockages can lead to machine malfunction, so automatic shutdown sensors are recommended.

Regular maintenance (on a daily, weekly, monthly and yearly basis) is essential to ensure that all equipment within the NIR sorter is functioning correctly. Air supply pressure, bulb operation and belt speed are all important metrics to maintain, regardless of the specific NIR technology. Each operating site should work with their NIR technology supplier to establish maintenance schedules, frequency and define spare parts/consumables that should be stored on site.

Although NIR sorters are generally reliable pieces of equipment, any breakdowns should be dealt with accordingly. If the problem is complex the NIR technology supplier should be consulted.

Most leading NIR technology suppliers can also offer maintenance packages which can include remote diagnostic fault finding and regular site visits. Typically two visits per annum post installation and commissioning may be required, for example to perform calibration tests and configuration checks. Whilst these services are recognised as an important part of any overall maintenance package there is still a need for continued process optimisation and maintenance activities at the site between visits.

### 6.7 Key good practice - planned maintenance

- A structured cleaning and maintenance programme should be implemented based on shift, daily, weekly and monthly activities;
- The programme should be audited to ensure it is being implemented correctly; and
- NIR technology suppliers should be used to provide regular detailed maintenance.
7.0 Conclusions

This good practice guide has identified, and covered in detail, five key topics relating to NIR sorters. These were:

- Feed materials;
- Output products;
- Feed preparation processes;
- Optimising NIR operations; and
- Planned maintenance.

The advice in this guide comes from observing and measuring good practice in action. NIR operators following good practice by implementing monitoring, optimisation and maintenance, maximise product purity, recovery yields and separation efficiencies.

It is hoped that implementation of the suggestions contained within this guide will help increase the quality and quantity of recycled plastic and support the sustainability of UK plastics recycling operations.

Improving NIR separations can bring a range of benefits and this guidance should help both MRF and PRF operators currently using NIR sorting systems.

Benefits from implementing the guidance should include:

- Increased understanding of NIR sorters and their context in the overall process;
- Ability to change the NIR process parameters, and take more control over the separation process;
- Ability to respond to varying feedstock compositions; being able to optimise and tweak the NIR process parameters means the system should be more flexible and able to handle minor fluctuations in feedstock composition;
- Produce higher quality products which may increase selling prices, attract new customers and retain existing ones; and
- Producing a detailed and complete record of production via the use of feed specifications, product purities, yields, compositional analysis, separation efficiencies and OEE's. This allows progress to be monitored and improvements to be observed.

The key action for existing NIR operators should be to assess their current levels of understanding and methods of operation against the recommended good practice guidance and advice. In each of the key topic areas any gaps which could be improved should be identified. A strategy should then be drawn up and implemented to deal with aspects of the NIR operation which are below good practice standard.

The good practice guidance recommends the implementation of quality control procedures and production monitoring. In order for any of these procedures to be implemented successfully and work effectively all those involved (including managers and operatives) need to fully understand the reasons for, and benefits, of the new systems.

It is recommended that any new procedures are thoroughly documented and training of existing personnel may be necessary.

The advice, guidance and recommendations made in this guide should, if implemented, enable the standards achieved by existing NIR users to improve to the common level of good practice.
Appendix 1

Guidance on how to conduct compositional analysis, measure purity and calculate yield and separation efficiency.

Compositional analysis

Feedstock analysis can be completed by conducting compositional analysis of the feed. All the different types of material found in the feed should be identified. A representative sample of feed material should be taken and separated into the respective components.

MRF feed analysis

For example, for a MRF accepting mixed dry recyclables, excluding glass, the following categories may be present:

- Cardboard;
- Newspaper/mixed papers;
- Ferrous metal;
- Non-ferrous metal;
- PET plastic bottles;
- HDPE plastic bottles;
- Other plastic; and
- Residue/fines.

PRF feed analysis

For a PRF the feed material needs to be split by polymer type and can also include sub-categories based on colour. For example:

- Natural HDPE;
- Coloured HDPE;
- Clear PET;
- Coloured PET;
- PP;
- Other plastic;
- Metal; and
- Residue/fines.

Product purity analysis

Purity is defined as the percentage of target product within a product fraction.

Product purity is determined by conducting compositional analysis. Each product to be analysed should be split into the same categories as the feed material.

For example if compositional analysis of a HDPE product fraction shows it contains 95% HDPE by weight then the purity is described as being 95%.

Yield

Yield is the percentage of material recovered from the feed stream to the target product stream.

