Final Report

Commercial scale mixed plastics recycling

A report on the technical viability of recycling mixed plastic packaging waste from domestic sources on a commercial scale in the U.K.

Project code: MDP021
Research date: Oct 2008 – April 2009
Date: June 2009
WRAP helps individuals, businesses and local authorities to reduce waste and recycle more, making better use of resources and helping to tackle climate change.

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**Acknowledgements**
It is acknowledged that without the co-operation, access and information provided by all the organisations involved in this project, the key assessments of recycling of mixed plastics would not have been possible. Their contribution and support was greatly appreciated.

**Front cover photography:** [Mixed plastics packaging from domestic sources used in project trials]
Executive summary

There are a number of technical challenges to the successful recycling of mixed plastics in the UK. This report sets out some of the work being done to address these challenges.

The term ‘mixed plastics’ covers the range of rigid and flexible plastic packaging typically found in the household waste bin such as trays, tubs, pots and films. It excludes plastic bottles and non-packaging items. Mixed plastics packaging is made from a wide range of polymers and comes in various colours.

WRAP (Waste & Resources Action Programme) commissioned the report to assess the business case for a commercially sustainable, integrated mixed plastics waste processing solution in the UK. This involved commercial scale recovery and recycling trials working with 26 different businesses and processing over 150 tonnes of mixed plastics packaging waste.

Three core questions were asked:

- How can plastics be sorted from other materials at a Materials Recovery Facility (MRF)?
- Does collection of plastics at retail outlets, such as supermarkets, have a role to play?
- How can mixed plastics be sorted by polymer type and reprocessed to produce high quality raw materials?

The main conclusion from this work is that recycling of mixed plastics in the UK is technically viable on a commercial scale. Previous research (June 2008) demonstrates that recycling of mixed plastics also has the best environmental outcome. The materials collected, sorted and reprocessed were then used in place of virgin materials to create products used in everyday life. It is clear that there are markets for the majority (over 95%) of these recycled mixed plastics.

MRF sorting trials

Three Materials Recovery Facilities (MRFs), located in different regions of the UK, took part in extensive sorting trials:

- one of the MRFs sorts plastic bottles but not mixed plastics;
- the second sorts plastic bottles and rigid mixed plastics, and also handles glass; and
- the third handles mixed plastics (including rigid and film plastics) already, but not glass.

The aim of the trials was to understand more about how mixed plastics can be sorted in MRFs and how it would affect the quality of their other outputs. The need to add equipment and manpower was also explored. This was done by monitoring processes at two facilities that currently sort mixed plastics and reconfiguring a third to sort mixed plastics.

By identifying the challenges and discovering best practices, the trials would help to determine how MRFs can successfully sort mixed plastics from other dry recyclables.

It became clear from the trials that MRFs can recover large quantities of mixed plastics.

Input and output material compositions in the MRFs were analysed and it was found that the MRFs were able to sort the mixed plastics without any impact on the quality of their other material streams, such as paper. However, MRFs need to remove films early in the separation process to minimise potential problems with sorting downstream.

There is potential for MRFs to be modified to accept and process mixed plastics. In some cases modification may be minimal.
In addition, the research found that MRFs can use automated sorting techniques to significantly improve the purity of materials recovered.

Smaller MRFs could be encouraged to adopt low technology solutions such as manual sorting, while larger ones could consider automated technologies.

**Retail take-back collection schemes**

WRAP wanted to identify the challenges faced by retailers adopting a take-back policy for household plastics packaging. The report outlines the experiences involved in collecting around 20 tonnes of mixed plastics packaging from over 20 Sainsbury’s stores in the London area.

Although Sainsbury’s specifically asked for ‘mixed plastics’, excluding bottles, the consumers did not differentiate between a plastic bottle, a plastic tray or a multi layer squeezable pack. However, although the mixed plastics returned to the retail sites contained a high percentage (57%) of bottles, there was very little contamination from non-plastic packaging such as paper, glass and steel.

Providing a high quality of collection can be maintained, retail mixed plastics take-back schemes can provide excellent product quality with minimal crossover from non-plastic packaging.

For front of store collection to be effective, a well-designed system that minimises the number of transport trips, maximises recovery of plastics yet minimises cross contamination from paper and cans is needed.

If household plastic packaging can be kept separate from paper and other materials, it can be sent directly to a Plastics Recovery Facility (PRF). A PRF specialises in sorting plastic by polymer type to recover high value polymers such as Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Polypropylene (PP), Polystyrene (PS) and Polyvinyl Chloride (PVC). If the materials are co-mingled during collection then it is best to send these to a MRF for sorting first.

**Plastics Recovery Facility (PRF) and reprocessing trials**

Commercial scale trials have been carried out at a number of plastics sorting and reprocessing companies in the UK, The Netherlands, Germany and Austria. These trials have been used to assess the technical viability of commercial scale recycling of mixed plastics in an integrated plastics sorting and reprocessing operation.

The different processes trialled included:

- sorting of mixed rigid plastics into polymer streams;
- reprocessing of natural HDPE and clear PET;
- reprocessing of PP, PS and coloured HDPE;
- reprocessing of film; and
- examining the best use of residual materials.

The sorting of more than 100 tonnes of mixed rigid plastics by polymer type (the PRF function) was done by Valpak Recycling.

The major polymer groups were successfully sorted using standard NIR (Near Infra Red) automatic sorting machines. One problem identified was the amount of black plastics present (mainly PP and PET trays and tubs), which the NIR sorting systems could not identify. The sorted plastics were baled and transported for reprocessing.
Natural High Density Polyethylene (HDPE) and clear Polyethylene Terephthalate (PET)

Reprocessing of natural HDPE and clear PET was carried out at Closed Loop Recycling (CLR), a plastic bottle recycling facility. More than 63 tonnes of mixed HDPE and PET bottles and other rigid plastics were processed. The natural HDPE packaging was turned into recycled food packaging. Clear PET was successfully used in the manufacture of thermoformed products such as cups and trays. Coloured PET was segregated and used to make strapping.

Polypropylene (PP), Polystyrene (PS), and coloured High Density Polyethylene (HDPE)

Reprocessing of PP, PS and coloured HDPE fractions was carried out by LINPAC Packaging at their plastics recycling plant. LINPAC received 33 tonnes of PP from the PRF sorting trials, 17 tonnes of coloured HDPE from the Closed Loop Recycling trials and additionally sourced five tonnes of PS. The quality of the pellets produced from the processed PP, HDPE and PS was equivalent to normal production grades. Manufacturing trials with the recycled PP material successfully produced plant pots, underground drainage chambers and mouldings for external covers. Manufacturing trials with the recycled PS compounds successfully produced hose reels. The recycled coloured HDPE produced was suitable for manufacturing a range of items such as pipes.

Film

Reprocessing of film was carried out by a number of specialists. The raw material included a range of consumer packaging waste, such as crisp packets and carrier bags. Polyethylene (PE) based materials accounted for almost 78% of the total, with Polypropylene (PP) making up 13%. Trials using the latest processing technologies in Germany and Austria showed that household plastics packaging films can be recycled at commercially viable speeds to produce PE pellets. Manufacturing trials at CeDo’s plastic film production facility demonstrated that recycled film has the potential to be used to make new film products such as refuse sacks. Whilst these are very encouraging results further trials would be required to verify this.

Integrated PRF and reprocessor

No matter how efficient the recycling process, there is always a residue left over. Currently, most of this goes to landfill, with a disposal cost. Clearly, this has an impact on the cost-effectiveness and environmental benefit of the overall recycling operation.

During the trials, residual materials were investigated and analysed. There is potential for using the residue as Solid Recovered Fuel. The wash plant residues had a calorific value of 23 MJ/kg (dry basis). This is substantially lower when compared to the calorific value of plastics. The low value is attributable to the high paper/organics composition levels in the wash plant residues.

A visual assessment of several samples of the dried wash plant residue indicated that a typical composition of non-plastics (e.g. paper/organics) is likely to be approximately 60-70%, with the remaining 30-40% being fines from plastic labels, glues and plastic fines from the granulation process.

Conclusions

Recycling of mixed plastics in the UK is technically viable on a commercial scale. In these trials, reprocessed plastics were successfully substituted for virgin materials in end-product applications. It is clear that markets exist for the majority (over 95%) of the recycled plastics.

A PRF and reprocessor on one integrated site will be more efficient and will produce less residual waste through increased recovery yields. The expected achievable material recovery by an integrated PRF and reprocessing facility is 55% and could be as high as 60%.

For the avoidance of doubt no direct comparison of individual equipment, technology or process performance should be drawn from the tables and information published throughout this report.
For all equipment, technology or processes tested, the equipment, technology or process may have been tested under different conditions and using different methodologies and therefore may not be comparable.
## Contents

1.0 **Project Introduction** ................................................................. 11

2.0 **Introduction - MRF Processing of Mixed Plastics** ......................... 13

3.0 **Trial Results from MRFs Currently Sorting Mixed Plastics** ............... 14

   3.1 MRF Assessment Methodologies and Trial Differences ......................... 14
   3.2 MRF Processing Trial Objectives .......................................................... 14
   3.2.1 Requirements for MRF Assessment ...................................................... 15
   3.3 Selection of MRFs and Material Supply .................................................... 15

4.0 **MRF B Processing Trials** ............................................................ 17

   4.1 MRF B Targeted Materials ................................................................. 17
   4.2 The Sorting Process ............................................................................. 17
   4.3 Feed System ....................................................................................... 17
   4.4 Film Removal ..................................................................................... 17
   4.5 Non-Plastic Materials Separation ......................................................... 17
   4.6 Manual Sorting of Natural HDPE and Mixed Plastics .............................. 18
   4.7 MRF B Trial Results: Compositional Analysis ........................................ 18
   4.8 Composition of Other Rigid Plastics ..................................................... 19
   4.9 MRF B Plant Performance – Operating and Material Capture Efficiencies .... 20
   4.10 MRF B: Assessment of Product Quality ............................................. 20
   4.10.1 MRF B: Plant Performance – Residue .............................................. 22
   4.10.2 MRF B: Mixed Plastics Processing Issues ....................................... 23
   4.10.3 Key Findings from MRF B Processing Trials ..................................... 23

5.0 **MRF C Processing Trials** ............................................................ 25

   5.1 MRF C Targeted Materials ................................................................. 25
   5.2 MRF C Material Sorting Process .......................................................... 25
   5.2.1 Feed System ..................................................................................... 26
   5.2.2 MRF C Trial Results: Compositional Analysis ....................................... 27
   5.3 MRF C: Plant Performance - Operating and Material Capture Efficiencies .. 29
   5.4 Plant Throughput and Product Data ..................................................... 29
   5.4.1 MRF C Trial Product Quality ............................................................ 30
   5.4.2 Mixed Rigid Plastics Composition and Quality ..................................... 31
   5.4.3 Separation and Baling of Film Stream ............................................... 32
   5.4.4 MRF C Material Residues ................................................................. 33
   5.5 Mixed Plastics Processing Issues ........................................................ 33
   5.6 Key Findings from MRF C ................................................................. 34

6.0 **Trial Results from MRF A - Currently NOT Sorting Mixed Plastics** ........ 35

   6.1 MRF A Targeted Materials ................................................................. 35
   6.2 MRF A Sorting Process ....................................................................... 35
   6.3 MRF A Processing Trials ..................................................................... 37
   6.4 MRF A Stage 1 Trial Results: Compositional Analysis ............................ 37
   6.5 Stage 1 Trial Results: Operating and Material Capture Efficiencies ........... 39
   6.6 Stage 1 Trial Results: Product Quality .................................................. 40
   6.7 Stage 1 Trial Results: Material Residues ................................................. 41
   6.8 Stage 2 Trial Methodology ................................................................. 41
   6.9 Stage 2 Trial Results – Processing Issues with Mixed Plastics .................. 42
   6.10 Stage 3 Trial – Material Capture Efficiencies ....................................... 42
   6.11 Stage 3 Trial Results: Product Quality ................................................ 42
   6.12 Stage 3 Trial Results: Processing Issues with Mixed Plastics .................. 43
   6.13 Potential Reconfiguration Costs ........................................................ 43
   6.14 Key Findings from MRF A ............................................................... 43

7.0 **Key Findings from MRF Processing Trials** ..................................... 45

   7.1 Overview: Throughput, Infeed Composition and Capture Efficiencies .......... 45
   7.2 Overview: Purity, Contamination from Plastics and End of Line Composition 46
   7.2.1 Plastic Film and Other Rigid Plastics as Contaminants .......................... 47
   7.2.2 Contamination of Paper ..................................................................... 47
   7.2.3 Contamination of Aluminium ........................................................... 47
   7.2.4 Contamination of Steel ....................................................................... 47

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Commercial scale mixed plastics recycling 7
Recycling of Rigid PP, Coloured HDPE and PS Household Plastic Packaging ........................................ 72

8.0 Overall MRF Processing Trial Conclusions ................................................................................ 51
9.0 Recommendations for Consideration ....................................................................................... 53
10.0 Collection and Recycling of Mixed Plastics from Retail Front-of-Store ................................ 54
11.0 Introduction – Combined Plastics Recovery Facility (PRF) + Reprocessing of Mixed Plastics 60
12.0 Plastic Reclamation Facility (PRF) Sorting Trials .................................................................. 61
12.1 Input Material Specification of the PRF .................................................................................. 61
12.2 The PRF Plastic Sorting Process ............................................................................................. 62
12.2.1 Material Infeed System ..................................................................................................... 62
12.2.2 Removal of Film and Contaminants – Vibrating Screen .................................................. 62
12.2.3 NIR Sorting of Mixed Plastics .......................................................................................... 62
12.2.4 PRF Sorting Trials: Compositional Analysis ..................................................................... 63
12.3 PRF Plant Performance - Operating and Material Capture Efficiencies ................................. 65
12.4 PRF Sorting Trial Results – Product Quality ......................................................................... 65
12.4.1 PET and HDPE Output Stream Composition Quality ...................................................... 66
12.4.2 PP Output Stream Composition Quality ......................................................................... 67
12.4.3 PS Output Stream Composition Quality .......................................................................... 68
12.4.4 PVC Output Stream Composition Quality ....................................................................... 69
12.4.5 Sorting Trial Residual Material ...................................................................................... 70
12.5 Key Findings from the PRF Sorting Trials ............................................................................. 71
13.0 Recycling of Rigid PP, Coloured HDPE and PS Household Plastic Packaging .................... 72
13.1 LINPAC Recycling PP, HDPE and PS Recycling Trials Methodology .................................. 73
13.1.1 Analysis of Plastics in Polypropylene Bale ...................................................................... 73
13.2 Recycling of Rigid Polypropylene Post-Consumer Packaging ............................................. 75
13.2.1 Characterisation and assessment of PP washed flake ....................................................... 75
13.2.2 Formulation for End Markets and Associated Testing (PP) ............................................ 76
13.2.3 Summary of Results for Extruded Recycled PP ................................................................ 77
13.2.4 Consideration of Potential End Product Applications .................................................... 77
13.2.5 Compounding and Characterisation of Recycled PP Resin ............................................ 77
13.2.6 Recycled PP Resins - Market Options ............................................................................. 78
13.2.7 Moulding of End Products from Recycled PP Resins ...................................................... 79
13.3 Recycling of Rigid Coloured HDPE Post-Consumer Packaging .......................................... 80
13.3.1 Mass Balance (Trial 1) ..................................................................................................... 80
13.3.2 Washed HDPE Flake Characterisation ......................................................................... 80
13.3.3 Summary of results ......................................................................................................... 81
13.3.4 Coloured HDPE Recycling (Trial 2) ............................................................................... 81
13.3.5 Washed HDPE Flake Characterisation ......................................................................... 81
13.3.6 Summary of Results ....................................................................................................... 81
13.3.7 Products Manufactured from Recycled Coloured HDPE Stream ................................... 81
13.4 Recycling of Rigid Polystyrene Post-Consumer Packaging .................................................. 82
13.4.1 PS – Mass Balance of PS Bale (1810W) ............................................................................ 82
13.4.2 Washing of Baled Plastic – Polystyrene (PS) (Sourced from secondary PRF) ............... 83
13.4.3 Summary of results ......................................................................................................... 84
13.4.4 Washed PS Flake Characterisation ................................................................................. 84
13.4.5 Compounding of PS – Extrusion Trial ............................................................................ 84
13.4.6 Consideration of Potential End Product Applications ..................................................... 85
13.4.7 Characterisation of Recycled Polystyrene Compound ..................................................... 85
14.0 Recycling of PET and Natural HDPE from Household Plastic Packaging .............. 86

14.1 CeDo film recycling trials and methodology ......................................................... 89
  14.1.1 Film Recycling Trial Objectives ........................................................................ 89
  14.1.2 Film Recycling Methodology .......................................................................... 90
  14.1.3 Pre-trial visual compositional analysis of film balestock .................................. 90

14.2 Natural HDPE Recycling Trials .......................................................................... 92
  14.2.1 Natural HDPE Hot-Washed Flake Results .................................................... 92
  14.2.2 Characterisation of Recycled Natural-HDPE flake .......................................... 94
  14.2.3 Decontamination, Extrusion and Filtration of Nat-HDPE to Pellet .................. 96
  14.2.4 Natural HDPE Flake End-Product Markets .................................................. 96

14.3 PET Recycling Trials ............................................................................................ 98
  14.3.1 rPET Flake Product Results .......................................................................... 98
  14.3.2 Characterisation of Recycled PET Flakes ...................................................... 99
  14.3.3 Clear rPET Flakes - End Market Opportunities ............................................. 99
  14.3.4 End-Markets for Coloured PET ................................................................. 100

15.0 Recycling of Household Plastic Film Packaging ................................................. 102

15.1 CeDo film recycling trials and methodology ......................................................... 103
  15.1.1 Film Recycling Trial Objectives ........................................................................ 103
  15.1.2 Film Recycling Methodology .......................................................................... 105
  15.1.3 Pre-trial visual compositional analysis of film balestock .................................. 105

15.2 Pre-trial wash plant and extruder condition setting ............................................... 106

15.3 First stage recycling and assessment .................................................................. 106

15.4 Second Stage film recycling refinement and assessment ...................................... 108

15.5 Recyclate production ......................................................................................... 109

15.6 CeDo Film Recycling Trials Mass Balance .......................................................... 109

15.7 Film Extrusion Trials ........................................................................................... 110

15.8 End-Product Market Opportunities .................................................................. 110

15.9 Summary and Conclusions from CeDo Film Recycling Trials ......................... 110

15.10 Conclusions ....................................................................................................... 110

15.11 Recommendations .............................................................................................. 111

16.0 Recycling of Domestic Post-Consumer Film - Best Practise Investigation .......... 116

16.1 Sorting of Film at MRF source ............................................................................ 116

16.2 Relux Umwelt GmbH ......................................................................................... 118
  16.2.1 Relux Plant Capacity and Structure ................................................................. 118
  16.2.2 Magdeburg Site Operations ............................................................................ 119
  16.2.3 Residual Waste ............................................................................................... 119
  16.2.4 Relux Brennstoffproduktion GmbH ................................................................. 120
  16.2.5 Mass Balance ................................................................................................... 120

16.3 Relux Extrusion Trials ......................................................................................... 121

16.4 CeDo Blown Film trials of Relux Resin ............................................................... 121

16.5 Gneuss Ring Extruder Devolatilisation Trials ...................................................... 124
  16.5.1 Gneuss Trial Background ............................................................................... 124
  16.5.2 Gneuss Trial Results ...................................................................................... 124
  16.5.3 Gneuss - 100 micron filtration trial ................................................................. 125
  16.5.4 Gneuss - 200 micron filtration trial ................................................................. 125

16.6 CeDo Blown Film Trials of Gneuss Resin ............................................................ 125

16.7 Extricom Ring Extruder Trials ............................................................................ 125
  16.7.1 Principles of Ring Extruder Operation ............................................................. 125
  16.7.2 Extricom Ring Extruder Venting/Devolatilisation .......................................... 125
  16.7.3 Extricom Trial Results .................................................................................... 126
  16.7.4 Conclusions ..................................................................................................... 126

16.8 Erema Film Recycling Trials .............................................................................. 126
  16.8.1 Erema Film Recycling - Trial Objectives ....................................................... 126
  16.8.2 Erema Film Recycling - Trial Results .............................................................. 126
  16.8.3 Erema Film Recycling Trial Conclusions ........................................................... 126

16.9 MAS Film Recycling Trials .................................................................................. 126
  16.9.1 MAS Film Recycling – Trial Objectives ........................................................... 126
1.0 Project Introduction

This project was commissioned by WRAP to build on previous work involving mixed plastics, including the project ‘Domestic Mixed Plastics Waste Management Options’ (MDP017). This report concluded that it is technically feasible and environmentally beneficial to remove mixed plastics from the waste stream prior to disposal.