Yield can be calculated for the entire plant or for individual unit operations/NIR sorters. Yield is calculated for each material component as follows:

\[
\text{Yield} \% = \frac{\text{Quantity of product produced}}{\text{Quantity of product material in feed fraction}}
\]
For example if 10 tonnes of feed material is processed per day with a clear PET composition of 25% (2.5 tonnes) and 2 tonnes of clear PET product is produced the daily yield is:

\[ \text{Yield} = \frac{2.0}{2.5} = 80\% \]

Note that yield and purity need to be used in conjunction with each other to obtain a full picture of a process. A yield of over 100% can be achieved as the yield is based on the entire product fraction, not just the target material. It is possible to have a high yield and low purity in which case the NIR sorter has incorrectly ejected non-target material into the product stream. A low yield and high purity means the NIR sorter has not been able to identify all of the target material and hence it is not ejected. A high yield and high product purity means the NIR sorter is correctly identifying the target material and removing it and minimising the ejection of any non-target material.

**Separation efficiency**

Separation efficiency measures how effective the NIR sorter is at sorting.

It can be defined as the probability of the target material being correctly separated into the desired product stream by the NIR sorter.

A value of above 90% is considered to be very good, between 80-90% is good, between 70-80% is acceptable, whilst below 70% indicates a poor separation.

Separation efficiency is calculated as follows:

\[ \text{Separation efficiency} = \frac{\text{Quantity of target material in product (weight)}}{\text{Quantity of target material fed into NIR (weight)}} \]

For example, if 10 tonnes is fed through an NIR sorter and the material contains 30% HDPE (3 tonnes).

The NIR is configured to positively remove HDPE and produces 2.5 tonnes of HDPE product with a HDPE purity of 96% (2.4 tonnes).

\[ \text{Separation efficiency} = \frac{2.4 \text{ tonnes}}{3 \text{ tonnes}} = 80\% \]
## Appendix 2

### Examples of feed and product specifications from MRFs and PRFs

Example of three feedstock specifications from a UK PRF

<table>
<thead>
<tr>
<th>Specification 1</th>
<th>Specification 2</th>
<th>Specification 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mixed bottles</strong></td>
<td><strong>Clear PET bottles</strong></td>
<td><strong>Natural HDPE bottles</strong></td>
</tr>
<tr>
<td>%</td>
<td>Description</td>
<td>%</td>
</tr>
<tr>
<td>---</td>
<td>-------------</td>
<td>---</td>
</tr>
<tr>
<td>45-55</td>
<td>Clear/light blue PET bottles</td>
<td>90-100</td>
</tr>
<tr>
<td>30-40</td>
<td>Milk bottles</td>
<td>0-6</td>
</tr>
<tr>
<td>0-15</td>
<td>PET/HDPE colour and PP</td>
<td>0-3</td>
</tr>
<tr>
<td>0-1</td>
<td>PET detergent</td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>HDPE detergent</td>
<td></td>
</tr>
<tr>
<td>0-3</td>
<td>Out throws (metal/paper/card)</td>
<td>0-2.5</td>
</tr>
<tr>
<td>0-1</td>
<td>Prohibited material (film, non-plastic bottles/oil/gravel &gt;40mm/glass &gt;40mm)</td>
<td></td>
</tr>
</tbody>
</table>

### Example of feedstock specification from a European PRF

<table>
<thead>
<tr>
<th>DSD Fraction No.</th>
<th>Mixed plastic bottles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post consumer, completely emptied, rigid, system-compatible packaging made of plastic, volume less than 5 litres, for example drinks bottles, household cleaner and detergent bottles, personal care bottles including packaging parts such as caps, lids and labels</td>
</tr>
<tr>
<td>Purity</td>
<td>At least 94% mass meeting above description</td>
</tr>
<tr>
<td>Maximum total amount of impurities</td>
<td>6% mass</td>
</tr>
<tr>
<td>Other metal items</td>
<td>&lt;0.5% mass</td>
</tr>
<tr>
<td>Other plastic items</td>
<td>&lt;3% mass</td>
</tr>
<tr>
<td>Other residual materials*</td>
<td>&lt;3% mass</td>
</tr>
</tbody>
</table>

* Example of residual materials includes glass, paper, cardboard, beverage cartons, aluminised plastics, rubber tones, wood, textiles, nappies and compostable waste.

It should be noted that the PRF feedstock specifications are also product specifications for MRFs as the material accepted by the PRFs is usually pre-processed at a MRF.
### Example set of product specifications from a European MRF

<table>
<thead>
<tr>
<th>Product</th>
<th>Specification</th>
<th>% Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear PET bottles</td>
<td>Clear PET</td>
<td>91.80%</td>
</tr>
<tr>
<td></td>
<td>Light blue PET bottles</td>
<td>3.00%</td>
</tr>
<tr>
<td></td>
<td>Coloured or opaque PET bottles</td>
<td>0.70%</td>
</tr>
<tr>
<td></td>
<td>Other packaging made from PET</td>
<td>1.00%</td>
</tr>
<tr>
<td></td>
<td>PE/PP bottles</td>
<td>2.00%</td>
</tr>
<tr>
<td></td>
<td>PVC packaging</td>
<td>0.50%</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>1.00%</td>
</tr>
<tr>
<td></td>
<td>Total contamination</td>
<td>8.20%</td>
</tr>
</tbody>
</table>

| Coloured PET bottles         | Coloured PET bottles            | 90.50% |
|------------------------------| Light blue or clear PET bottles | 5.00%  |
|                              | Other packaging made from PET   | 1.00%  |
|                              | PE/PP bottles                   | 2.00%  |
|                              | PVC packaging                   | 0.50%  |
|                              | Others                          | 1.00%  |
|                              | Total contamination              | 9.50%  |

| Light blue PET bottles       | Light blue PET bottles          | 88.80% |
|------------------------------| Clear PET bottles               | 4.00%  |
|                              | Coloured or opaque PET bottles  | 2.70%  |
|                              | Other packaging made from PET   | 1.00%  |
|                              | PE/PP bottles                   | 2.00%  |
|                              | PVC packaging                   | 0.50%  |
|                              | Others                          | 1.00%  |
|                              | Total contamination              | 11.20% |

| PE/PP bottles                | PE/PP bottles                   | 92.00% |
|------------------------------| PET bottles                     | 1.00%  |
|                              | Other packaging made from PE    | 5.00%  |
|                              | PVC packaging                   | 1.00%  |
|                              | Other                          | 1.00%  |
|                              | Total contamination              | 8.00%  |
## Example product specifications from a European MRF

<table>
<thead>
<tr>
<th>Polymer type</th>
<th>PE</th>
<th>PP</th>
<th>Mixed PET (90/10)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DSD Fraction No.</strong></td>
<td>329</td>
<td>324</td>
<td>328-1</td>
</tr>
<tr>
<td><strong>Product description</strong></td>
<td>Used, completely emptied rigid system compatible articles made from PE with volume less than 5 litres, for example bottles, dishes, tubs including packaging parts such as caps, lids and labels</td>
<td>Used, completely emptied rigid system compatible articles made from PP with volume less than 5 litres, for example bottles, dishes, tubs including packaging parts such as caps, lids and label</td>
<td>Used, emptied, rigid system compatible, packaging made from PET, container volume less than 5 litres in the composition: 1 - Transparent bottles, such as detergent bottles, beverage bottles 2 - Other rigid PET packaging such as cups, bowls Clear, colour, opaque including residues such as closures, labels, etc.</td>
</tr>
<tr>
<td><strong>Purity</strong></td>
<td>At least 92% mass of PE</td>
<td>At least 94% mass of PP</td>
<td>At least 90% transparent bottle PET Maximum 10% of other rigid packaging made from PET</td>
</tr>
<tr>
<td><strong>Maximum total amount of impurities</strong></td>
<td>8% mass</td>
<td>6% mass</td>
<td>2% mass</td>
</tr>
<tr>
<td><strong>Other metal items</strong></td>
<td>&lt;0.5% mass</td>
<td>&lt;0.5% mass</td>
<td>&lt;0.5% mass</td>
</tr>
<tr>
<td><strong>Other plastic items</strong></td>
<td>&lt;3% mass of PP</td>
<td>&lt;1% mass of PE</td>
<td>&lt;2% mass</td>
</tr>
<tr>
<td><strong>Expanded plastics including EPS articles</strong></td>
<td>&lt;0.5% mass</td>
<td>&lt;0.5% mass</td>
<td>-</td>
</tr>
<tr>
<td><strong>Plastic films</strong></td>
<td>&lt;5% mass</td>
<td>&lt;2% mass</td>
<td>-</td>
</tr>
<tr>
<td><strong>Other residual materials</strong></td>
<td>&lt;3% mass</td>
<td>&lt;3% mass</td>
<td>&lt;2% mass</td>
</tr>
<tr>
<td><strong>Delivery</strong></td>
<td>Transportable bales, minimum density 300 kg/m³, dry stored, produced with conventional bale press, identified with DSD label stating sorting plant No. fraction No. and production date</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Examples of other residue include glass, paper, cardboard, beverage cartons, aluminised plastics, rubber, stone, wood textiles, nappies, food and garden waste.