‘Mixed Plastics’ is a term that covers all non-bottle plastics packaging sourced from the domestic waste stream and includes rigid and flexible plastic items of various polymer types and colours that are typically found in the household waste bin. It excludes plastic bottles and non-packaging items.

There is approximately 1.3 million tonnes of domestic mixed plastics packaging waste arising in the UK each year and most of this is going to landfill. This material is a valuable resource and WRAP aims to develop capacity in the UK to recycle mixed plastics packaging waste to produce valuable raw materials that can be substituted for virgin plastic in the manufacture of new items. This realises environmental benefits by reducing waste sent to landfill and reducing CO₂ emissions.

This project assesses the detailed business case for a commercially sustainable, integrated mixed plastics waste management solution in the UK. To help address this, WRAP aims to develop a minimum of 40,000 tonnes/yr of recycling capacity in the UK for mixed plastics by 2011, which can process the anticipated increase in household mixed plastics recovered for recycling, and support end market demand for recycled plastics.

This project investigates the challenges for Materials Recovery Facilities (MRFs) in supplying mixed plastics waste for recycling, and demonstrates how MRFs can handle mixed plastics in an integrated and economically sustainable way.

The project also describes the practical & commercial feasibility of the next stage in the recycling chain, with the establishment of Plastic Recovery Facilities + further reprocessing (PRFs +) to utilise the maximum percentage of plastic waste, otherwise destined for landfill.

Project Structure

The project was carried out on a large scale. For example, there were 26 different businesses involved and more than 165 tonnes of waste plastic materials was processed. In order to provide the breadth and depth of detail required in each area, the project was split into three subsections as follows:

LOT 1 - MRF Processing and Supply of Mixed Plastics Waste

This section carried out a detailed assessment of the sorting process in three MRFs to distribute wider knowledge of the role of MRFs in the mixed plastic recycling chain. It investigated processes and equipment required for sorting mixed plastics as well as the economic drivers for supplying mixed plastics to a downstream PRF, in an economical and sustainable format.

LOT 2 - Commercial Scale Recycling Trials and Management of Residual Waste

This part of the project carried out large scale recycling trials using an integrated approach capable of handling mixed plastics, including films and rigid plastics. This phase demonstrates the feasibility of recovering mixed plastics waste using current best practices incorporated into a plant that covers PRF + reprocessor functionality. It then demonstrates conversion of this waste stream into resins that have the potential to replace high value virgin plastics and ultimately places the reprocessed plastics into commercial end products.

The project objective was to build a PRF + reprocessor mixed plastics recycling plant model for the UK. This was done by working together with the key recycling experts, technology providers and reproducers in the UK and where needed in the EU. Reprocessing of mixed plastics packaging using the latest available technologies in separate plants was performed to show that if a combined PRF + reprocessor mixed plastics plant was built with the key recycling technologies in the UK it would be capable of producing high quality output polymer resin streams that could be used in a number of commercial plastics markets.

LOT 3 - Economic/Financial Assessment of the Business Case

This section of the project illustrates financial models for an integrated mixed plastics waste management solution. This includes detailed assessments of the economic sustainability of: Sorting co-mingled waste into mixed plastics streams in a MRF; Installation of new capital equipment or additional infrastructure requirements; An integrated ‘PRF + reprocessor’ producing recycled polymers as defined by the trial phase.
The main body of the report follows the journey of the mixed plastics waste from MRF to viable end products or usable residuals. Each section of the report provides detailed analysis and each sub-section has a summary and highlights key points learned as a result of the trials.

The flowchart on the next page graphically illustrates the origins of the mixed plastics used in the trials and traces the routes of the mixed plastic waste through sorting, processing and onto manufacture of new items.
2.0 Introduction - MRF Processing of Mixed Plastics

The first section of this report provides the key findings from MRF processing of mixed plastics and retail collection of mixed plastics from front of store units. A Materials Recovery Facility (MRF) is a specialised plant that receives, separates and prepares recyclable materials for further reprocessing. WRAP has identified the growing role of MRFs in increasing the recovery of materials from the waste stream.

One of the key project objectives was to develop an understanding of the role of MRFs in supplying mixed plastics packaging for recycling. The project investigated the challenges involved and identified the equipment and processes for sorting mixed plastics packaging from a commingled stream. In particular it identified the equipment and processes required for a prospective MRF to recover mixed plastics packaging in an efficient and economically sustainable way. This is described in Sections 2 to 6 of this report.

MRF Processing and Supply of Mixed Plastics Waste

This section of the project carried out a detailed assessment of the sorting processes in three different MRFs. The aim was to better understand the way in which MRFs handle mixed plastics and the challenges facing those that may be considering adding mixed plastics to their own activities. It investigated processes and equipment currently used for sorting of mixed plastics in two MRFs with different types of local authority collection schemes, as well as reconfiguring systems in a third MRF that currently does not handle mixed plastics.

At the start of the project, twenty MRFs were contacted around the UK and surveyed regarding their current capabilities. From this list, three located in three different regions in the UK geographically diverse MRFs from England, Scotland and Wales were chosen to take part. Trials lasting a minimum of 48 hours production time at standard throughput rates was undertaken, using the MRFs own facilities, during this phase of the project. This ensured that the trials were of a commercial scale and relevant to MRFs considering adding plastics in the future.

The trials do not directly compare the MRFs against each other, but the report does detail current practices and systems, which would be common to any MRF considering mixed plastic recycling.

MRF C currently handles mixed plastics in all forms (films and rigids), but does not accept glass. MRF B recycles some plastic bottles, includes rigid mixed plastics, but also asks for glass in their collection scheme. MRF A asks for plastic bottles but does not ask for mixed plastics, had no real mixed plastic recycling, but receives some mingled in with its normal intake.

Figure 1. Manual sorting at one of the trial MRFs

MRFs Structure and Capacity

The following table provides an overview of the MRFs processing capacity, shift patterns and also actual average throughput rates. All MRFs have higher available capacity than their actual average throughput rates.
Focus of the MRF trials

The focus of the MRF trials was to measure the following parameters:

- Compositional analysis of materials going into the facility.
- Operating efficiencies and outputs.
- Product quality and contamination risks.
- Residual materials.

The report details the effects of mixed plastics processing on other MRF output streams, when mixed rigid plastics and film are already collected, or indeed introduced. Specific data showing contamination levels that can be expected and the effect on overall MRF output quality, is demonstrated and shows that MRFs can sort mixed plastics (films and rigids) and this does not impact on the quality of other material streams.

All trial results were cross-referenced with normal production data to ensure that this was typical and that the trials did not lead to anomalous results.

During trials at all three MRFs, particular attention was paid to the challenge posed by the acceptance of film within the mixed plastic stream. This report demonstrates that MRFs can handle the processing of films from household plastic packaging but need to remove films early in the separation process to minimise potential problems with sorting downstream.

All the MRFs in the trials had some form of automated sorting, but this was not always concentrated on their plastics recovery. The report looks at manual and automatic sorting of plastics in detail and focuses on the output quality that can be expected when these techniques are introduced, showing that MRFs can use automated sorting techniques to improve purity of materials recovered.

### 3.0 Trial Results from MRFs Currently Sorting Mixed Plastics

#### 3.1 MRF Assessment Methodologies and Trial Differences

Each MRF differs in configuration, equipment selection and operating practice. For these reasons the methods used to investigate process behaviour needed to be tailored to each set of circumstances. Methodologies adopted for the assessment of the MRF processing trials are fully described in the 'Mixed Plastics Commercial Scale Recycling: Appendices' report. The MRFs already processing mixed plastics were experienced in handling this material composition, unlike the MRF only used to handling plastic bottles, and this should be taken into account when viewing results.

#### 3.2 MRF Processing Trial Objectives

The overall objective of the MRF processing trials was to determine how mixed plastics can be effectively handled by a MRF in an economically sustainable way. This involved engaging with three local authority MRFs spread throughout the UK to undertake a detailed analysis of the MRF processes over a combined period of 48 hours to
assess setup, efficiency, and capacity for processing mixed plastics. It also examined the impact on quality that mixed plastics had on other recyclate product streams. The detailed objectives included:

- conduct a compositional analysis of input/output materials with detailed breakdown of material composition by generic material type as well as material composition by polymer type within the plastic bottle and mixed plastics fractions;

- operate trials involving a minimum of two MRFs already accepting a co-mingled stream containing mixed plastics; and

- conduct trials at one MRF not currently accepting mixed plastics.

3.2.1 Requirements for MRF Assessment

Initially, an evaluation of the current key MRF processes and technologies was performed. A compositional analysis methodology was developed for input/output materials from domestic co-mingled local authority collection systems to be analysed (objectives are above. This required the project team to:

- Secure a supply of co-mingled domestic mixed plastics packaging waste sufficient for at least 48 hours of actual processing time within a commercially operating MRF environment;

- Develop trial methodology including a waste analysis methodology based on the representative sampling of 48 hours worth of procured materials;

- Carry out composition analysis of mixed plastics; (e.g. composition by polymer type within the mixed plastic bottle and mixed rigid plastic fractions);

- Undertake a compositional analysis of the input/output materials to evaluate the level of contamination caused by mixed plastics on other material product streams (e.g. contamination of output material and potential effect on process efficiencies);

- Evaluate plant performance: (i) key operating rates and capture efficiencies; (ii) plant and operational data; (iii) fees and operational costs; (iv) value of the output material streams; and (v) product quality and contamination and residue;

- Cross-reference trial results with normal production data to check that they were typical and consistent with the MRFs normal operational parameters. Ensure that results were not isolated or anomalous.

3.3 Selection of MRFs and Material Supply

In the initial stage of the project, research was carried out to identify the MRFs most appropriate for these trials. The aim was to identify MRFs, which accepted municipal sourced mixed plastics co-mingled with a selection of other dry recyclate materials. A number of privately operated MRFs were identified and many were keen to be involved in these trials, however due to commercial sensitivities those selected were MRFs operated by local authorities.

The following sections outline the MRFs selected. The MRFs have been made anonymous to protect their commercial identities and they are referred to as MRF A, MRF B and MRF C. Due to the trial methodology adopted, the MRF trial results are not reported in MRF alphabetical order, but are reported as they took place.

MRF B

Operates a collection system where the recyclate is collected in plastic sacks, a stock of which is provided to each household. Materials requested include: food tins; drink cans; aerosols; plastic bottles; yoghurt pots; margarine tubs; plastic punnets/ready meal trays; glass bottles and jars (unbroken); jam jar lids; newspapers; telephone directories; magazines; junk mail/flyers; office paper; catalogues and all card. This MRF was selected as it requests glass in its co-mingled collection service which would allow the trials to assess the impact of glass on the
segregation of mixed plastics and the quality of other recyclate streams. This MRF did not specifically request post-consumer film from households, however it had to deal with film because of the recyclate collection plastics sacks.

**MRF C**

Materials for MRF C are collected loose from kerbside and included: newspapers and magazines; cardboard; drinks cans; food tins; plastic bottles and other plastic containers; junk mail and catalogues; clean plastic carrier bags; telephone directories; clean aluminium foil. MRF C was selected as it requested plastic film in its co-mingled collection service, which would allow the trials to assess the impact film would have on the segregation of mixed plastics and the quality of other recyclate streams.

**MRF A**

Operates a kerbside collection system which accepts paper, plastic bottles, food tins, and drink cans. Card, glass and plastic film are excluded from collection. Although mixed plastics are not requested, a relatively high proportion is received at the facility, which ends up in the residual waste pile. It was therefore assumed that the facility could handle some quantity of mixed plastics. MRF A’s participation was important to allow the trials to identify the systems, processes and equipment required to retrofit a MRF not currently accepting mixed plastics to enable it to start sorting them.
4.0 MRF B Processing Trials

MRF B is responsible for the handling of approximately 37,500 tonnes of recyclate from neighbouring areas and has a capacity of around 50,000 tonnes per annum. The facility accepts material from collections, including those using plastic sacks and those who collect co-mingled material in a 240l wheeled bin system (though many householders use plastic carrier bags). The bulk of the supply comprises householder separated co-mingled recyclables in plastic sacks that are provided to each household within the county. The sacks are collected fortnightly by dedicated compacting collection vehicles.

4.1 MRF B Targeted Materials

MRF B was asked to participate in the trials because it accepts co-mingled recyclate materials, including mixed plastics, from domestic collections, and glass. Its inclusion in the trials enabled a demonstration of the impact mixed plastics has on other material streams, including glass. Materials are requested clean from householders and include:

- Plastic bottles; yoghurt pots; margarine tubs; plastic punnets/ready meal trays;
- Food tins; drink cans; aerosols;
- Glass bottles and jars (unbroken); jam jar lids;
- Newspapers; telephone directories; magazines; junk mail/flyers; office paper; catalogues; all card.

4.2 The Sorting Process

MRF B requires some manual sorting as well as considerable investment in various screening devices for dividing materials into categories. The facility uses Lubo screening technology for material separation.

4.3 Feed System

Collection vehicles discharge recyclables to an offload area. The bulk of the recycled materials are contained within the MRF B in plastic sacks. Different local authorities use differently coloured plastic sacks. A front end loader picks material from the delivery hall and deposits it into the bag opening unit which comprises a conveyor belt which forces the feed beneath a spiked roller. The bags are ripped and the contents discharged indirectly onto an elevating conveyor via an intermediate conveyor.

4.4 Film Removal

The elevating conveyor takes the stream to a Lubo (star) screen. En route, the elevating conveyor passes through the first sorting cabin where two sorters remove as much film as they can access (mainly plastic sacks used to collect the recyclate). A suction hood is located centrally over the belt, which is used to send the film to a baling system. Miscellaneous contamination is also removed and dropped into collection baskets.

4.5 Non–Plastic Materials Separation

**Glass**

Glass fines are removed at first screen, following removal of steel, by a dedicated glass breaker and subsequent Lubo star screens.

**Cardboard and Plastic Film**

Cardboard is removed manually for later baling. Manual removal of plastic film utilises overhead suction tubes with film being transported pneumatically to a dedicated baler.

**Paper**

The remaining material is conveyed to an inclined twin deck star screen, which has three output streams; at the higher end of the top deck high grade (newspaper and magazines grade) paper is separated, at the higher end of the bottom deck second grade (mixed grade) paper is separated and at the lower end of the bottom deck, containers fall through for onward separation.
The two paper streams are then subjected to manual quality control. The newspaper and magazines grade proceeding from sorting cabin three to discharge directly into the top of walking floor trailers. The mixed paper grade is fed from sorting cabin four directly to a large automatic baler.

**Steel**
The container stream is joined by the fines and the combined stream then passes beneath an over-band magnet where steel is removed and subsequently densified in a dedicated steel ‘biscuit’ baler.

**Aluminium**
An eddy current separator discharged the aluminium stream onto a sorting table where aerosols and aluminium foils were removed; manual removal of any paper and plastic contamination is also performed. The aluminium product is manually inspected before being sent to a storage bunker through a pneumatic conveyor system. A conveyor then transports the remaining container stream (mostly plastics) on to sorting station 5.

### 4.6 Manual Sorting of Natural HDPE and Mixed Plastics

The stream now comprises mixed plastics, misdirected papers and contamination. This is sent to a manual sort conveyor (sorting station 5), which runs above a series of five storage bunkers. Bunker 1 receives aluminium, bunkers 2, 3, 4 and 5 are capable of storing manually segregated plastic containers. Currently natural HDPE, mixed PET (natural and coloured), and mixed plastics containers are sorted into bunkers. All bunkers are served by a dedicated conveyor system leading to a large automatic baler. Remaining material from sorting station 5 is baled for subsequent sorting at another MRF.

### 4.7 MRF B Trial Results: Compositional Analysis

The compositional analysis at MRF B was carried out by collecting samples of input and output materials and conducting a detailed composition analysis. Two trials took place at MRF B.

- Trial 1 MRF B: 8/12/08 (16 hours); and Trial II MRF B: 21/1/09 (8 hours).

Figure 3 shows an overview of the flow of material from what the local authority request from the public and the composition of what they actually receive. This shows that at the MRF B paper is the largest infeed material 44% followed by cardboard (20%) and glass (14%). Figure 3 also shows the product streams are produced by the MRF after the materials are sorted. Glass accounts for 32% of the output material with paper accounting for 44%.

**Figure 3. Overview of MRF B material infeed and product streams**

At MRF B, eight samples of infeed material were taken with an average sample weighing 26.6kg. In total 212.6kg were analysed over the 16-hour period of operation.
Figure 4 provides aggregate data on the overall composition of infeed material, including a breakdown of some polymer types. Paper and cardboard made up the majority of the material, followed by glass and plastics.

**Figure 4.** MRF B Infeed Composition [Note: these results are based on trial data; MRF B operator reports that normal card content would be around 5% and normal glass 23% of the feed]

<table>
<thead>
<tr>
<th>MRF B Overall MRF Infeed Composition Sample 1 to 8 input analysis</th>
<th>%</th>
<th>Max %</th>
<th>Min %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>43.81%</td>
<td>67.36%</td>
<td>10.13%</td>
</tr>
<tr>
<td>Cardboard</td>
<td>20.38%</td>
<td>62.25%</td>
<td>7.08%</td>
</tr>
<tr>
<td>Glass</td>
<td>13.52%</td>
<td>25.33%</td>
<td>2.75%</td>
</tr>
<tr>
<td>Plastic Film</td>
<td>3.81%</td>
<td>7.83%</td>
<td>2.23%</td>
</tr>
<tr>
<td>PET Bottles</td>
<td>3.43%</td>
<td>6.06%</td>
<td>1.83%</td>
</tr>
<tr>
<td>Other plastics rigids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PET</td>
<td>0.92%</td>
<td>1.51%</td>
<td>0.36%</td>
</tr>
<tr>
<td>PP</td>
<td>0.90%</td>
<td>1.59%</td>
<td>0.43%</td>
</tr>
<tr>
<td>PVC</td>
<td>0.68%</td>
<td>1.67%</td>
<td>0.12%</td>
</tr>
<tr>
<td>PS</td>
<td>0.53%</td>
<td>1.14%</td>
<td>0.20%</td>
</tr>
<tr>
<td>HDPE</td>
<td>0.28%</td>
<td>0.69%</td>
<td>0.03%</td>
</tr>
<tr>
<td>LDPE</td>
<td>0.02%</td>
<td>0.05%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other rigid plastics</td>
<td>0.00%</td>
<td>0.03%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Total other rigid plastics</td>
<td><strong>3.33%</strong></td>
<td><strong>4.62%</strong></td>
<td><strong>1.40%</strong></td>
</tr>
</tbody>
</table>

During the trials the average composition of other rigid plastics was 3.33%. Over the eight samples this had a standard deviation of 1.08% of the total sample size.

### 4.8 Composition of Other Rigid Plastics

The other rigid plastics category separated during the trial was retained for further analysis at the PRF. The analysis enabled the relative quantities of polymers to be identified. The results are shown in Figure 5.

**Figure 5.** Composition of Other Rigid Plastics (MRF B)

<table>
<thead>
<tr>
<th></th>
<th>Aggregate %</th>
<th>Max %</th>
<th>Min %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET Bottle</td>
<td>27.60%</td>
<td>40.14%</td>
<td>17.61%</td>
</tr>
<tr>
<td>PP</td>
<td>27.06%</td>
<td>42.19%</td>
<td>17.56%</td>
</tr>
<tr>
<td>PVC</td>
<td>20.47%</td>
<td>40.00%</td>
<td>3.70%</td>
</tr>
<tr>
<td>PS</td>
<td>15.85%</td>
<td>24.63%</td>
<td>8.49%</td>
</tr>
<tr>
<td>HDPE Bottle</td>
<td>8.35%</td>
<td>19.38%</td>
<td>1.24%</td>
</tr>
<tr>
<td>LDPE</td>
<td>0.55%</td>
<td>2.34%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other/Contamination</td>
<td>0.13%</td>
<td>0.74%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Closures</td>
<td><strong>4.46%</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A proportion (4.46%) of the polymers were found to be closures (bottle tops, lids, etc). These were loose closures, expected to leave the container stream at the first screen. However, closures can be found at various other points throughout the plant, largely because many plastic bottles, for example, are collected with the tops on and these are removed or fall off throughout the process.
4.9 MRF B Plant Performance – Operating and Material Capture Efficiencies

MRF B processes the collected recyclable materials at a rate of between 10 and 12 tonnes per hour.

4.10 MRF B: Assessment of Product Quality

Product quality was determined through a combination of composition analysis, visual inspection, existing MRF data and video/photographic evidence.

Plastic products and ‘end of line’ material are stored outside, but only for limited periods. The baled paper is stored under cover and the prime paper grade is fed dry and loose directly to vehicles. The glass product is stored outside in concrete bays.

The input material had little contamination from materials not requested by the council. The exception to this was liquid carton board packs, which are currently not requested by the local authority, but account for 1.28% of the composition. Other contamination materials accounted for 2.54%, however on visual inspection this was mostly small fragments of paper and plastics.

Plastic film accounted for 3.81% of the input stream; however this was principally made up of the plastic collection sacks used to collect the recyclate from the public but made up only 1% of the output.

Paper Quality

Paper product quality was analysed by looking at video footage of the final conveyor and by directly observing the line. For both methods it was firstly required to estimate the throughput of paper at the MRF. The assessments made of paper rate were calculated using the overall throughput estimates of the MRF using a paper infeed composition of 43.8% and a capture efficiency (for loose paper) of 51%. In summary:

- The materials observed were used to provide approximate contaminant weights and the plastic contamination level was calculated to be 0.18% (0.14% film, 0.04% other rigid plastics);
- It was concluded from the video assessments that the quality of the MRF B loose paper stream was high, with a contamination level of between 0.074% and 0.12%. It is more likely to lie at the lower end of this range;
- It was concluded from direct visual assessments of the infeed belt that the quality of the MRF B loose paper stream is high, with a contamination level of between 0.018% and 0.11%.

Glass Quality

To assess the level of contamination from other containers an approach similar to paper was undertaken, whereby the glass product conveyor was observed for two-minute periods and counts made of the plastic and metal contaminants.

The metallic contamination was exclusively aluminium and the plastic contamination included generally smaller plastic bottles, smaller plastic rigid items and fragments. The contamination level of the glass stream from containers was assessed at 1.51%, of which 1.18% was rigid plastics and plastic bottles.

In terms of loss of material available for subsequent sort/selection points, approximately 2% of rigid flattened plastics and around 3% of aluminium (as flattened cans) are lost to the glass stream.

Aluminium Quality

Observing bales and reviewing the method for aluminium separation was sufficient to establish that the quality of aluminium was high.
**Steel Quality**  
During the trials steel bales were broken, analysed and weighed to assess the contamination levels.

This showed that on average 4.1% of the steel bales were non-steel materials by weight.

The contamination of the bales attributable to plastics was 1.2%, the 'other rigid' component being 0.8% of the bale weights.

**Natural HDPE Quality**  
Bales of HDPE natural bottles were reviewed and the quality was noted as high at 99.03%. Occasional contamination was observed in the form of incorrect polymers in bales, but this was rare.

Natural HDPE bale contamination was 0.03% film, 0.3% closures, 0.1% PP, 0.03% PS and 0.37% paper and card.

**Mixed Plastics Composition and Quality**  
The selection criterion for mixed plastics is all remaining plastic after upstream selection of natural HDPE bottles. Observation of the sorters showed that an emphasis was placed on remaining bottles, as they are easier to recover and contribute more to weight diversion. Surprisingly, PET bottles were not actively recovered even though they formed 50% of the mixed plastics residue. The key results of the mixed plastics analysis are shown in Figure 6 and tabulated in Figure 7.

![Figure 6. Composition of Mixed Plastic Product: Key Materials (MRF B)](image)

As can be seen from Figure 7, 51% of the mixed plastic material stream at MRF B was made up of clear PET bottles, followed by rigid PP (14%) and natural HDPE bottles (12%) were most commonly found.
Contamination in this mixed plastics product was made up of materials such as paper/card; liquid carton board; glass and residues and equated to 7.37%, of the stream. This was considered to be a relatively low level of contamination.

Figure 8 shows the obvious presence of this high level of PET in the mixed plastics output stream.

### Figure 8. Mixed Plastics output from MRF B clearly showing the large proportion of clear PET bottles

4.10.1 MRF B: Plant Performance – Residue

The residual materials at the plants (2.5% of output) were analysed to identify the quantity of recyclate not being captured by the MRF. The residual material was baled and its destination was typically determined by the current market conditions. A bale of this material was forwarded to the PRF in order to carry out a compositional analysis. The analysis by material type is shown in Figure 9.
MRF B operates on the assumption that bales of residue comprise of approximately 50% plastic and 50% paper. Mixed paper and plastic from MRF B was recently forwarded for further processing. The ‘normal’ route for the material is to an energy from waste scheme, which provides energy to a linked cement works. The results of the trial compositional analysis suggest that the plastic content is in fact lower at approximately 30%. Since the residue stream at MRF B is 12% of the infeed, the presence of 30% mixed plastics in the residue stream means that approximately 30% of all plastic processed is lost to this low value stream.

4.10.2 MRF B: Mixed Plastics Processing Issues

There are five product bays available beneath the final sort area. One bay is reserved for aluminium cans pneumatically transferred from the quality control table beneath the eddy current separator. The second bay receives natural HDPE and the third a stream referred to as mixed plastic. Clear PET bottles form the greatest part of this mixed plastic stream. This means that the bulk of the mixed plastic material stays on the conveyor and is baled as end of line residual material.

The MRFs ability to handle film was assessed, even though the public are requested not to include plastic sacks/film with their recyclables. MRF B has to remove film/sacks used as collection containers and those erroneously included by the householder. Previously film was included in the collection, but process problems resulted in a change in policy. No challenging process problems were observed, except that the presence of film provides a potential to contaminate other products. The nature of film is such that this is more visible than it is damaging to product quality. Technically, the approach of removing film from the conveyors manually, is effective and the suction system easily sends the film material to a central point for baling.

4.10.3 Key Findings from MRF B Processing Trials

Where glass is already collected as part of a co-mingled scheme, the inclusion of mixed rigid and film plastics is feasible.

- The inclusion of other rigid plastics co-mingled with paper/cardboard, cans, plastic bottles and glass did not greatly affect the quality of the product streams; the overall value of the materials was therefore not affected;

- Minimal quantities of rigid and film plastics contamination was identified in paper (0.18%), steel (0.8%) and glass (1.18%) products;
The infeed material was considered clean with only 4.2% contamination present; and contamination from glass breakages across all product streams was minimal due to glass fragments being screened out early in the process;

The paper product quality was not affected by inclusion of mixed plastics, film and glass;

Paper quality observed during the trials was high, with only 0.2% of contamination recorded;

Rigid plastics accounted for 0.04% of contamination and film for 0.14%.

**The mixed plastics residue product contained high levels of PET and HDPE bottles.**

The majority of the mixed plastics residue product during the trials was PET (58%), followed by HDPE (19.49%), PP (14.03%), PVC (1.75%) and PS (0.37%) with the remainder being contamination;

The 58% PET included 51% clear bottles, 6% coloured bottles and 1.5% other rigid plastics;

It should be noted that during the trial the MRF was not collecting PET due to end market conditions, which contributed to the high levels found in the mixed plastics composition.

There is plenty of scope to improve material capture efficiencies and reduce quantities of residual material.

The majority of the residual stream is made up of paper/card (65%) and packaging plastics (28%);

Currently MRF B sends its residue to a private contractor for further treatment and recovery;

The capture rate for HDPE was estimated at 35%, other rigid plastics at 59% and plastic films at 26%.
5.0 MRF C Processing Trials

MRF C was selected for the trials as it actively requests plastic film and mixed rigid plastics from a kerbside collection service, in addition to the usual co-mingled materials such as paper, cans and plastic bottles. The involvement of MRF C in the trial would show how accepting plastic film can be recovered and how film affects MRF processes and the recyclate streams. The trials at MRF C were carried out over a two-day period.

5.1 MRF C Targeted Materials

MRF C was established in 2001 and was designed to process 12,000 tonnes per annum (tpa) and currently operates at approximately 8,500 tonnes per annum (tpa). The MRF has continually adapted its targeted materials in line with local authority policy and contracts. The materials that MRF C currently collects are:

- Newspapers and magazines, cardboard, catalogues and junk mail, and telephone directories;
- Drinks cans, food tins, clean aluminium foil;
- Plastic bottles and other rigid plastic containers, film including clean plastic carrier bags.

5.2 MRF C Material Sorting Process

The material is collected loose at kerbside in containers provided to each household. These containers are emptied into a collection vehicle and deposited at the offload area of the MRF. MRF C includes a series of manual sort cabins with each allocated specific materials to collect.

A central part of the processing line is an automated Bezner inclined sort table. This is essentially a conveyor belt which uses an incline for moving containers down the belt whilst the friction of the belt helps the paper move across it, thus segregating the paper from the containers. This is positioned immediately after a vibrating screen and this combination removes fines from the material as well as separating containers from paper. The acceptance of mixed plastics introduces both plastic film and various trays and other rigid plastic profiles. Figure 10 presents a schematic of the facility.

Figure 10. Schematic of MRF C material separation
5.2.1 Feed System

Vehicles bring mainly loose recyclables, there are also some bags containing recyclable items. For this reason a bag opener is installed at the start of the infeed conveyor.

Initial Sort Cabin
The loose materials are conveyed to the first sort cabin where seven manual sorters are employed on three tasks. Firstly, plastic film is picked from the line, then large non packaging contaminants are removed and sent to a waste pile, and thirdly card and cardboard items are collected.

Material Screening
The remaining material is then screened to remove items smaller than 63mm and passed onto the Bezner inclined table. Objects capable of sliding down the conveyor incline are directed to the containers processing line. Flat items pass onto the paper processing line.

Bezner Screen
Figure 11 shows the MRF C shaker table and Bezner Screen, which is used for removing fines and segregating paper from containers.

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Figure 11. MRF C shaker table and Bezner screen for removal and fines and segregating paper from containers

Paper and Sort Cabin
Initially the paper processing line is contaminated with material that has not moved downward on the Bezner inclined table. A conveyor takes the paper stream through a Near Infra Red (NIR) automatic sorting machine, which identifies all non-paper items such as containers and ejects them; these items are then conveyed to join the container processing line. The paper stream then passes through a sort cabin where 3 manual sorters remove any remaining contaminating materials. The paper product discharges from the end of the sort cabin to a storage bay. Contaminating materials are collected in a bin below the cabin and are exported to another MRF.

Containers Sorting
The container material stream rejected by the NIR unit introduces missed containers, mixed plastic and other items to the container line but also brings with it a considerable amount of paper. The joint container stream passes through a small sort cabin with two manual sorters. One removes as much paper as possible and the other removes plastic film that was missed in the first sorting cabin. This product is baled directly underneath the second sorting cabin.

Steel
The remaining container stream passes beneath an over-band magnet, which removes steel and ferrous metals from the container stream.
Final Sort Cabin  
The final sort cabin has seven manual sorters. At the time of the first visit the product streams targeted in this cabin were:

- Clear PET bottles;
- Natural HDPE bottles;
- Plastic film;
- Mixed plastics (where: mixed plastics were made up of coloured bottles, pots, tubs and trays);
- Aluminium.

MRF C Residue Stream  
The residue material is transferred to a storage bunker outside the building. When time allows this may be put back through the processing line to try and recover more material. When all desired processing is complete all residue is sent to another MRF where remaining recyclable materials are recovered. MRF C pay a gate fee for this, however it avoids landfill costs and ensures its net residue is maintained at around 3%.

5.2.2 MRF C Trial Results: Compositional Analysis  
A detailed compositional analysis at MRF C was carried out by taking samples of input and output materials. Figure 12 shows an overview of the flow of material requested from the public and the composition actually received. This shows that at MRF C the largest percentage of infeed material is paper (61%) and cardboard (18%).

Figure 12. Overview of MRF C material infeed and product output streams

- At MRF C, paper accounts for 48% of the output material. The end of line material accounts for 26% of the output, however it should be noted that MRF C sends this material for further recovery of recyclate;

- Nine different samples of infeed material were analysed at MRF C with the average sample weighing 24.6kg. In total 221.3kg were analysed over the 16 hour period of operation.

Figure 13 provides aggregate data on the overall composition of infeed material, including a breakdown of materials and specific polymer types:
Paper and cardboard accounted for the highest percentage of the infeed material at 79.67%, with paper accounting for 61.41% and cardboard 18.26%;

Of the metal content (5.55%), aluminium accounts for 20.4% of this, with steel making up the remaining 79.6%;

No glass was identified in the MRF C infeed material. If any were present it would have been seen as a contaminant as it is not a requested material;

Only a small amount of liquid carton board was found in the sample at 0.27% and fines accounted for 0.35%;

Plastics accounted for 10.56% of the total infeed composition. This was comprised of HDPE at 2.45%, which is comparable with that of MRF B, with a comparably lower PET presence of 2.25%;

During the trial the average level of other rigid plastics was 3.29%. Over the nine samples this had a standard deviation of 0.98% of the total sample size;

The content of plastic film at 2.57% is less than that of other MRFs (e.g. MRF B 4%), which use plastic sacks in its kerbside collection schemes.

Once an initial composition analysis had been conducted on the infeed material to the MRF, the rigid plastic component was further analysed to identify the composition by polymer type.

The results of this analysis are given in Figure 14 and show that the most common polymers to be found in the 'other rigid plastics' category were PP (28%), PET (23%), PVC (20%) and PS (15%). Bottle tops (closures), which are primarily PP or PE, accounted for 2.55% of the rigid plastics.

<table>
<thead>
<tr>
<th>MRF C Overall Infeed Composition Sample 1 to 9 input analysis</th>
<th>%</th>
<th>Max %</th>
<th>Min %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>61.41%</td>
<td>76.22%</td>
<td>48.67%</td>
</tr>
<tr>
<td>Cardboard</td>
<td>18.26%</td>
<td>33.92%</td>
<td>8.54%</td>
</tr>
<tr>
<td>Steel</td>
<td>4.42%</td>
<td>9.17%</td>
<td>2.06%</td>
</tr>
<tr>
<td>Residual</td>
<td>3.60%</td>
<td>7.54%</td>
<td>0.31%</td>
</tr>
<tr>
<td>Plastic Film</td>
<td>2.57%</td>
<td>4.08%</td>
<td>0.91%</td>
</tr>
<tr>
<td>HDPE Bottles</td>
<td>2.45%</td>
<td>3.58%</td>
<td>1.61%</td>
</tr>
<tr>
<td>Other plastic rigid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>0.91%</td>
<td>1.27%</td>
<td>0.23%</td>
</tr>
<tr>
<td>PET</td>
<td>0.76%</td>
<td>1.08%</td>
<td>0.37%</td>
</tr>
<tr>
<td>PVC</td>
<td>0.64%</td>
<td>1.13%</td>
<td>0.36%</td>
</tr>
<tr>
<td>PS</td>
<td>0.49%</td>
<td>0.89%</td>
<td>0.04%</td>
</tr>
<tr>
<td>HDPE</td>
<td>0.31%</td>
<td>0.57%</td>
<td>0.06%</td>
</tr>
<tr>
<td>Other rigid plastics</td>
<td>0.16%</td>
<td>0.54%</td>
<td>0.00%</td>
</tr>
<tr>
<td>LDPE</td>
<td>0.01%</td>
<td>0.13%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Total other rigid plastics</td>
<td>3.29%</td>
<td>4.65%</td>
<td>1.67%</td>
</tr>
<tr>
<td>PET Bottles</td>
<td>2.25%</td>
<td>4.75%</td>
<td>1.22%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>1.13%</td>
<td>1.36%</td>
<td>0.72%</td>
</tr>
<tr>
<td>Particles&lt; 10mm</td>
<td>0.35%</td>
<td>1.63%</td>
<td>0.06%</td>
</tr>
<tr>
<td>Liquid Carton Board</td>
<td>0.27%</td>
<td>0.65%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Glass</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
5.3 MRF C: Plant Performance - Operating and Material Capture Efficiencies

The MRF operational data was evaluated within the context of longer term MRF performance. MRF C provided comparative data for the past 12 months, during which time the MRF configuration and material composition has remained reasonably constant.

5.4 Plant Throughput and Product Data

Combining MRF C’s 2007-2008 annual data for processed recyclables, as shown in Figure 15, with the equivalent annual downtime, provides an average throughput of 6.22 te/hr.

The plant throughput was estimated at 6.39 te/hr after taking into account the production rate of steel bales, the percentage contribution to the infeed steel represents and the capture efficiency of the plant for steel. There is reasonable agreement between the two methods.

Capture efficiency data by material, for three different periods are provided in Figure 16, along with the overall mass balance for each period. The mass balance figure over the 2007-2008 period was 3.59%. This is the difference in quantity of kerbside material supplied into the MRF and the sum of all materials and residue sorted.

During the trials the capture efficiency was estimated at 77% for HDPE bottles, PET bottles (68%), other rigid plastics (60%) and plastic film (59%).
5.4.1 MRF C Trial Product Quality

Product quality was determined by a combination of composition analysis, visual inspection, existing MRF data and time lapsed camera recording.

All paper and card products are stored indoors. The paper forms a loose pile, which is loaded onto vehicles with mobile plant. The card is baled and stored indoors. Plastic products are baled and stored outside. Metals are baled and may be stored either both indoors or outdoors as space allows.

The main trial contaminants were liquid carton board (0.27%) and fines (0.35%). The fines were principally made up of degraded paper and plastic fragments.

Paper Throughput and Quality
The MRF C paper product quality assessment is represented by a grade; usually between 0 and 6, with any score less than 1 potentially being rejected, this assessment is done by MRF C’s key client. Quality is assessed on receipt and MRF C is provided with a report of the findings. Average score over the last 12 months awarded was 3.41.

Time lapsed camera recordings were taken (156 seconds) of the paper line at the end of the manual sort cabin. Two assessments on the quantity and quality of paper produced were conducted.

- Observed contamination - total 86 g;
- 15g card; 36g plastic film; 30g rigid plastic (small containers); and 5g miscellaneous (ties/string);
- Paper feed rate is estimated at 3,822 kg/hr (from long term data and operating hours); 156 seconds equates to an estimated volume of 130 kg;
- Using a capture rate of 79% suggests 3,009 kg/hr passes along the final sort belt (ignoring relatively minor paper recovered at bins).
- This equates to an overall contamination level of 0.07% for paper product based on a camera recorded assessment.
- An alternative throughput estimate was made based on MRF C’s production of steel bales.
- Paper constitutes 61% of the overall infeed rate/throughput of MRF at 5.9 te/hr. Feed rate for paper is therefore 3.6 te/hr.
- Capture rate for paper product is therefore estimated at 2.84 te/hr. within 156 seconds: 156 kg sample of paper input and 123 kg sample of product
- This equates to an overall contamination level of 0.07% for paper.
- Using a minimum rate estimation, which assumes all steel is captured - the MRF feed rate predicted is 3.8te/hr. If an infeed composition of 61% and a capture rate of 79% were applied to this figure the minimum paper product rate is 80 kg in 156 secs. The resulting maximum assessment of paper contamination was 0.11%.
- Both methods of assessment provide very similar contamination levels of 0.07%.

---

1 An example but reasonable estimate – rates for any period of interest can be recalculated using the appropriate values
2 MRF feed rate is based on trial data - steel bale rates, steel capture and steel composition
The paper contamination measured during the trial was therefore 0.07% of which 0.054% is due to plastic. Even where a minimum rate estimate of 0.11% (of which 0.084% is due to plastic) is employed the paper contamination remains within acceptable quality parameters for reprocessing.

**Aluminium Quality**

Bale analysis and an assessment of aluminium separation efficiencies established, that the quality of aluminium was consistently high and the purity of aluminium was measured at 99.74%. The contamination found consisted of 0.09% plastic film and 0.17% of other rigid plastics. Generally, these were small items that could conceivably be picked accidentally along with an aluminium item.

**Steel Quality**

Steel bales were broken up to assess the contamination levels and approximately 10% of the bale weight was found to be non-steel materials. The location of the over band magnet and upstream conditions contribute to a relatively high steel bale contamination. This was principally due to the high content of paper, card, film and other containers still present on the line, which could be pulled off along with steel depending on their position on the conveyor belt.

The total plastic contamination of steel bales by weight was 3.15%. This was made up of plastic bottles (2.12%); other mixed rigid (0.57%) and film (0.46%).

**Natural HDPE Quality**

Bales of HDPE were reviewed and the quality was noted as high at 99.69% (contamination – 0.31% caps). Occasional contamination was observed in the form of incorrect polymers in bales, however this was rare. The target at the time of the trial was natural HDPE only and it was hand picked, contributing to the high purity.

**Clear PET Quality**

Bales of PET were reviewed and again the quality was noted as high at 98.56% (contamination – 0.65% caps, 0.59% HDPE, 0.21% PP). Occasional contamination was observed in the form of incorrect polymers in bales, but this was rare. The target at the time of the trial was clear PET only and it was hand picked contributing to the high purity.

**5.4.2 Mixed Rigid Plastics Composition and Quality**

The definition for mixed plastics in this specific trial was all remaining plastic after upstream selection of natural HDPE and clear PET bottles. It was noted that sorters concentrate on maximising the collection of all remaining plastics from the conveyor and they collaborate in passing any prime polymer that was missed either directly to the appropriate sorter or via local bins. The results of the analysis of MRF C’s mixed plastics stream are illustrated in Figure 19.

**Figure 17. Composition of mixed rigid plastic product (MRF C)**
Figure 17 shows that PET bottles made up the largest proportion of the rigid mixed plastics product and accounted for 45% of the composition with clear PET (31%) and coloured PET (14%). The proportion of clear PET remaining in the mixed plastics product stream is high given that it is specifically targeted at MRF C as a product stream.

The next highest polymer was PP at 21%; PVC made up 14%. Natural HDPE bottles accounted for 2%, however as this is targeted for recovery at the facility it would be expected to be low. Coloured HDPE bottles accounted for 3%. Non-packaging plastic accounted for 2.52%. Non-plastic contamination, accounting for 3.6%, consisted of (paper/card (3.4%) and metals (0.2%). Figure 18 shows a picture of the rigid mixed plastic bales produced by MRF C.

**Figure 18.** An example of the rigid mixed plastics output from MRF C

### 5.4.3 Separation and Baling of Film Stream

After film has been manually removed it is collected in bins and then transferred manually to be baled. This is due to the multiple removal and collection points for plastic film at the MRF. The principal collection point for film is beneath the first sort cabin. Figure 19 shows bales of the post-consumer film product produced by MRF C. The quality and purity of the film was considered to be very high (>95%). The quality of paper was not affected by the film fraction as the film was manually extracted before the paper NIR sorting unit.
5.4.4 MRF C Material Residues

The residue stream at the plant was analysed to identify the types of materials not being captured by the MRF. Technically this material cannot yet be counted as residue as it is forwarded, with another reject stream, to a MRF capable of extracting additional material from it. However, for consistency, the rate and composition of this stream was assessed during the 16-hour trial period and the end of line material was found to be leaving the plant into the compactor at 455kg/hr. This material was paper/card (59%) as shown in Figure 20.

<table>
<thead>
<tr>
<th>Residue</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>34.9</td>
</tr>
<tr>
<td>Cardboard</td>
<td>24.4</td>
</tr>
<tr>
<td>Other plastics - rigid</td>
<td>16.9</td>
</tr>
<tr>
<td>Plastic film</td>
<td>7.9</td>
</tr>
<tr>
<td>Residual</td>
<td>5.3</td>
</tr>
<tr>
<td>PET bottles</td>
<td>4.0</td>
</tr>
<tr>
<td>HDPE bottles</td>
<td>2.0</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2.0</td>
</tr>
<tr>
<td>Liquid carton board</td>
<td>1.9</td>
</tr>
<tr>
<td>Steel</td>
<td>0.7</td>
</tr>
<tr>
<td>Fines (particle &lt; 10mm)</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Rigid plastics accounted for the next highest proportion of material left in sample at 17%, whilst film was 7.9%.

5.5 Mixed Plastics Processing Issues

A number of process related issues were identified at the MRF C, however none of these were as a direct result of sorting for mixed plastics.
5.6 Key Findings from MRF C

The collection of plastic film with other rigid plastics is feasible if it is manually sorted early in the process.

- The inclusion of plastic film co-mingled with paper/cardboard, cans and plastic bottles did not affect the overall value and quality of all product streams;
- Contamination from plastic film was minimal due to the film being positively sorted early in the process;
- Minimal quantities of rigid plastics contamination was identified in aluminium (0.17%) and steel (0.57%);
- Minimal plastic film contamination was found in aluminium (0.09%), steel (1.03%) and mixed plastics (0.58%);
- The infeed material was considered clean with only 4.2% contamination present;
- The collection of mixed plastics using boxes at kerbside managed to yield 3.29% mixed plastics for the infeed composition and 2.57% film.

The paper product quality was not affected by other rigid plastics or film.

- The paper quality observed during the trials was excellent, with only 0.07% of contamination, of which a minimal 0.054% was due to plastic;
- The MRF configuration at MRF C was designed to capture high quality paper with little contamination;
- Plastic film was manually extracted before the optical paper sort, to ensure paper quality was not compromised.

The quality of the plastic film product was high.

- The separated plastic film product had a purity of over 95%;
- The quality of the film collected from households was considered high, with a purity of over 95%. However, it should be noted that this was a visual analysis performed on site during the trials and that samples of this film were also procured for film recycling trials and further analysis.

The mixed plastics product contained high levels of PET bottles.

- The mixed plastics product contained a high level of PET at almost 52%. This consisted of 31% clear bottles, 14% coloured bottles and 6% other rigid plastics;
- Mixed plastics had a contamination level of 6.73% of which only 9% (0.58% of contamination level) was from plastic film. Non-packaging plastics constituted 37% (2.52% of contamination level).

There is potential to recover additional quantities of recyclate materials from residual end of line materials.

- The majority of the residual stream was paper/card (59%) and packaging plastics (31%);
- Currently MRF C sends its residue to a private contractor for further treatment and recovery;
Capture efficiencies of individual plastic polymers or types were not available, however the overall capture rate for plastic was estimated between 52-63%.

6.0 Trial Results from MRF A - Currently NOT Sorting Mixed Plastics

It was important to include MRF A because it is a MRF that currently does not actively collect or sort mixed plastics. It sorts domestic material from both kerbside and bring collection systems. The incoming material is made up of co-mingled paper, cans and plastic bottles. The specific purpose of the trials at MRF A was to identify what retrofitting would be required to enable the plant to accept and sort other rigid plastics and film. Any retrofitting deemed necessary from trial results and estimated to require the hire or purchase of capital equipment, was proposed to be undertaken as a 'virtual retrofit' due to budget and timescale limitations. This meant that where necessary in the sorting process, material would be taken from MRF A and transferred to a MRF outfitted with the capital equipment required to carry out the sorting.

6.1 MRF A Targeted Materials

MRF A is responsible for the handling of recyclate from approximately 300,000 households and has a capacity of processing 40,000 te/year. The majority of materials entering the MRF are sourced from high density housing. MRF A Council specifically requests householders to exclude card, glass, plastic film and other non-bottle plastics from their recycling facilities. MRF A accepts:

- paper;
- plastic bottles; and
- food tins and drink cans.

MRF A also operates a small-scale collection service from commercial properties collecting paper, cans and plastic.

6.2 MRF A Sorting Process

The MRF features a paper screen as the central automated stage of the process. The screen’s function is to primarily separate two-dimensional flat items such as newspapers and pamphlets from three-dimensional items such as bottles, cans, trays and other containers. Other sorting sections include:

- An NIR sort unit for removal of paper from the container stream (however, this was not in operation during the trials);
- An over-band magnet for steel removal from the container line;
- An eddy current separator for aluminium removal from the container line;
- 21 manual sorting staff are typically used within the MRF.
Incoming material is fed into the process via a charge hopper. Twin conveyor belts aid the movement of material to the centre of the charge hopper. Material is gravity fed to the charge hopper via these belts from the building's top floor. A short elevating conveyor picks up the discharged material and uses a metering drum to distribute material across the belt and to partially smooth the flow. The rate of production is determined by the charge hopper conveyors when the plant is run within normal operating parameters. The elevating conveyor discharges to a sort cabin where large contaminating items are manually removed along with film and card.

The outlet from the pre-sort cabin falls directly into the paper screen. Paper flows up the screen while containers tend to stay in the notch and flow to the end of the screen where a container stream is formed.

The container stream is conveyed to another area where segregation is performed. En route the containers pass through an NIR sort unit for recovering any paper remaining in the container stream. Any paper detected on the container conveyor is ejected and rejoins the paper stream via a recovery conveyor belt. Metals are removed first on the container belt, followed by removal of plastics.

Metals are removed from the container line by an over-band magnet, which extracts steel items followed by an eddy current separator, which extracts aluminium items. This material falls directly down chutes and into automatic balers.

At the time of the trials the only target plastics for recovery were plastic bottles: HDPE (natural); and PET (clear and blue) grades. The bottle tops on PET bottles are a problem for the PET baler and are removed manually by sorters. During the first and second trials (1/12/08 and 17/12/08) three manual sorters were typically present at this point and the amount of labour required to remove PET closures was observed to be all three manual sorters. Two manual sorters were dedicated to sorting natural HDPE.

Film plastic is removed at the first sort cabin immediately upstream of the paper screen. This is classed as a contaminant and is not treated as a product stream.

The paper conveyed to the top of the paper screen is collected, and after being combined with the paper removed from the container stream, passes through a sort cabin where contamination is manually removed. The paper product is conveyed to a hall where it is stored loose and loaded onto vehicles as required for forwarding to a large paper reprocessor.

There are two positions within the MRF where out-throws occur. The first position is after the first sort cabin. This is where the large contamination items are removed and this material is sent to landfill. The second out-throws occur after the plastic sort cabin. This material still contains relatively high levels of paper and plastic and is sold to a private MRF.
6.3 MRF A Processing Trials

The trials were undertaken in three different stages:

- The first stage involved undertaking benchmarking studies of MRF A during a 16-hour period of continuous operation. The objective of this stage of the MRF A trials was to establish the normal operation of the plant;

- The second stage trial involved mixing ten tonnes of normal input co-mingled material with one tonne of mixed plastic material sourced externally typical of non-bottle plastics input found at other MRFs in these trials. This was sourced from the Valpak Preston PRF after bottles have been removed. The objective of stage 2, was to establish what adjustments would be required for the MRF to accept mixed plastics. The lines of the MRF were cleared of all material and the new combined mixed plastics input material was introduced via the feed hopper;

- The stage 3 trial, was necessary due to significant contamination occurring in all product streams during the Stage 2 trial, as well as material jams at various points in the MRF. In this trial rigid and film mixed plastics were added to the normal infeed material at 3%. This ratio imitated typical composition of MRF A infeed material if it were to start accepting mixed plastics and was comparable to the levels of mixed plastic found in the infeed material at both MRF B and MRF C. The objectives of stage 3 mixed plastic trial were to establish:

  - Whether the proposed reconfiguration would allow mixed plastic material to be accepted at the MRF (with an infeed composition similar to that of the two MRFs currently collecting mixed plastic);

  - The levels of contamination in the various product streams;

  - The capture efficiency of mixed plastics and associated costs.

6.4 MRF A Stage 1 Trial Results: Compositional Analysis

An overview of the flow of material requested from the public and the composition actually received. This shows that at MRF A paper (80%) is the largest infeed material.

Figure 22. Overview of MRF A material infeed and product streams

![Diagram showing infeed and product streams at MRF A](image)

Figure 22 shows what product streams are produced by the MRF after the materials are sorted. At MRF A paper accounts for 67% of the output material. The end of line material accounts for 25% of the output, however, this material is sold for further processing and recovery.

At MRF A, five samples of infeed material were taken with an average sample weighing 29.9kg. In total 149.6kg were analysed over the 16 hour period of operation.
Figure 23 shows the composition of the infeed material into the MRF. Paper is the main product of the MRF A and its configuration is therefore geared towards maximising the value it can extract from this stream. Plastics accounted for 9% of infeed composition, with metals constituting 5%. In general, contamination from materials not requested by the Local Authority were found to be low.

Figure 23 also shows the average, minimum and maximum percentages identified from the analysis. During the trial the average composition of other rigid plastics was 0.95%. Over the five samples this had a standard deviation of 0.37% of the total sample size.

In general within domestic mixed plastic bottle collections there is typically a 50:50 split between PET and HDPE plastic bottles. However, at MRF A the infeed analysis initially indicated that the split was closer to being a two-thirds/one third split between PET and HDPE bottles. On analysing the composition of the ‘other rigid plastics’ category as shown in Figure 24, a considerable amount of PET was found, such as trays and tubs, which suggested a split of approximately three-quarters/one quarter for all types of PET and HDPE products.

### Table 23. Table of Infeed Composition by All Material and some Polymers (MRF A, Benchmarking)

<table>
<thead>
<tr>
<th>Material</th>
<th>%</th>
<th>Max%</th>
<th>Min%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>79.79%</td>
<td>83.79%</td>
<td>75.10%</td>
</tr>
<tr>
<td>PET</td>
<td>4.88%</td>
<td>9.28%</td>
<td>2.76%</td>
</tr>
<tr>
<td>Residual</td>
<td>3.34%</td>
<td>5.76%</td>
<td>0.41%</td>
</tr>
<tr>
<td>Steel</td>
<td>3.21%</td>
<td>4.48%</td>
<td>0.41%</td>
</tr>
<tr>
<td>HDPE</td>
<td>2.74%</td>
<td>4.23%</td>
<td>0.34%</td>
</tr>
<tr>
<td>Cardboard</td>
<td>2.27%</td>
<td>3.98%</td>
<td>0.38%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>1.94%</td>
<td>3.09%</td>
<td>0.34%</td>
</tr>
<tr>
<td>Other plastics rigids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>0.45%</td>
<td>1.08%</td>
<td>0.11%</td>
</tr>
<tr>
<td>PET</td>
<td>0.17%</td>
<td>0.61%</td>
<td>0.00%</td>
</tr>
<tr>
<td>HDPE</td>
<td>0.14%</td>
<td>0.36%</td>
<td>0.02%</td>
</tr>
<tr>
<td>PVC</td>
<td>0.08%</td>
<td>0.22%</td>
<td>0.00%</td>
</tr>
<tr>
<td>PS</td>
<td>0.08%</td>
<td>0.12%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other</td>
<td>0.03%</td>
<td>0.09%</td>
<td>0.00%</td>
</tr>
<tr>
<td>LDPE</td>
<td>0.00%</td>
<td>0.02%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Total other rigids</td>
<td>0.95%</td>
<td>1.43%</td>
<td>0.57%</td>
</tr>
<tr>
<td>Plastic Film</td>
<td>0.54%</td>
<td>0.84%</td>
<td>0.34%</td>
</tr>
<tr>
<td>Particles &lt; 10mm</td>
<td>0.33%</td>
<td>0.44%</td>
<td>0.21%</td>
</tr>
<tr>
<td>Liquid Carton Board</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Glass</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

Figure 24 shows the composition of a sample taken from the infeed material as delivered by collection vehicles.

### Figure 24. Composition of Other Rigid Plastics: MRF A Infeed (Benchmarking)

<table>
<thead>
<tr>
<th>Composition of Other Rigid Plastics MRF A (benchmarking)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
</tr>
<tr>
<td>PET Bottles</td>
</tr>
<tr>
<td>HDPE Bottles</td>
</tr>
<tr>
<td>PVC</td>
</tr>
<tr>
<td>PS</td>
</tr>
<tr>
<td>Other/Contamination</td>
</tr>
<tr>
<td>LDPE</td>
</tr>
<tr>
<td>Closures</td>
</tr>
</tbody>
</table>

Figure 25 shows the composition of material obtained directly from the line adjacent to the bottle sorting activity. Sample differences reflect composition variability, sort bias and losses along the process line. Figure 25 shows the mixed rigid plastics product recovered by the sorters during the reconfiguration trials.
The sample profiles have broadly similar composition of PP, PS and PVC; however, the infeed material sample contained considerably less PET, considerably more HDPE and a little more contamination/unknown.

The reduction in HDPE between MRF infeed and the sort line is attributed to closures and small HDPE containers being lost early in the process. Small items easily fall through the paper screen and trommels and are typically lost as waste. Loose closures were collected as part of the compositional analysis. Normally these would be expected to leave the container stream at the first screen where they are removed from the PET bottles. Other closures are detected at various points through the plant largely because many bottles are received with closures. Figure 26 shows examples of the materials that were collected during the trials.

6.5 Stage 1 Trial Results: Operating and Material Capture Efficiencies

The MRF is designed to operate at a throughput of approximately 10 tonnes per hour. However, benchmark data established from the trial suggests rates observed during the trials were approximately 6 to 8 tonnes per hour. The reason why the MRF throughput rates were not at optimum rates was not determined.
6.6 Stage 1 Trial Results: Product Quality

All the material is stored in a way that has minimum impact on product quality. The paper product is stored loose under cover inside. Plastic bales are stored in a covered area outside the MRF. As identified in the compositional analysis of the infeed, there were relatively low levels of contamination present. MRF A’s management put this down to a good local authority communication programme for residents. The main contaminant by weight was cardboard, and the main contaminant by volume was plastic film. Both plastic film (including bags) and cardboard are manually removed at the pre-sort cabin prior to the material entering the paper screen.

MRF A has consistent sales of paper, aluminium, steel, HDPE and PET bottles with agreed purity levels for each product stream.

**Paper Quality**

The quality of paper is determined by the MRFs customer, a paper reprocessor. The quality is based on the occurrence of specific items during inspections of measured areas of material, which is converted to a gravimetric result. The overall contamination of the paper product assessed by the paper reprocessor who receives the sorted paper in the period 1st June 2008 to 8th December 2008 comprised 0.85% plastic bottles and 0.86% steel and aluminium cans. The maximum observed in the period was 2.09% plastic bottles and 3.66% steel and aluminium cans.

As part of the MRF A trials, a 1,100 litre bin was used to collect paper samples and the contamination of this product was assessed. The paper quality in Figure 27 shows (i) contamination relative to paper quantity; and (ii) the composition of the contamination found in the paper product.

**Figure 27.** Contamination relative to paper quantity and composition of the contamination found.

![Graph showing paper quality and composition of contaminants](image)

The contamination found within the paper stream was equivalent to that reported by the paper reprocessor. The paper stream from MRF A has a higher proportion of mixed rigid and film plastic contamination, even though it specifically only requests plastic bottles as infeed. Overall, the paper quality in MRF A is slightly lower than the other two MRFs, which are currently collecting mixed plastics, however, MRF A’s volume is higher.

**Aluminium Quality**

Composition analysis of aluminium bales established that aluminium had a purity of 98%. This is considered to be a high level of purity and is acceptable to aluminium reprocessors. The type of contamination varied with typical contaminants including paper, card, plastic film and rigid plastics. The level of contamination of the bales attributable to other rigid plastics was 0.63% and to all plastics was 1.6 %.

**Steel Quality**

Steel bales were broken to assess the contamination levels and 6% of the bale weights proved to be non-steel materials similar to components found in aluminium. The level of contamination of the bales attributable to all plastics was 1.2% and the level attributable to other rigid plastics was 0.52%. The level of plastics related contamination is considered to be small and does not affect the value of the steel product.
**HDPE Quality**
Bales of HDPE were reviewed and the quality was noted as high at 99.47% - (contamination 0.45% caps, 0.08% paper/card). Contamination was low and was in the form of incorrect polymers in bales, but this was rare.

**PET Quality**
Bales of PET were reviewed and the quality was noted as high at 98.93% - (contamination 0.17% film, 0.28% caps, 0.4% paper/card, 0.22% aluminium); occasional contamination was observed in the form of incorrect polymers in bales, but this was rare.

### 6.7 Stage 1 Trial Results: Material Residues

Compositional analysis of the collected material was performed and the rate of residual flow assessed. The composition of this stream was highly variable with occasional elevated PET and steel levels. On careful observation these were attributed to changes in operational practices such as movement of sorters to other areas and blockages of the magnet chute, etc.

#### Figure 28. Composition of residual material (MRF A) – sample A and sample B

It is clear from Figure 28 that a significant quantity of paper remained unsorted in sample A. Looking at the plant schematic, it can be seen that the residual material is a combined residue stream from the container and paper processing lines, but a significant fraction of the paper has passed along the container stream. The higher paper content seen in sample A was caused by rejection of wet paper from the paper product line into the container line. This material was manually removed in the paper sort cabins and ended up on the residue conveyor. The paper analysed from the residue sample was very wet and reflected the processing conditions on the day. Note that the moisture content also inflated the percentage recorded.

PET and HDPE make up 7.99 % of the residue in sample A, comprised overwhelmingly of PET. Mixed plastics make up 5.8% of sample B, and in contrast are comprised mainly of HDPE. Mixed rigid plastics comprise 17.87% of sample B and only 1.37% of sample A. Film makes up only a small percentage of both samples at 0.19% and 0.73% in sample A and sample B respectively.

There are significant quantities of recyclate remaining in the residual waste at MRF A. This residual product is sold to a private MRF for further sorting and recovery of material.

### 6.8 Stage 2 Trial Methodology

As part of the second phase of trials at MRF A, mixed plastics were introduced to the normal infeed. Approximately four tonnes of mixed plastic bales (rigids and films) were sourced from a local authority domestic kerbside collection of mixed plastics. The objective was to establish where the mixed plastics would go within the process lines and where they would end up when the MRF was operating under normal conditions. The remaining one tonne of the mixed plastic was mixed with ten tonnes of normal input material and this was fed into the plant. Observers were placed on the paper product line, steel and aluminium can baling stations and the plastic sort cabin to record capture efficiencies and record any enhanced levels of contamination.
6.9 Stage 2 Trial Results – Processing Issues with Mixed Plastics

Stage 2 of the trials experienced problems at the paper screen when the baled mixed plastic material was introduced. The material was fed into the hopper without the bales being broken down adequately. The inability to properly debale the mixed plastics materials resulted in clumps of material becoming stuck within the MRF equipment. As a consequence, the clumps that were not effectively debaled, came through the system and adversely affected the metering drum just before the first sort cabin allowing surges of material to enter the process line. The subsequent build-up of materials and surging of clumps of material through the system were the principal reasons for the operational problems experienced during this trial.

Most of the clumped material passed down the paper screen and spilled onto the non-paper line; this caused major problems downstream as the belts were pushed beyond their capacity and material jams occurred at both the steel and aluminium baling points. There were also material jams at the entry to the plastic sort cabins.

Following analysis of the film footage and discussion between trial observers it was agreed that the principle cause of the paper screen blockages was that the material had been put in to the hopper without the bales being broken up adequately.

As a consequence of the inability to effectively debale the introduced mixed plastics, contamination levels in all product streams were so high that there would be no value to the project to measure them, as no MRF could operate under these conditions. The key finding from the trials was that if a MRF is considering the introduction of mixed plastics it needs to understand and evaluate the effect of mixed plastics on its specific equipment and to understand where specific modifications (e.g. modified debaling set-up) to the system may be required.

6.10 Stage 3 Trial – Material Capture Efficiencies

In Stage 3 trials, the mixed plastics were sourced from MRF A’s out-throws, therefore avoiding any baling or compaction of the material. This mimicked a typical MRF input of 3% mixed rigid plastics. From the experience gained in the previous trial the plastic processing line speed was slowed down to a rate of approximately 5.5 tonnes per hour. This line speed was slightly outside normal speed of operation, however, it was considered more precautionary than necessary for a successful trial. Manual sorting of mixed plastics was then conducted under normal operating conditions, followed by detailed compositional analysis.

To establish the capture efficiencies of mixed plastics a benchmark under normal operation was established. This was accomplished by placing two sorters in the plastic sort cabin picking for mixed plastics for a 15 minute period. The total quantity of mixed plastic collected in this period was 6.7kg. Following this the sorters then collected 21kg of mixed plastics to be mixed with the normal infeed.

When the mixed plastics were introduced into the infeed, the total weight of mixed plastics and film collected over this period was 13.8kg.

Given that the input weight was 27.7kg and the normal level of mixed plastics in the MRF for a 15 minute period is 6.7kg, this equates to a capture rate for the two sorters of 50%. This is comparable to the capture rate for other materials.

The MRF management reported that during this stage there was no reduction in the capture rate of any other materials as it was only the plastic belt that had been slowed. The main paper belts and paper screen operated at normal running rates. No extra labour requirements were needed as part of these trials.

6.11 Stage 3 Trial Results: Product Quality

The main concern of the MRF A management team was contamination of the paper product through the introduction of mixed plastics. During this stage despite the introduction of mixed plastics no increase in the number of contaminating objects was observed. Visual examinations of the steel and aluminium bales were also undertaken and no increase in the level of contamination was observed.

As HDPE and PET bottles are manually positively sorted in the plastic sort cabin it was not anticipated that contamination levels would increase due to the introduction of mixed plastics.
6.12 Stage 3 Trial Results: Processing Issues with Mixed Plastics

The main processing issues that were identified as a consequence of introducing the mixed plastics were:

- Paper line speed;
- Masking of mixed plastic containers;
- Size of sort cabin;
- Material jams post sort cabin;
- Routing of film to a collection bay;
- Selection of plastic containers by paper optical sort.

The plastic sort line was slowed down as a precaution on introducing the non-bailed / compacted mixed plastics, however sorters were operating well within their capabilities and the same capture efficiency could have been achieved if the line had been operating at its normal speed.

Plastic bottles that had not been captured by the manual plastic bottle sorters often masked the mixed plastic containers and resulted in a lower capture efficiency of mixed plastics. At the MRF there were issues regarding the baling of PET bottles and sorters had to remove caps from bottles on the line. This resulted in a low capture efficiency for PET and high residual levels which then mask the mixed plastics. A PET bottle perforator would alleviate the need for sorters to remove plastic caps allowing for higher capture efficiencies.

During all three trial days it was observed that material jams were occurring often on the line outside of the plastic sort cabin. This resulted in down time to clear the lines, resulting in lower material capture efficiencies. The cause of the material jams was the flow of the clumped material exiting the plastic sort cabin and the width of the belt. This was directly related to the debaling difficulties and was not attributable to the mixed plastics materials. The debaling issues could be resolved as part of continuous process improvement within MRF A.

A significant quantity of plastic film is removed at the first pre-sort cabin. This material is placed in a chute, mixed with other contaminants and sent to landfill. To sort for film the pre-sort cabin would need to be re-configured to send the film to a separate collection bay via separate chute to then directly feed into a baler to prevent handling problems. This is potentially a simple engineering change.

Evidence from the trials at MRF A, shows that the plastic content in the paper product from MRF A is higher than for either of the other two MRFs handling mixed rigid plastics (MRF C and MRF B). This is assumed to be caused by the specific configuration of the paper sort at MRF A, which is set to maximise the quantity of paper processed and extracted compared with, for example, the MRF C which is focused more on paper purity and maximising the removal of non-paper items from the paper stream.

6.13 Potential Reconfiguration Costs

Based on the processing issues identified at MRF A, the estimated capital and operational costs were noted and are included in the financial assessment of the report.

6.14 Key Findings from MRF A Trial

**Accepting other rigid plastics and film as an infeed into the plant will not affect the paper value**

- Paper line speed was not adjusted as part of the reconfiguration; and there was no significant increase in the level of contamination measured on the paper line when mixed rigid plastics and film was introduced;
Based on the compositional analysis of the MRFs trialed as accepting mixed plastics, the estimated quantity that could be collected by MRF A is 280 tonnes of other rigid plastics per year and 215 tonnes of film. This equates to a total of 495 tonnes being diverted from landfill.

**Film could be captured at the pre-sort cabin with a potential annual cost saving**

- Film is already manually removed from the line at the pre-sort cabin, but is not separately collected and baled and therefore simply ends up becoming part of the waste stream. The existing chutes and manual sorters could be used to separately collect the film. This would require up to four sorters in the pre-sort cabin targeting film;

- Using the collection rates of MRF C of 31.5kg/hr/sorter the potential capture rate of film and adjusting it downwards by 30% (because the sorters in MRF C only target film and the MRF A sorters target two other contamination streams), would give a 23.8 kg/hr/sorter. Based on a 37 hour a week operation, 52 weeks of the year, this equates to 183 tonnes per year, which could be diverted from landfill;

- A PET bottle perforator could improve baling and hence improve plastic capture rates and lids would then not have to be manually removed by sorters;

- The low capture rate for PET bottles (50%) may be because lids have to be manually removed by sorters;

- PET bottles mask other rigid plastics because of their high levels in the residual waste stream;

- The percentage of other rigid plastics in the standard infeed composition of MRF A is 0.95% and the percentage of other rigid plastic in the infeed from MRF C where other rigid plastics are requested is 3.29%. This provides some guidance on increased levels that could be expected by a MRF reconfiguring to take mixed plastics.
7.0 Key Findings from MRF Processing Trials

In order to provide an insight into the differences between throughputs, capture efficiencies and quality/contamination from the three trial MRFs, a comparative analysis has been carried out. The results are presented below as an overview, which considers throughput, infeed composition and capture efficiency data and an overview of the purity of materials, levels of contamination caused by all plastics and end of line composition.

It is important to note that the MRFs cannot be compared because they all have different material throughputs; different collection methods; different material inputs, therefore different sorting requirements and material outputs. The overview of all three MRFs does however show us that mixed plastics processing is viable and that it does not affect the key MRF processing parameters such as throughput rates, capture efficiencies and purity of end product streams. This is described in greater detail in the following sections.

7.1 Overview: Throughput, Infeed Composition and Capture Efficiencies

As can be seen from Figure 29, the benchmark throughputs from each of the three MRFs are all different. Reasons for this include the times selected for undertaking the trials as the MRFs may not have been operating to their capacity. Also, as can be seen with MRF C, which has a lower throughput than MRF A, the focus is on recovering quality of material rather than quantity which is the focus of the MRF A facility. The throughputs of the MRFs participating in the trials ranged from 6 to 12.3 tonnes per hour.

<table>
<thead>
<tr>
<th>MRF and Material Throughput (tonnes per hour)</th>
<th>Infeed Composition</th>
<th>Capture Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRF C</td>
<td>MRF B</td>
<td>MRF A</td>
</tr>
<tr>
<td>Paper</td>
<td>6.22-6.39</td>
<td>10.13-12.30</td>
</tr>
<tr>
<td>Cardboard</td>
<td>3.82-3.92</td>
<td>4.44-5.39</td>
</tr>
<tr>
<td>Aluminium</td>
<td>1.14-1.17</td>
<td>2.06-2.51</td>
</tr>
<tr>
<td>Steel</td>
<td>0.07</td>
<td>0.19-0.23</td>
</tr>
<tr>
<td>Glass</td>
<td>0.28</td>
<td>0.32-0.39</td>
</tr>
<tr>
<td>HDPE Bottles</td>
<td>0.15-0.16</td>
<td>0.25-0.31</td>
</tr>
<tr>
<td>PET Bottles</td>
<td>0.14</td>
<td>0.35-0.42</td>
</tr>
<tr>
<td>Other Rigid Plastics</td>
<td>0.20-0.21</td>
<td>0.34-0.41</td>
</tr>
<tr>
<td>Plastic Film</td>
<td>0.16</td>
<td>0.39-0.47</td>
</tr>
<tr>
<td>Other</td>
<td>0.04</td>
<td>0.17-0.20</td>
</tr>
<tr>
<td>Plastic for External Recycling / Residual</td>
<td>0.22-0.23</td>
<td>0.26-0.31</td>
</tr>
</tbody>
</table>

Calculated from composition and total rate; * Sum of PET coloured, HDPE and Plastic for External Recycling

For the avoidance of doubt no direct comparison of individual equipment, technology or process performance should be drawn from the tables and information published throughout this report.

For all equipment, technology or processes tested, the equipment, technology or process may have been tested under different conditions and using different methodologies and therefore may not be comparable.

- MRF A receives the highest percentage of paper at 80%, but does not collect cardboard as per MRF B and MRF C;
- Levels of aluminium and steel in the infeed compositions were broadly similar;
- MRF B was the only MRF which accepted glass, accounting for 14% of infeed composition;
- Levels of HDPE in the infeed compositions were broadly similar;
Levels of PET were higher at MRF A than at the other two facilities at 4.88%; this has been recognised in other studies and has been largely attributed to the high consumption of carbonated drinks in the area;

Mixed Plastics accounted for just over 3% at MRF B and MRF C. Both MRFs request mixed plastics in their collections. However, MRF A only request plastic bottles (PET and HDPE), but were found to have a mixed plastic element of nearly 1% to its infeed;

MRF B does not request plastic film, however it still constituted 3.8% of its infeed material due to recyclate being collected in plastic sacks. MRF C does request film, but only achieves 2.6% in the infeed composition. MRF A only requests plastic bottles, but receives 0.5% film.

The capture efficiencies of the MRFs vary depending on the processes, types of equipment, staff and contamination levels. Key findings include:

- The capture efficiency levels for steel were recorded at 62-88% in the trials;
- The very high efficiency for paper was attributed to there being two grades recovered and as such two points of recovery. The end of line material is also sent for recovery;
- The capture efficiency of mixed plastics at MRF C and MRF B are similar at approximately 60%.
- The conclusions from the overview of throughput, composition and capture efficiency are:
  - The highest throughput for the facilities involved in the trials was approximately 12 tonnes per hour;
  - Where aluminium, steel, HDPE bottles and cardboard were requested from the public the infeed percentages were comparable between each of the MRFs involved in these trials.

### 7.2 Overview: Purity, Contamination from Plastics and End of Line Composition

Figure 30 shows that the purity levels of all product streams at the three MRFs is high with a purity level of approximately 90% or over for all materials, excluding glass at the MRF B.

The other rigid plastics purity at both MRF C and MRF B was broadly similar at 93% and 94% respectively. Film is a product stream at both MRF C and MRF B; film purity was considered high with contamination estimated at less than 5%.

Figure 30. MRF Overview: Purity, Contamination from plastics and End of line composition

<table>
<thead>
<tr>
<th>Purity</th>
<th>Contamination from All Plastics</th>
<th>End of Line Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MRF C</td>
<td>MRF B</td>
</tr>
<tr>
<td>Paper</td>
<td>99.93%</td>
<td>99.80%</td>
</tr>
<tr>
<td>Cardboard</td>
<td>&gt;95.00%</td>
<td>&gt;95.00%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>99.74%</td>
<td>&gt;99.00%</td>
</tr>
<tr>
<td>Steel</td>
<td>89.88%</td>
<td>95.90%</td>
</tr>
<tr>
<td>Glass</td>
<td>&gt;99.00%</td>
<td>&gt;99.00%</td>
</tr>
<tr>
<td>HDPE Bottles</td>
<td>&gt;99.00%</td>
<td>&gt;99.00%</td>
</tr>
<tr>
<td>PET Bottles</td>
<td>&gt;99.00%</td>
<td>-</td>
</tr>
<tr>
<td>Other Rigid Plastics</td>
<td>93.27%</td>
<td>94.42%</td>
</tr>
<tr>
<td>Plastic Film</td>
<td>&gt;95.00%</td>
<td>&gt;95.00%</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>End of Line/Residual</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Plastic bottles only
- not applicable

For the avoidance of doubt no direct comparison of individual equipment, technology or process performance should be drawn from the tables and information published throughout this report.

For all equipment, technology or processes tested, the equipment, technology or process may have been tested under different conditions and using different methodologies and therefore may not be comparable.
7.2.1 Plastic Film and Other Rigid Plastics as Contaminants

It was noted that film is often found on MRF process lines even when not requested from households. Manual sort is required to remove this at appropriate points in the system (normally at the front end). This was also true for other rigid plastics and when not requested, levels were at around one third of those found in MRFs handling other rigid plastics, although the other rigid plastics did not pose the same risk to paper quality.

7.2.2 Contamination of Paper

All of the MRFs studied used automatic screen equipment to create a paper/container stream split at the beginning of the process. Various technical solutions were observed, but all were successful in achieving the required level of segregation. Any film present at this device has the potential to contaminate the paper stream and is therefore best removed early in the process. Other rigid plastic packaging tends to follow the container stream, when cross-contamination can be found in the paper stream then it is typically dealt with by the manual sorters employed to further improve the quality of the paper. The two MRFs (B and C) requesting mixed plastics achieved a higher quality paper product than MRF A, which did not request mixed rigid and film plastics. Food contamination from mixed plastics did not appear to be an issue on the quality of paper obtained.

7.2.3 Contamination of Aluminium

Some MRFs have invested in eddy current separators whilst others used manual separation of aluminium. Where there was manual intervention the quality of the aluminium was higher and in one case manual intervention took place after eddy current separation of the metal. The quality of the aluminium product was always found to be acceptable.

7.2.4 Contamination of Steel

Separation of steel from the container line relied on over-band magnets in all cases. The influence of plant layout on steel quality was apparent from the trials and this factor is more significant than the composition of the stream at this point. However, none of the MRFs studied produced unacceptable quality steel product.

7.2.5 Contamination of Glass

Glass was processed in one of the MRFs studied and was recovered as broken fragments having fallen through screens employed at various stages in the process. This material was not of a high quality and was exported wet with significant metal, plastic and paper contamination. The removal of metal and plastic should not present a great challenge and it is understood that the original installation was supposed to achieve this. The paper contaminating the glass stream is chiefly shredded paper and fragments identified may be hard to remove. The mixed plastics present did not appear to pose a disproportionate threat to quality.

7.2.6 End of Line Composition

- The end of line composition at all three MRFs was dominated with paper/card ranging from 59% at MRF C to 71% at MRF A;
- The NIR paper sorting unit at MRF A has been out of operation for several months which may have contributed towards the high paper content at the end of line. Also, paper at MRF A tends to be heavier due to moisture levels of paper;
- MRF C had the highest cardboard content at 24% with MRF B containing 14% and MRF A 2%; however MRF A do not request cardboard and as such is a contaminant;
- Aluminium and steel content is low in the end of line compositions at all three facilities;
Considerable levels of PET were found in the end of line at MRF A (10%) and MRF B (8%). At MRF A this can be attributed to the sorters having to remove bottle tops, causing them to miss bottles on the line and at MRF B PET bottles were not being separated at the time of the trial.

**MRF Overview Conclusions**

- Contamination from all plastics was low at all facilities with the highest recorded level of contamination by plastics being recorded in the MRF C steel product (3.15%);
- Where mixed plastics are accepted they did not have a negative effect on the quality of other products (over and above that experienced in more conventional co-mingled schemes). In any retrofitted facility this should remain the case provided that sufficient care is taken at design stage and during operation;
- Any threat posed by inclusion of mixed plastics is seen to lie mainly in the difficulties of segregating them as streams separate from conventionally collected plastic bottles;
- The inclusion of mixed plastics did not affect the overall value of the product streams;
- The end of line compositions revealed that at all three MRFs there is an opportunity to recover greater quantities of recyclate from the end of line material; paper/cardboard and plastics offer the greatest scope for recovery.

All systems assessed can effectively be used for the collection of mixed plastics without a significant impact to the quality of other recyclate product streams

**7.2.7 Key General Considerations**

When adding new infeed materials to a MRF, the operation and actual throughputs need to be reviewed thoroughly. The inclusion of additional materials will inevitably increase the quantity of material that has to be handled and as such there must be sufficient capacity to handle this. It was found that the two MRFs in these trials that actively process mixed plastics had experienced an additional throughput of approximately 3.5% by weight for rigids and 2% for film.

**Early Removal of Plastic Film**

If film is accepted it is critical to remove as much as possible at the earliest opportunity. No satisfactory automatic methods are apparent for separating film from other materials when paper is part of the co-mingled collection. Manual sort rates for film of 28 kg/sorter/hr were recorded during the trials. Normally film contamination is experienced by MRFs accepting a co-mingled infeed, therefore some film removal is required even without the introduction of other rigid plastics or film to collections. A direct connection between the sort chute for film and its baler is recommended to reduce handling costs. However if space is limited vacuum suction systems can effectively collect film collected from various points to a central handling system and automatically feeding the baler.

**Sorting Methods and Order of Sort**

In addition to selecting whether to implement manual and/or automated sorting techniques, the order of the sort stations and removal of each polymer type is also important if separate bottle and/or other rigids are being collected. Targeting mixed rigid plastics upstream of bottle sort stations is likely to result in lower sort rates for the bottles, which is not preferable as they currently have a higher value. For a manual approach it is suggested that once film has been removed early on in the process, that the remaining rigid plastic stream is first sorted for plastic bottles followed by effective sorting and removal of other rigid plastic packaging such as trays, etc.

**Separating HDPE and PET Bottles from Other Rigid Plastics**

Consideration should be given to the quality issues that may arise from collecting/sorting ‘other rigid plastics’ to the HDPE and PET bottle grades. If feedstock containing other rigid plastics is fed to automatic polymer sorting equipment they will be selected with the bottle materials of the same polymer type, unless very sophisticated shape or sensitive polymer differentiation were possible by the units used. If mixed bottles and other rigids are
unacceptable to the onward reprocessor, methods need to be devised to protect the automated systems from other rigid plastics content, by removing (most likely by manual positive sort) the other rigid fraction upstream of the automatic sort units. If additional automatic sorting can be justified, the HDPE sort unit could be followed by PP and PET (and/or PS/PVC, if justified) stages. A potential arrangement for sorting HDPE, PP and PET is shown in Figure 31.

**Figure 31. Potential arrangement of automatic NIR sorting units at a MRF**

![Diagram of automatic NIR sorting units at a MRF]

**Quality Requirements**

All product streams assessed during the trials were of acceptable quality for each reprocessor.

7.2.8 **Key Findings - Optimum Mixed Plastics Collections**

For this project MRFs were selected which accepted different mixes of co-mingled materials in order to be able to identify whether the inclusion of mixed plastics in co-mingled recyclate had a detrimental affect on the quality of the other segregated materials. Particular emphasis was given to the contamination of paper due to this being the prime material sorted at many MRFs in the UK.

**Key Finding 1 - The inclusion of mixed rigid plastics and film with co-mingled materials, did not have an adverse affect on the quality of other products streams.**

The collection of mixed plastics with glass and paper was of particular significance to this project, as glass and organic residue from mixed plastics have the potential to significantly reduce the quality of the recovered paper. The findings on quality were as follows:

- A low level of contamination (5.58%) was found in the mixed plastics category, of which 1.91% was from unwanted plastics in the form of film (0.62%) and non-packaging plastics (1.29%);

- Paper quality was found to be very high, with only 0.2% contamination, the majority of which was attributable to plastics (0.18%);

- Glass had the highest proportion of material contamination at 23%, however this was primarily due to the fines fraction from all materials being removed with the glass early in the processing stage;

- The quality of most products was high, with minimal contamination from mixed plastics;

- Paper quality was very high with only 0.07% contamination and only 0.054% attributable to plastics;
Steel included contamination at 10.12% at its highest, however, only 3.15% was from plastics of which film accounted for 1.03%;

Plastic film purity was found to be over 95% when collected deliberately from a stream that contained 4% film. Small pieces of paper and mixed rigid plastics accounted for less than 5% contamination;

Although there was slight contamination from rigid plastics in aluminium and steel it was not considered high enough to reduce the overall quality of the product to the end market.

**Key Finding 2 - Good mixed plastics recovery is possible using a variety of collection methods**

This trial demonstrated that reprocessing of materials using plastic sacks as a collection method was also manageable and did not affect the MRF reprocessing ability. The potential contamination from glass broken in the sacks during collection did not appear to impact significantly on the other recyclate product streams as this fraction was screened early in the process.

Provided MRFs have the correct systems, procedures and technologies in place to sort for plastic bottles then it is feasible for them to accept mixed plastics, including plastic film, co-mingled with cans, paper/card, plastic bottles and glass without a significant capital expenditure;

Capital requirements to handle mixed plastics are specific to the individual MRF;

No one system can be considered ‘optimum’ as the practicality and success of mixed plastics sorting will depend very much on the individual circumstances of the MRF responsible for the separation of the materials;

Both MRFs that currently sort for mixed plastics have refined their facility over time to optimise the quality and/or quantity of recovered materials at their plants. Any local authority adding mixed plastics sorting to their operations should consider a trial phase and implement any adjustments required to the system gradually.

7.3 **Factors to Consider when Collecting Mixed Plastics**

The collection of film should only be considered if there is provision for manual removal of film from the paper and container streams, early in the MRF process;

Mixed plastics should be requested clean, without food residue;

By excluding DIY, garage and gardening related packaging the relative amount of PVC collected would be reduced. PVC is still present in many food-packaging items. A higher than anticipated level of PVC was discovered in the other rigid plastics category. End markets for recovered mixed coloured PVC are currently limited in the UK and suitable reprocessors could not be found to participate in the trials;

Automated NIR sorting systems cannot currently identify dark/black plastics and these materials become residual material. Although in a manual sorting system black mixed plastics can be identified and positively sorted, the exact polymer type that the black packaging item belongs to is difficult to identify, unless the packaging item is specifically marked.
8.0 Overall MRF Processing Trial Conclusions

The capacity of MRFs that included mixed plastics in this study was not affected as they experienced an additional throughput of approximately 3.5% by weight.

- The capacity of MRFs in this project was not affected as they experienced an additional throughput rate of approximately 3.5% by weight for rigid and 2% for films. In terms of volume, mixed plastics would expect to be similar to plastic bottles.

Contamination from all plastics was low at all facilities in the trials.

- The highest recorded level of contamination by all plastics was recorded in MRF C’s steel product (3.15%);
- Any threat posed by the inclusion of mixed plastics is seen to lie mainly in the difficulties of segregating them as streams separate from conventionally collected plastic bottles.

The inclusion of mixed plastics didn't affect the overall value of product streams.

- The main product from the three MRFs was paper. The paper quality from the two MRFs currently collecting mixed plastics and film is higher than the paper quality from the MRF that is not currently collecting for mixed plastics and film;
- When mixed plastics were introduced into the MRF not currently collecting mixed plastics there was no increase in the contamination levels observed on the paper product line.

The paper product quality was not affected by inclusion of mixed plastics.

- The paper quality observed during the trials was high at the MRFs currently collecting mixed plastics, with only 0.1% - 0.2% of contamination recorded;
- Mixed rigid plastics typically accounted for 0.04 - 0.05% of paper contamination;
- Plastic film was manually extracted before ballistic separation or screening (as far as possible), to ensure the film was minimised in the paper stream.

Where glass is already collected as part of a co-mingled scheme, the inclusion of mixed plastics is feasible.

- The inclusion of mixed plastics co-mingled with paper/cardboard, cans, plastic bottles and glass did not considerably affect the quality of the product streams; and the overall value of the product streams were not affected;
- Minimal quantities of other rigid plastics contamination were identified in paper (0.04%), steel (0.8%) and glass (1.18%) products;
- The infeed material was considered clean with only 4.2% contamination present;
- Contamination of product streams from glass breakages was minimal due to small glass fragments and debris being screened out early in the process.
The mixed plastics product contained high levels of PET and HDPE bottles.

- The majority of the mixed plastics product during the trials was PET (52-58%), followed by HDPE (5-19%);
- The PET included 31-51% clear bottles, 6-14% coloured bottles and 1.6-6% other rigid plastics;
- It should be noted that during the trial one of the MRFs were not separately sorting PET due to end market conditions which contributed to the high levels found in the mixed plastics composition.

There is scope to improve material capture efficiencies and reduce quantities of residual material.

- Within MRFs accepting mixed plastics the majority (59-65%) of the residual stream constituted paper/card, followed by mixed plastics (28-31%);
- If greater quantities of recyclable materials are recovered from the waste streams this will lead to increased revenue, avoided landfill costs and improved recycling rates;
- Currently both MRFs collecting mixed plastics send their residue to a private contractor for further treatment and recovery;
- The economic feasibility of improving capture efficiencies is described in the economic section of the report.

The collection of plastic film with mixed plastics is feasible if it is manually sorted early in the process.

- The inclusion of plastic film co-mingled with paper/cardboard, cans and plastic bottles did not affect the quality of the product streams considerably;
- Minimal quantities of rigid plastics contamination was identified in aluminium (0.17%) and steel (0.57%) at the facility requesting both film and other rigid plastics;
- Minimal plastic film contamination was found in aluminium (0.09%), steel (1.03%) and mixed plastics (0.58%) product streams;
- The infeed material was considered clean with only 4.2% contamination present;
- Contamination from plastic film was minimal due to the film being positively sorted early in the process.

The quality of the plastic film product was high.

- The plastic film collected from MRF B, which had 4% film in the infeed had a purity of over 95%.

Factors to consider when collecting mixed household plastics packaging

- Those MRFs not requesting plastic film still received plastic film as contamination and were required to separate it, especially where recyclate was collected in plastic sacks;
- Dark/ Black PP, PVC and film accounted for between 14 and 24% of mixed plastics infeed composition in the trials. Excluding these materials would mean excluding up to a quarter of mixed plastics;
The level of contamination acceptable in the separation of recyclates is very much dependent on the type of sorting systems in place and the requirements of the contractor procuring the sorted products.

**Factors to consider for bottle sorting**

- The MRFs handling all plastics include a high bottle content in their mixed plastic stream;
- HDPE and PET bottles tend to have more value than the other rigid plastics so are often co-separated;
- Remaining bottles may include untargeted colours and missed clear and natural bottles.

The above described conclusions are based on a technical assessment of MRF processing; the economic feasibility is covered in the accompanying 'Financial Assessment Report'.

### 9.0 Recommendations for Consideration

The following recommendations should be considered, based on the analyses and conclusions from all the trials undertaken as part of MRF processing trials.

**Recommendation 1** – MRFs and local authorities currently collecting and sorting plastic bottles should consider incorporating mixed rigid plastic and films.

**Recommendation 2** – MRFs should be encouraged to adopt low technology solutions (e.g. manual sorting) in order to incorporate mixed plastics into their operations at low throughput rates, however automated technologies and sorting systems are appropriate at higher throughputs. Smaller MRFs may find it hard to justify fully automated optical sorting systems for polymers, but in some cases automated separation of all plastics may be still cost effective.

**Recommendation 3** - Inclusion of film in collections should be considered in light of current and future material availability and space to access film at an early stage of the process.

**Recommendation 4** - Technical development and innovation should be encouraged in areas related to the separation of bottle plastics from other rigid plastics, however currently available technologies are highly capable of separation of these plastic packaging formats.
10.0 Collection and Recycling of Mixed Plastics from Retail Front-of-Store

10.1 Objectives for Collection from Retail Schemes

An element of the project was to assess the viability of recycling mixed plastics collected by retailers in front of store. As part of the project a minimum of 20 tonnes of mixed plastic packaging waste was to be collected and recycled. Sainsbury's designed collection points within selected stores to provide its retail customers with an option for mixed plastic packaging collection at the store site. Sainsbury's currently have more than 800 stores nationwide and designated 26 stores in and around London for the trial where they installed containers and signs in its recycling areas next to the existing facilities for paper and glass. The 26 Sainsbury's London stores started collections in December 2008 and between them collected a consistent volume of 3.5 tonnes to 4 tonnes per week, meaning that the overall collection target was exceeded by the end of January. Sainsbury's created publicity within its own stores but also publicised its commitment to investigating the feasibility of mixed plastics collection at its front-of-stores. As plastic carrier bags are separately collected at many of these stores, the bins were marked with the key words of 'mixed plastics recycling'.

10.2 Collection Issues

All the stores used in the trial reported that the collection facilities had been well accepted and were being used by customers. However, the nature of the initiative meant that there would inevitably be a slow uptake while the trial gained momentum. Sainsbury's did not designate the mixed plastics packaging collection bins as 'Sainsbury's packaging only', and as a result, received packaging from all retail sources. In general, the plastics collected were relatively clean, with a noticeably high percentage of PET bottles. One of the collection issues for any retailer considering this type of scheme is to note that the composition of the waste collected was never exclusively Sainsbury's own. The analysis of the collected packaging found that 44% was Sainsbury's own brand and the rest of the packaging was evenly split across other brands and retailers.

This evidence suggests that the general public use the recycling facility provided, but did not differentiate between different retail sources. This issue is not a problem for the plastics processor further down the line as most of the plastics used across the retail industry are made from standard generic polymers.

10.3 Retail Waste Collection

Nextek and a designated waste management company confirmed details of all the participating stores and discussed detailed routes and collection challenges as well as collection efficiencies. The early findings were that although the drivers of the waste collection vehicles knew that the stores had changed the plastic collection policy, they had not noticed much difference to 'normal' Sainsbury waste coming in. The waste collection vehicles have three separate compartments, but always collect four different waste streams (glass, paper, cans, and plastics), so the best that is achieved is a separate stream of glass and paper and a mixed stream of co-mingled plastics and cans.

*Figure 32. Standard collection of mixed plastics and cans*
Because of the bulk involved with the plastics collected, the collection vehicles could only collect 375 kg per compartment before it was full. This made collections very un-economic and was the main reason why plastics and cans were mixed. A separate plastics only collection was possible, but this would have needed to be performed with a compacting vehicle to minimise volume and maximise recovery. Uncompacted collection could only collect up to 5 tonnes before it is full and this would be an expensive collection method. As the Sainsbury’s stores were collecting a maximum of 4 tonnes of plastics per week, the collection costs for uncompacted plastics packaging alone were considered to be high.

**Figure 33.** Examples of sorted ‘mixed plastics’ collected from Sainsbury’s (after a manual sort is performed at waste management company waste transfer station to remove metal cans)

The waste management company drivers involved in Sainsbury’s store collections were interviewed to identify the challenges associated with front of store material collection. All drivers reported that plastics and cans get mixed together in a single compartment and although they tried to keep paper separated most of the time. Sometimes this was not possible, when the sheer volume of paper left for collection after the weekend meant that all 3 compartments on the waste collection vehicle were quickly filled up with paper, thus resulting in the mixing of paper with the plastics and cans. When this happened, any bales produced from this mix were difficult to reprocess. This was particularly the case when wet paper was compressed together with plastics and metal and the bales were then extremely difficult to debale using standard debaling equipment.

The actual quality of the waste plastics packaging collected within the Sainsbury’s bins was high and a large proportion was bottles, with approximately 20% to 25% trays and tubs and negligible amounts of films. There were surprisingly few supermarket carrier bags mixed with the rigid packaging, with most of these coming from being used for the packaging of the rigid packaging items by the householders for transportation to the collection site.

### 10.4 Compositional Analysis of Sainsbury’s Retail Mixed Plastics

A detailed compositional analysis of the retail waste stream was carried out at the waste management company’s main depot. The Sainsbury’s stores had provided clearly marked plastics collection bins and six of these were isolated after being in place for a minimum of four days. More than 1,300 individual items were then examined. As previously mentioned, the high bottle content was expected, partially as these sites had previously encouraged bottle only collections. The material from the collection bins was found to be of very high quality in terms of cleanliness and high levels of plastics purity. It was visually evident that there was very little contamination from other materials such as paper, glass or metals. The recovered packaging was found to be very clean (packaging appeared to have been washed/rinsed) when compared to materials found in kerbside collections during MRF trials.
10.4.1 Sample Selection and Size

The methodology adopted was designed to coincide with other analysis carried out as part of the project. The packaging items were separated by types of polymer and by product formats. Packaging was checked for evidence of contamination, especially from food, liquid carton board and multi-layer film products. It was noted that there are economic and logistical problems involved in plastics collection of uncompacted packaging being of low weight, but of high volume. For example, the total sample from two days of store collections had been analysed, yet it only had a combined weight of 42 kg. It is clear that if collection is to be effective and more economically viable, compaction or size reduction needs to be considered.

10.4.2 Composition of Mixed Plastics

The packaging items were examined and weighed by category. It should be noted that although the overall weight of the sample was relatively small, more than 1,300 items were individually examined. The composition of the 42 kg worth of packaging analysed is provided in Figure 34.

**Figure 34. Analysis of Sainsbury's mixed plastics collections January 2009**

<table>
<thead>
<tr>
<th>Total Weight</th>
<th>sub category</th>
<th>Weight (kg)</th>
<th>Number of items</th>
<th>% of category</th>
<th>% of total by weight</th>
<th>% of total by items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>Newspaper</td>
<td>1.00</td>
<td>30</td>
<td>100.0%</td>
<td>2.4%</td>
<td>2.2%</td>
</tr>
<tr>
<td></td>
<td>Magazines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.40</td>
<td>Non packaging recyclable</td>
<td>0.40</td>
<td>9</td>
<td>25.0%</td>
<td>0.2%</td>
<td>0.7%</td>
</tr>
<tr>
<td></td>
<td>Card Packaging</td>
<td>0.10</td>
<td>2</td>
<td>8.3%</td>
<td>0.2%</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Card non packaging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquid Cartons</td>
<td>0.30</td>
<td>6</td>
<td>75.0%</td>
<td>0.7%</td>
<td>0.4%</td>
</tr>
<tr>
<td></td>
<td>Refuse sacks</td>
<td>0.10</td>
<td>2</td>
<td>8.3%</td>
<td>0.2%</td>
<td>0.1%</td>
</tr>
<tr>
<td>1.20</td>
<td>Film- non packaging</td>
<td>1.10</td>
<td>20</td>
<td>91.7%</td>
<td>2.6%</td>
<td>1.5%</td>
</tr>
<tr>
<td></td>
<td>Film packaging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carrier bags</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PET Clear</td>
<td>10.80</td>
<td>270</td>
<td>45.4%</td>
<td>25.7%</td>
<td>19.9%</td>
</tr>
<tr>
<td></td>
<td>PET Coloured</td>
<td>1.60</td>
<td>35</td>
<td>6.7%</td>
<td>3.8%</td>
<td>2.6%</td>
</tr>
<tr>
<td></td>
<td>HDPE Clear</td>
<td>8.40</td>
<td>221</td>
<td>35.3%</td>
<td>20.0%</td>
<td>16.3%</td>
</tr>
<tr>
<td></td>
<td>HDPE Coloured</td>
<td>2.00</td>
<td>56</td>
<td>8.4%</td>
<td>4.8%</td>
<td>4.1%</td>
</tr>
<tr>
<td></td>
<td>Other Bottles (PVC and EVOH)</td>
<td>1.00</td>
<td>26</td>
<td>4.2%</td>
<td>2.4%</td>
<td>1.9%</td>
</tr>
<tr>
<td>14.60</td>
<td>Food Packaging PP</td>
<td>2.60</td>
<td>150</td>
<td>17.8%</td>
<td>6.2%</td>
<td>11.1%</td>
</tr>
<tr>
<td></td>
<td>Food Packaging PS</td>
<td>0.40</td>
<td>54</td>
<td>2.7%</td>
<td>1.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td></td>
<td>Food Packaging PET</td>
<td>2.20</td>
<td>129</td>
<td>15.1%</td>
<td>5.2%</td>
<td>9.5%</td>
</tr>
<tr>
<td></td>
<td>Food Packaging EPS</td>
<td>0.20</td>
<td>6</td>
<td>1.4%</td>
<td>0.5%</td>
<td>0.4%</td>
</tr>
<tr>
<td></td>
<td>Food Packaging Other</td>
<td>2.60</td>
<td>184</td>
<td>17.8%</td>
<td>6.2%</td>
<td>13.6%</td>
</tr>
<tr>
<td></td>
<td>Non Food Packaging</td>
<td>2.60</td>
<td>114</td>
<td>17.8%</td>
<td>6.2%</td>
<td>8.4%</td>
</tr>
<tr>
<td></td>
<td>Other items (VTR tapes etc)</td>
<td>4.00</td>
<td>20</td>
<td>27.4%</td>
<td>9.5%</td>
<td>1.5%</td>
</tr>
<tr>
<td>0.10</td>
<td>Man made fibres (veg. nets)</td>
<td>0.10</td>
<td>8</td>
<td>100.0%</td>
<td>0.2%</td>
<td>0.6%</td>
</tr>
<tr>
<td>0.60</td>
<td>Kitchen food waste</td>
<td>0.60</td>
<td>3</td>
<td>100.0%</td>
<td>1.4%</td>
<td>0.2%</td>
</tr>
<tr>
<td>0.10</td>
<td>particles &lt;10mm</td>
<td>0.60</td>
<td>1</td>
<td>100.0%</td>
<td>1.4%</td>
<td>0.1%</td>
</tr>
<tr>
<td>42.00</td>
<td>Total</td>
<td></td>
<td>31</td>
<td>1,357</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
However, due to the collection method used to collect this waste from the Sainsbury’s sites, the highly pure plastics stream in fact becomes immediately mixed with cans and often with paper too. When it becomes mixed and compacted with the collected paper the materials become too difficult to separate for recovery and recycling. The analysis of the mixed plastics collected in the bins from front-of-store is shown in the following table. The table shows that there is very little non-plastic contamination and if the plastic stream can be kept separate by waste collection vehicles then it could be sent directly for reprocessing at a PRF + reprocessor and avoid the need for sorting at a MRF.

**Figure 35.** Compositional analysis of front-end store mixed plastics collection from Sainsbury’s stores

The following images show some of the collected packaging items sorted at the Sainsbury’s trials.

**Figure 36.** Examples of mixed plastics sorted and analysed at waste management company waste transfer station

| Small PS based yoghurt bottles | Multi-layer bottles, classified as ‘other’ |
10.5 Additional Sorting of Retail Collection Before PRF

The waste management company has a waste transfer station facility, which was configured to hand sort and remove the majority of cans and eliminate the majority of paper and card contamination. This created two valuable waste streams, but performing this task on continuous basis would add extra costs to the process.

Due to the small number of compartments in waste collection vehicles, materials arriving at the waste management company were typically co-mingled. In order to recover the plastics component for reprocessing at Closed Loop Recycling, a plastic specific sorting trial was performed. This involved a ‘mini MRF’ trial involving existing sort cabin and staff, where plastics and cans were positively picked out and segregated manually.

At the waste management company waste transfer station the product was unloaded and was stored loose. The material then travelled to the manual sort cabin via a standard incline conveyor. Prior to these trials, the sorting cabin was only used for the recovery of a high quality paper output for a specific customer. This meant the sorting staff had no knowledge of polymer types and needed to be trained to sort plastics packaging.

Non-ferrous metal cans could be easily removed by the addition of over belt magnets. Following this trial, the waste management company was keen to install them. The following images were taken during the retail mixed plastics sorting trial:

**Figure 37.** Separation of metal and paper from mixed plastics from Sainsbury’s collection

The paper, cans and residual element were denser than the plastics, especially in the case of paper and cardboard as both of these products had a relatively high moisture content.

Although more than 20 tonnes of co-mingled compacted material was previously collected and shipped to the Valpak PRF for sorting trials, this material was not able to be debaled due to the tight bale compaction and the high levels of wet paper and cans in the bales. The following sorting trials were therefore organised to recover
plastics packaging from vehicles that did not have compacted mixed packaging. The sorting therefore primarily involved the removal of paper and metal cans. The plastics packaging materials recovered from this sorting trial were then sent to Closed Loop Recycling for reprocessing. The sorting trial ran for two days with four to six people in the sort cabin. The total amount sorted was 3,800 kg and the experiment concentrated on positively sorting for clear / natural HDPE and PET bottles and trays, coloured plastics, mixed plastic films and metal objects such as drinks cans. The following chart provides the percentages of each type of waste stream found during this part of the trial.

**Figure 38.** Composition of Sainsbury’s material streams from front of store collection

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear plastic</td>
<td>26%</td>
</tr>
<tr>
<td>Coloured plastic</td>
<td>11%</td>
</tr>
<tr>
<td>Films</td>
<td>13%</td>
</tr>
<tr>
<td>Paper and residues</td>
<td>42%</td>
</tr>
<tr>
<td>Metal cans</td>
<td>11%</td>
</tr>
</tbody>
</table>

The increased amount of film seen during these sorting trials when compared to the compositional analysis was due to the inclusion of the film within the paper stream from the same collection points. Plastic film is considered to be a major contaminant for paper recyclers, so providing a mixed plastics recycling point at the same location as paper recycling would have benefits for recovery of both streams, if segregation can be maintained.

From these trials, only 50% of the weight collected could be classified as recyclable plastics, but a much greater percentage of volume space was taken up by the plastic elements. This underlines the logistical problems facing a retail take back scheme once the consumer’s involvement has been secured.

**Figure 39.** Amounts of packaging separated during a two day manual sort of mixed packaging from the Sainsbury’s collections at the waste transfer station

<table>
<thead>
<tr>
<th>Materials Sorted</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Plastics</td>
<td>1,000</td>
</tr>
<tr>
<td>Coloured Plastics</td>
<td>400</td>
</tr>
<tr>
<td>Films</td>
<td>500</td>
</tr>
<tr>
<td>Paper and residue</td>
<td>1,600</td>
</tr>
<tr>
<td>Metal cans</td>
<td>300</td>
</tr>
<tr>
<td>Total</td>
<td>3,800 kg</td>
</tr>
</tbody>
</table>
10.6 Summary of Sorting Trial

- Although the waste management company did everything that it could to collect the plastics separately and segregate them at the waste transfer station, there was still a very high degree of cross contamination, especially with paper and card due to only three compartments in the waste collection vehicle;

- Although at least 20 tonnes was collected during the course of December and January. The expense of hand sorting and the high percentage of non-plastic contamination meant that substantially less was available for the reprocessing trials. This was due to the collection method used, resulting in materials becoming cross contaminated with the paper, cardboard and metal cans in the vehicles with three sections. The total amount of materials from the 20 tonnes collected that was made available for the reprocessing trials was 3.8 tonnes;

- Due to the tight compaction of wet paper/cardboard with the plastics and metal packaging components debaling was difficult and resulted in clumps of materials and not in separated items and these materials therefore could not be processed in plants that used automated sorting equipment;

- When the materials were not cross contaminated and compacted, manual sorting at the waste transfer station resulted in the recovery of a highly pure and clean plastic waste stream. This stream was able to be sent directly to Closed Loop Recycling and the coloured polyolefin segment to LINPAC without the need for further sorting at a MRF or a PRF;

- In order to make this collection system succeed, it needs a collection and transport solution that is economic and results in separated material streams. The current collection method means that significant levels of re-sorting are required at the waste transfer stations. If the plastics packaging was able to be collected in a separate vehicle and compacted or size reduced then there would be the potential to capture a highly pure and clean stream that would be of value and could be sent directly to plastics reprocessors;

- Successful front of store collection of mixed plastics packaging therefore requires an optimised collection method that ensures separation from other packaging materials and utilises compaction of plastics for efficient recovery and cost effective logistics.

11.0 Introduction - Combined Plastics Recovery Facility (PRF) + Reprocessing of Mixed Plastics

The purpose of this part of the project was to bring together the key plastics sorting and recycling technologies and systems in an integrated manner to investigate the feasibility of recovering a wide range of materials from the mixed plastics waste stream and assessing the potential for them to be recycled into resins or products of sufficient quality to replace plastics in the manufacture of new products.

Films recovered and sorted at the MRFs were sent directly to a specialist film reprocessor (CeDo) and were not processed at the PRF. CeDo operate a 40,000 tonne per annum film recycling plant in Holland and produce several grades of recycled film resin that are utilised back into film products. Approximately 36 tonnes of post-consumer plastic film packaging was sent to CeDo for reprocessing.

Rigid mixed plastics packaging from the MRFs and from Valpak’s own collection (112 tonnes) was sorted at the Valpak facility. The rigid plastics materials that were sorted were then forwarded onto specialist reprocessors, Closed Loop Recycling and LINPAC Recycling.

Closed Loop Recycling operate a 35,000 tonne per annum reprocessing facility and supply a number of customers with recycled food grade PET and HDPE resins that are then converted back into food contact packaging. Closed Loop Recycling was sent approximately 63 tonnes of mixed PET and HDPE balestock.
LINPAC Packaging is a specialist PP, PE and PS reprocessor and compounding. LINPAC Packaging recycles a wide variety of post-consumer and post-industrial plastics and produce a variety of compounds that are used in injection moulded and extruded products. LINPAC Packaging received 33 tonnes of PP and approximately a tonne of PS balestock from the sorting trials and an additional 4.8 tonnes sourced externally.

## 12.0 Plastic Reclamation Facility (PRF) Sorting Trials

A PRF can be considered as a plastic specific MRF. The role of such a PRF is to separate the rigid mixed plastics stream into the appropriate polymer streams such as, PET, HDPE, PP, PS and PVC. The sorting facilities at Valpak were used as a PRF. The facility has an operating capacity of approximately 20,000 tonnes of plastic bottles per annum.

The Valpak PRF facility was selected to automatically sort the mixed rigid plastics into particular polymer types, which would allow each fraction to be segregated for further reprocessing. A complete compositional picture of inputs, outputs and residual streams was built up during the trial when more than 100 tonnes were sorted over a two day period. The sorting trials on the mixed plastics feedstocks from MRF C and B were performed in two passes. In the first sorting pass all PET and HDPE packaging was positively identified by the NIR units and was sorted (regardless of colour) from the other polymer materials. The mixed PET/HDPE stream (63 tonnes) was then sent to Closed Loop Recycling. In the same sorting pass PP was also positively identified by the NIR units and separated as a separate output. The PP component (33 tonnes) was then sent to LINPAC Recycling.

The second pass involved identification and sorting of PS and PVC. A single bale of PS was recovered (725 kg) from the mixed plastics sorting trials. The PS bale was shipped to LINPAC Recycling for further reprocessing.

The remaining materials were classified as 'final residues' and there was approximately 13 tonnes of this material left after the PRF sorting trials. In addition, a further 2 tonnes of PVC were separated. Due to the inability to find a short-term market for this material it was added to the residual fraction making the final quantity 15.75 tonnes.

The PRF sorting trials provided useful data on sorting efficiency for the MRFs as automated plastic sorting systems were used and consequently providing a basis for comparing the cost and efficiency of manual vs. automatic sorting.

### 12.1 Input Material Specification of the PRF

The participating PRF normally accepts mixed cans and plastic bottles for sorting using its processing line consisting of magnets, eddy current and two automated near infrared sorting units. Although other materials such as paper are accepted at the facility, they do not go through the sorting line. The plant typically sorts PET and HDPE bottles, but for the purposes of these trials sorted samples of mixed plastics into the target polymer streams: PET; HDPE; PP; PS and PVC.
12.2 The PRF Plastic Sorting Process

The facility is automated, with two distinct processing lines. At the beginning of the process a can line is in place to remove metals from a co-mingled container infeed stream; however when the infeed is mostly plastics this is not required and the plastics go directly to the plastics processing line. The plastics processing lines use Near Infra Red (NIR) sorting units to automatically identify and separate selected polymer types. For this project it was used to segregate the mixed plastics into PET, HDPE, PP, PVC, PS and residual material product streams. The plant processes and separates the recyclables through the facility in the following manner:

![Process schematic of the PRF sorting operation](image)

**12.2.1 Material Infeed System**

The bales were either broken up manually or material was taken from bays where it had already been singulated and was loose. A front-end loader picked material from the delivery hall and deposited it into a bag opening unit. This was a large rectangular hopper with a rotating auger shaft device performing a bale breaking function as it discharged the broken material to the PRF feed system.

**12.2.2 Removal of Film and Contaminants – Vibrating Screen**

After a short horizontal conveyor an elevating conveyor takes the stream to a vibrating screen. Small size fragments are removed and deposited in bins under the screen. Manual sorters also remove film and larger contaminating items.

**12.2.3 NIR Sorting of Mixed Plastics**

The debaled material flows into a splitter where the material is distributed between two parallel conveyors each with a NIR sorting unit. In normal operating mode this identifies and removes PET from the stream and conveys it to storage bays. The remaining material from these two PET sort units is then combined and fed through a third NIR unit that targets HDPE and conveyed to storage bays.
PRF Reprocessing Material Residues
The material remaining on the processing line after the NIR sorting units is considered as residue and is conveyed to a residue storage area. As this can often contain some recyclable materials it may be put back through the processing line to recover more material or be consigned for third party treatment or disposal.

Benchmark Data
In order to assess the effectiveness of processing mixed rigid plastics compared to typical feedstock of mixed bottles benchmark, Valpak undertook analysis of its out-throw material stream in 2008. The results of this study are summarised below and provide a comparison for the manual operation capture rates. Following on from this work the PRF changed the process to improve on its capture rate of saleable polymers and increased its capacity. Below are the key findings from the analysis by polymer type of the out-throws from the PRF at a first pass.

Figure 41. Benchmark composition in detail

<table>
<thead>
<tr>
<th>Primary Classification</th>
<th>Secondary Classification</th>
<th>Tertiary Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass (kg)</td>
<td>Bottle %</td>
</tr>
<tr>
<td>PET</td>
<td>75.5</td>
<td>21.15%</td>
</tr>
<tr>
<td>PP</td>
<td>78.5</td>
<td>21.99%</td>
</tr>
<tr>
<td>PS/ HIPS</td>
<td>5.5</td>
<td>1.54%</td>
</tr>
<tr>
<td>HDPE</td>
<td>42.5</td>
<td>11.90%</td>
</tr>
<tr>
<td>PVC</td>
<td>12.5</td>
<td>3.50%</td>
</tr>
<tr>
<td>OTHER PLASTICS</td>
<td>5.5</td>
<td>1.54%</td>
</tr>
<tr>
<td>LARGE PLASTIC FILMS</td>
<td>10.5</td>
<td>2.94%</td>
</tr>
<tr>
<td>RESIDUE</td>
<td>115.5</td>
<td>32.35%</td>
</tr>
<tr>
<td>OVERALL</td>
<td>357</td>
<td></td>
</tr>
</tbody>
</table>

In addition, the following points were made:

- Largest composition by mass in the residue is paper, cardboard and small plastic films;

- Of the total material, black plastic items account for 12.4% and this is related to the inability of current NIR sorting systems to identify plastics that are black. The black plastic stream equates to approximately 318 tonnes per year, mainly made up of PP and CPET trays;

- The majority of the out-throw PET and HDPE were bottles; PVC and PS had no bottle content and PP was predominantly non-bottles;

- From the analysis of the out-throw quantities, and based on the fact that the PRF facility had an input capacity at the time of the analysis of 20k tonnes of plastic per annum, the capture rate of saleable plastic polymers is 76 – 78%.

12.2.4 PRF Sorting Trials: Compositional Analysis
In order to establish the polymer types found in the samples from the mixed plastics outputs at MRF C and MRF B, compositional analyses were carried out manually at the participating PRF. This analysis formed an extensive data set for the input streams for the PRF reprocessing trials.
Composition of other rigid plastics products at MRF C (outputs)

Figure 42 illustrates the proportions of different polymer types found in the other rigid plastics product from MRF C. A more detailed breakdown is provided in the subsequent table of results.

Half of the mixed plastics product from MRF C was still bottles, (e.g. after bottles had already been taken out as a separate bottle stream); surprisingly 31% was attributable to clear PET, which was collected as a single stream. However, this was approximately 20% less than the percentage available within MRF B’s mixed plastics category (51%), which is not complemented by separate sorting of clear PET. MRF C also separates out natural HDPE from its mixed plastics, which was evident from the minimal 2% found within the mixed plastics category. The most significant non-bottle polymer was polypropylene (PP) constituting 21%, followed by PVC at 14%, other PET packaging at 6% and polystyrene (PS) at 2%.

The ratio of PP to PS content is approximately 10:1 and contrasts with the previously determined ratio in the MRF infeed of 9:5. This suggests, that there is a loss of PS throughout the MRF system as there appears to be a higher content of PS in the residue from the plant than PP. There is also evidence that PS material is lost on passage through the MRF system, where smaller items are removed at screens, as PS as a material is more vulnerable to damage and size reduction than some other plastics. For example fragments of PS containers can be seen in the fines bins. The following table shows materials going from MRF C into the PRF.

Figure 42. Detailed breakdown of mixed plastics composition received from MRF C

<table>
<thead>
<tr>
<th>MRF C Mixed Plastics Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottles PET clear</td>
</tr>
<tr>
<td>Other Rigid PP</td>
</tr>
<tr>
<td>Bottles PET Coloured</td>
</tr>
<tr>
<td>Other Rigid PVC</td>
</tr>
<tr>
<td>Other Rigid PET</td>
</tr>
<tr>
<td>Paper/Card</td>
</tr>
<tr>
<td>Bottles HDPE Coloured</td>
</tr>
<tr>
<td>Non-Packaging Plastics</td>
</tr>
<tr>
<td>Other Rigid PS</td>
</tr>
<tr>
<td>Bottles HDPE Natural</td>
</tr>
<tr>
<td>Film</td>
</tr>
<tr>
<td>Other Rigid Closures</td>
</tr>
<tr>
<td>Metals</td>
</tr>
<tr>
<td>Other Rigid HDPE</td>
</tr>
<tr>
<td>Other Rigid LDPE</td>
</tr>
<tr>
<td>Liquid Carton Board</td>
</tr>
<tr>
<td>Glass</td>
</tr>
<tr>
<td>Unknown</td>
</tr>
<tr>
<td>Residual</td>
</tr>
<tr>
<td>Fines</td>
</tr>
</tbody>
</table>

Figure 43 illustrates analysis of rigid plastics received from MRF B. More than three quarters (76%) of the MRF B other rigid plastics product was bottles; 57% attributable to PET (51% clear, 6% coloured PET), but only 19% is attributable to HDPE. However, at the time of the trials MRF B had a clear focus on recovery of natural HDPE as a single stream (due to current market conditions), therefore it should be expected that the proportion of this is much lower when the value of recovered PET resumes higher values.

As with MRF C, the most significant non-bottle polymer is polypropylene (PP) constituting 14%, followed by PVC at 2%, other PET packaging at 2% and polystyrene (PS) at 0.37%. The ratio of PP to PS in the infeed at MRF B is similar to that at MRF C at 9:5. However in the end of line material at the MRF it is 3:1 and 40:1 in product stream. The screening method at MRF B is likely to cause damage to PS items and it sometimes gets screened out early in the processing line with the glass product. Further research maybe required to determine what happens to the PS in the process.
Figure 43. Detailed breakdown of mixed plastics composition as received from MRF B

<table>
<thead>
<tr>
<th>MRF B Mixed Plastics Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottles PET clear</td>
</tr>
<tr>
<td>Other rigid PP</td>
</tr>
<tr>
<td>Bottles HDPE natural</td>
</tr>
<tr>
<td>Bottles HDPE coloured</td>
</tr>
<tr>
<td>Bottles PET coloured</td>
</tr>
<tr>
<td>Paper/card</td>
</tr>
<tr>
<td>Other rigid PVC</td>
</tr>
<tr>
<td>Other rigid PET</td>
</tr>
<tr>
<td>Non-packaging plastics</td>
</tr>
<tr>
<td>Glass</td>
</tr>
<tr>
<td>Film</td>
</tr>
<tr>
<td>Other rigid PS</td>
</tr>
<tr>
<td>Other rigid LDPE</td>
</tr>
<tr>
<td>Aseptic</td>
</tr>
<tr>
<td>Other rigid closures</td>
</tr>
<tr>
<td>Metals</td>
</tr>
<tr>
<td>Residual</td>
</tr>
</tbody>
</table>

12.3 PRF Plant Performance - Operating and Material Capture Efficiencies

The 'Large Scale Trial' PRF data was collected by referring to the analysis of the materials sent for further processing at LINPAC Recycling and Closed Loop Recycling.

The plant has a normal operating rate of up to 6 tonnes/hr for plastic bottles. For this trial only one of the parallel NIR sorting units for the first stage separation was used. Thus the maximum sorting rate was approximately 3tonne/hr. Figure 44 illustrates the overall capture efficiencies of the plastic material fractions captured in the large scale PRF trials for materials received from MRFs B and C the PRF trial data was collected after the downstream reprocessing trials. It should be noted that the extremely low quantities of PVC and PS in the MRF B material distort the findings; this is possibly as a result of the small quantities of other rigid plastics found at MRF B.

Figure 44. System capture efficiency by polymer for other rigid plastics trials

<table>
<thead>
<tr>
<th>Material</th>
<th>Bottles</th>
<th>Other Rigid Plastics</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRF B</td>
<td>MRF C</td>
<td>Large Scale Trial</td>
</tr>
<tr>
<td>PET Clear</td>
<td>52.3</td>
<td>91.2</td>
</tr>
<tr>
<td>PET Coloured</td>
<td>56.7</td>
<td>87.9</td>
</tr>
<tr>
<td>HDPE Natural</td>
<td>52.8</td>
<td>92.6</td>
</tr>
<tr>
<td>HDPE Coloured</td>
<td>32.1</td>
<td>75.2</td>
</tr>
<tr>
<td>PET Clear</td>
<td>75.3</td>
<td>83</td>
</tr>
<tr>
<td>PET Coloured</td>
<td>14.5</td>
<td>30.7</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>67.2</td>
<td>80.7</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>1.79</td>
<td>80.7</td>
</tr>
<tr>
<td>PVC</td>
<td>0.67</td>
<td>32.5</td>
</tr>
</tbody>
</table>

12.4 PRF Sorting Trial Results - Product Quality

Product quality analysis was conducted for MRF B, MRF C and the Large Scale trial (sourced from Valpak). It should be noted that the analysis of the MRF B and MRF C materials took place on site whereas the large-scale
trial data was collated from downstream reprocessor supplied information. It is therefore possible that some contamination of the products from the large-scale trials has not been included in the information below (e.g. through intermediate removal, screening, etc). All polymer products produced from the trials were baled and stored outside.

12.4.1 PET and HDPE Output Stream Composition Quality

The MRF C, MRF B and PRF trial results for the HDPE/PET product are shown in Figure 45. The most common material type is PET and is dominated by bottles, though other rigid types of PET are prevalent particularly in the MRF C material (e.g. CPET trays). The target materials (HDPE, PET, PP, PVC and PS) make up 96% of the product for MRF B, 83% for MRF C and 93% for the PRF sorting trial. The MRF C product had a higher PVC content than the other two. The following table correspondingly shows the product purity from MFR B, MRF C and PRF sorting trials.

**Figure 45.** HDPE and PET product in mixed rigid plastics from MRF B, MRF C and PRF sorting trials

<table>
<thead>
<tr>
<th>HDPE/PET Product</th>
<th>MRF B</th>
<th>MRF C</th>
<th>PRF Sorting Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/Card</td>
<td>0.16%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Film</td>
<td>0.01%</td>
<td>0.29%</td>
<td>0.60%</td>
</tr>
<tr>
<td>Other Rigid PE-1</td>
<td>2.21%</td>
<td>11.17%</td>
<td>0.68%</td>
</tr>
<tr>
<td>Other Rigid HDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.15%</td>
</tr>
<tr>
<td>Other Rigid PVC</td>
<td>1.04%</td>
<td>9.62%</td>
<td>0.23%</td>
</tr>
<tr>
<td>Other Rigid LDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PP</td>
<td>2.95%</td>
<td>3.09%</td>
<td>0.53%</td>
</tr>
<tr>
<td>Other Rigid PS</td>
<td>0.00%</td>
<td>0.21%</td>
<td>0.15%</td>
</tr>
<tr>
<td>Other Rigid Closures</td>
<td>0.00%</td>
<td>0.05%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Bottles PET Clear</td>
<td>53.96%</td>
<td>33.45%</td>
<td>41.76%</td>
</tr>
<tr>
<td>Bottles PET Coloured</td>
<td>8.91%</td>
<td>11.45%</td>
<td>22.11%</td>
</tr>
<tr>
<td>Bottles HDPE Natural</td>
<td>24.24%</td>
<td>13.91%</td>
<td>20.03%</td>
</tr>
<tr>
<td>Bottles HDPE Coloured</td>
<td>6.52%</td>
<td>13.73%</td>
<td>7.56%</td>
</tr>
<tr>
<td>Aseptic</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Glass</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Metals</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.08%</td>
</tr>
<tr>
<td>Non-Packaging Plastics</td>
<td>0.00%</td>
<td>2.44%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0.00%</td>
<td>0.00%</td>
<td>4.31%</td>
</tr>
<tr>
<td>Residual</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Fines</td>
<td>0.00%</td>
<td>0.00%</td>
<td>1.81%</td>
</tr>
</tbody>
</table>

Figure 46 shows an image of the PET/HDPE product being produced during the trials at the PRF.
12.4.2 PP Output Stream Composition Quality

A polypropylene rich product was obtained from the mixed plastics making up 76% of the MRF B product, 75% of the MRF C product and 91% purity of the PRF sorting trial as shown in Figure 47. HDPE and PET bottles were found as contamination in all samples and smaller amounts of PVC and PS in the MRF C and MRF B samples.

<table>
<thead>
<tr>
<th>PP Product</th>
<th>MRF B</th>
<th>MRF C</th>
<th>PRF Sorting Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/Card</td>
<td>0.46%</td>
<td>0.44%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Film</td>
<td>6.15%</td>
<td>0.60%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PE</td>
<td>1.10%</td>
<td>6.46%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid HDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PVC</td>
<td>1.78%</td>
<td>2.84%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid LDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PP</td>
<td>76.03%</td>
<td>74.91%</td>
<td>90.53%</td>
</tr>
<tr>
<td>Other Rigid PS</td>
<td>0.27%</td>
<td>1.92%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid Closures</td>
<td>0.00%</td>
<td>0.43%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Bottles PET Close</td>
<td>6.51%</td>
<td>3.43%</td>
<td>5.64%</td>
</tr>
<tr>
<td>Bottles PET Coloured</td>
<td>0.89%</td>
<td>0.69%</td>
<td>3.00%</td>
</tr>
<tr>
<td>Bottles HDPE Natural</td>
<td>0.56%</td>
<td>0.68%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Bottles HDPE Coloured</td>
<td>3.48%</td>
<td>1.09%</td>
<td>0.23%</td>
</tr>
<tr>
<td>Aseptic</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Glass</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Metals</td>
<td>0.33%</td>
<td>0.22%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Non-Packaging Plastics</td>
<td>2.44%</td>
<td>6.28%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Residual</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Fines</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
Figure 48 shows an image of the PP product produced during the trials at the PRF. The PP was segregated during the first NIR sorting pass.

**Figure 48.** PP product obtained for downstream reprocessing from mixed plastics PRF sorting trials

12.4.3 *PS Output Stream Composition Quality*

The quality of the MRF B PS product was very poor and content was dominated by polypropylene. This is thought to be due to the very small quantities of PS available in the stream processed.

The MRF C product was 70% polystyrene and the principal contamination was PE at 14% and other rigid PET at 9%. The PRF sorted product was 58% PS and principal contamination was other rigid PET at 23% natural HDPE bottles at 18%. The analysis of composition is shown in Figure 49.

**Figure 49.** PS product found in mixed rigid plastics from MRF B, MRF C and PRF sorting trials

<table>
<thead>
<tr>
<th>PS Product</th>
<th>MRF B</th>
<th>MRF C</th>
<th>PRF Sorting Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/Card</td>
<td>0.40%</td>
<td>0.73%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Film</td>
<td>1.05%</td>
<td>1.52%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PE</td>
<td>0.88%</td>
<td>8.62%</td>
<td>22.23%</td>
</tr>
<tr>
<td>Other Rigid HDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PVC</td>
<td>0.15%</td>
<td>0.39%</td>
<td>1.00%</td>
</tr>
<tr>
<td>Other Rigid LDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PP</td>
<td>63.32%</td>
<td>13.89%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PS</td>
<td>6.67%</td>
<td>69.88%</td>
<td>57.61%</td>
</tr>
<tr>
<td>Other Rigid Closures</td>
<td>0.82%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Bottles PET Clear</td>
<td>16.04%</td>
<td>0.32%</td>
<td>0.83%</td>
</tr>
<tr>
<td>Bottles PET Coloured</td>
<td>1.66%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Bottles HDPE Natural</td>
<td>4.37%</td>
<td>0.79%</td>
<td>17.78%</td>
</tr>
<tr>
<td>Bottles HDPE Coloured</td>
<td>3.53%</td>
<td>0.68%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Aseptic</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Glass</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Metals</td>
<td>0.00%</td>
<td>0.71%</td>
<td>0.54%</td>
</tr>
<tr>
<td>Non-Packaging Plastics</td>
<td>1.12%</td>
<td>2.97%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Residual</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Fines</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
Figure 50 shows the PS product, which was segregated on the same pass as the PVC product at the PRF.

**Figure 50.** PS product obtained for downstream reprocessing from mixed plastics PRF sorting trials

![PS product](image)

### 12.4.4 PVC Output Stream Composition Quality

The small amounts of PVC in the MRF B mixed plastic material was reflected in a low PVC content in the PVC product stream during the trial. This product stream comprised predominantly HDPE and PET bottles. The MRF C PVC product was 37% PVC and the stream included examples of all of the individual infeed components including 3% PS. The details are shown in Figure 51. The large-scale trial product was 82% PVC.

**Figure 51.** PVC product found in mixed rigid plastics from MRF B, MRF C and PRF sorting trials

<table>
<thead>
<tr>
<th>PVC Product</th>
<th>MRF B</th>
<th>MRF C</th>
<th>PRF Sorting Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/Card</td>
<td>0.22%</td>
<td>0.65%</td>
<td>3.79%</td>
</tr>
<tr>
<td>Film</td>
<td>0.02%</td>
<td>0.35%</td>
<td>1.54%</td>
</tr>
<tr>
<td>Other Rigid PE-I</td>
<td>0.74%</td>
<td>14.12%</td>
<td>1.87%</td>
</tr>
<tr>
<td>Other Rigid HDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PVC</td>
<td>1.59%</td>
<td>35.69%</td>
<td>81.80%</td>
</tr>
<tr>
<td>Other Rigid LDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PP</td>
<td>0.19%</td>
<td>11.62%</td>
<td>4.28%</td>
</tr>
<tr>
<td>Other Rigid PS</td>
<td>0.00%</td>
<td>3.23%</td>
<td>1.95%</td>
</tr>
<tr>
<td>Other Rigid Closures</td>
<td>0.05%</td>
<td>0.00%</td>
<td>0.15%</td>
</tr>
<tr>
<td>Bottles PET Clear</td>
<td>46.05%</td>
<td>8.08%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Bottles PET Coloured</td>
<td>4.13%</td>
<td>4.44%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Bottles HDPE Natural</td>
<td>38.61%</td>
<td>3.69%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Bottles HDPE Coloured</td>
<td>7.72%</td>
<td>9.95%</td>
<td>0.16%</td>
</tr>
<tr>
<td>Aseptic</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.77%</td>
</tr>
<tr>
<td>Glass</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Metals</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.70%</td>
</tr>
<tr>
<td>Non-Packaging Plastics</td>
<td>0.67%</td>
<td>7.19%</td>
<td>1.83%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Residual</td>
<td>0.00%</td>
<td>0.00%</td>
<td>1.67%</td>
</tr>
<tr>
<td>Fines</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
Figure 52 shows the PVC product produced at the PRF during the sorting trials. This was segregated during the same sorting pass as the PS product.

**Figure 52. PVC product obtained for downstream reprocessing from mixed plastics PRF sorting trials**

12.4.5 Sorting Trial Residual Material

Residual materials were left over after each pass through the processing line during trials:

- ‘Pass 1 Intermediate Residue’ represents the residue after sorting the infeed material for HDPE/PET and PP.
- ‘Pass 2 Final Residue’ represents the real residue, once ‘Pass 1 Intermediate Residue’ has been processed and PVC and PS have been removed from this other rigid plastics stream.

The composition of the residues varied significantly. The composition of the residue from the three trials is shown in Figure 53. PRF sorting trial shows that over 25% PET in different formats, 20% PP and over 20% paper and card were the main materials not extracted. Significant amounts of HDPE (7.5%) and PVC (5%) also were present. The MRF B final residue contains 80% unselected HDPE and PET bottles, 6% PVC, 4% PS and 3% PP. The reasons for this composition noted in section 5.2 MRF Sorting process. The MRF C residue contained only 15% bottles, but had a high content of non-packaging items (32%) and PP (23%). There was also 16% PET, 5% of PVC and 3% PS.
Figure 53. Final material residues from MRF B, MRF C and PRF sorting trial

<table>
<thead>
<tr>
<th>Final Residual Product</th>
<th>MRF B</th>
<th>MRF C</th>
<th>PRF Sorting Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/Card</td>
<td>3.72%</td>
<td>7.06%</td>
<td>22.57%</td>
</tr>
<tr>
<td>Film</td>
<td>0.10%</td>
<td>1.00%</td>
<td>1.49%</td>
</tr>
<tr>
<td>Other Rigid PE 1</td>
<td>4.83%</td>
<td>12.78%</td>
<td>7.27%</td>
</tr>
<tr>
<td>Other Rigid HDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PVC</td>
<td>6.25%</td>
<td>5.41%</td>
<td>5.01%</td>
</tr>
<tr>
<td>Other Rigid LDPE</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other Rigid PP</td>
<td>3.69%</td>
<td>23.13%</td>
<td>20.41%</td>
</tr>
<tr>
<td>Other Rigid PS</td>
<td>4.24%</td>
<td>2.96%</td>
<td>1.43%</td>
</tr>
<tr>
<td>Other Rigid Closures</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.54%</td>
</tr>
<tr>
<td>Bottles PET Clear</td>
<td>40.89%</td>
<td>2.07%</td>
<td>11.58%</td>
</tr>
<tr>
<td>Bottles PET Coloured</td>
<td>5.73%</td>
<td>2.48%</td>
<td>6.56%</td>
</tr>
<tr>
<td>Bottles HDPE Natural</td>
<td>17.92%</td>
<td>0.62%</td>
<td>1.96%</td>
</tr>
<tr>
<td>Bottles HDPE Coloured</td>
<td>11.29%</td>
<td>10.27%</td>
<td>5.54%</td>
</tr>
<tr>
<td>Aseptic</td>
<td>0.00%</td>
<td>0.00%</td>
<td>1.29%</td>
</tr>
<tr>
<td>Glass</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Metals</td>
<td>0.00%</td>
<td>0.13%</td>
<td>1.19%</td>
</tr>
<tr>
<td>Non-Packaging Plastics</td>
<td>1.36%</td>
<td>32.07%</td>
<td>6.23%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Residual</td>
<td>0.00%</td>
<td>0.00%</td>
<td>6.92%</td>
</tr>
<tr>
<td>Fines</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

Figure 54 shows the residual material left over when the PET/HDPE, PP, PS and PVC product streams have been targeted on one pass through the NIR sorting system. The large fraction of currently unidentifiable black plastic packaging is also evident.

Figure 54. Residual product obtained from mixed plastics PRF sorting trials

12.5 Key Findings from the PRF Sorting Trials

The inclusion of film and glass in kerbside collections did not affect the operation of the PRF.
Although glass and film were included in material collected from households it did not find its way through to the PRF and therefore had no affect on PRF performance.

NIR sorting systems have difficulty identifying polymers that are black, causing higher rejection rates.

- Of the total residual material at the PRF, black plastic items amounted to 12.4% and this is related to the problem that current NIR sorting systems are unable to identify black materials;
- This equates to approximately 318 tonnes per year for a 20,000 tonne capacity plant, mainly made up of PP and PET trays;
- It was also proved difficult to identify the polymer types of black/dark plastics when sorted manually.

In general automated sorting equipment has higher capture efficiency for plastics than a manual sort facility.

- The capture efficiencies for plastics at both MRF C and MRF B were 57% and 59% respectively. The capture rate for the PRF during the benchmarking trial was estimated at 78%. Both MRF C and MRF B are manual MRFs.

PS is lost through the MRF system.

- The analysis of mixed plastics products from both MRF C and MRF B confirm the suspicion that PS is lost through the MRF system, as it was not recovered as a product nor was it found in the end of line residue streams. PS tends to be brittle and this is likely to be the reason for this loss, and it is likely that after baling PS packaging breaks into fragments and is lost together with other fines and other material fragments;
- For both MRF C and MRF B the ratio for PP:PS in the MRF infeed is approximately 9:5;
- MRF C mixed plastic product has a PP:PS ratio of 10:1;
- MRF B end of line material for PP:PS is 3:1 and in the mixed plastic product 40:1. This shows that PP is targeted more effectively than PS and/or that little PS is available to select at the plastic sort point;
- There was also significantly lower performance for sorting PS from MRF B material – indicative of lower quality PS content.

13.0 Recycling of Rigid PP, Coloured HDPE and PS Household Plastic Packaging

The PP and PS packaging from the PRF sorting trials and coloured HDPE from Closed Loop Recycling (CLR) were sent to LINPAC Recycling for reprocessing, compounding and conversion to final moulding compounds. LINPAC Recycling specialise in commercial recycling of a wide range of plastics and participated in this part of the trial.

Valpak sent to LINPAC Recycling approximately 33 tonnes of sorted PP and almost 1 tonne of PS. LINPAC Recycling performed detailed compositional analysis on the received materials.
The delivered bales of PP and PS were given unique codes to allow for full traceability through the plant during the reprocessing trial.

**Figure 56. Load details for input materials for LINPAC Recycling PP and PS recycling trials**

<table>
<thead>
<tr>
<th>Batch #</th>
<th>Material</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1809W</td>
<td>PP</td>
<td>13,915</td>
</tr>
<tr>
<td>1810W</td>
<td>PS</td>
<td>725</td>
</tr>
<tr>
<td>1817W</td>
<td>PP</td>
<td>19,480</td>
</tr>
</tbody>
</table>

13.1 LINPAC Recycling PP, HDPE and PS Recycling Trials Methodology

The recycling trials comprised of four distinct stages:

- Individual material type analysis on one randomly picked PP and PS bale;
- Wash plant processing of PP and PS bales including full mass balance of plastic waste;
- Analysis of washed flake;
- Compounding of the washed flake.

13.1.1 Analysis of Plastics in Polypropylene Bale

**Method**

The material analysis was undertaken manually by the quality control staff on site. The bale was broken down into the following material types:

- General PP;
- Yellow Fat PP (e.g. margarine, butter tubs);
- PET (mainly soft drink bottles);
- PE (mix of HDPE, MDPE, LDPE);
PP with EVOH barrier (e.g. sauce bottles, etc.)

The PP fraction was separated into standard PP material, PP from margarine tubs (e.g. yellow fat PP) and PP packaging with barrier materials (e.g. PP with EVOH barrier). This separation is important, as the materials are recycled into different end-product applications due to the differences in the grades of PP used for these packaging applications. For example, PP with EVOH barrier will need to be processed differently to general purpose blow moulding grade of PP, whilst PP from margarine containers is made from a different PP grade and due to its high level of remaining fat residue may also need to be washed under different conditions. The following images show separation of a PP bale and the pictures provide a clear representation of the types of PP packaging received along with cross contamination from other plastics.

Figure 57. Separation and compositional analysis of infeed PP bales

Material identification for sorting was undertaken using visual indicators, plastic identification marks (where visible), and burn testing if material identification was still unclear. The materials were segregated into pre-weighed containers to allow %w/w on each material to be calculated. The detailed bale analysis was performed by three quality control staff.
Results

Compositional analysis of the polymer types found within a PP bale is shown in Figure 58.

Weight of bale: 553 kg
Total weight of sorted material: 237.5 kg
Total weight of unsorted material: 316.0 kg
The total mass balance is +/- 0.5 kg (0.1% variance)

![Figure 58. Compositional data for recycling trial input from PP bales](image)

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Weight of Material (kg) (Total sorted wt = 237.5 kg)</th>
<th>% w/w of material</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>189.0</td>
<td>79.7</td>
</tr>
<tr>
<td>Yellow Fat PP</td>
<td>14.5</td>
<td>6.1</td>
</tr>
<tr>
<td>PET</td>
<td>20.5</td>
<td>8.6</td>
</tr>
<tr>
<td>PE</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>PP / EVOH</td>
<td>11.5</td>
<td>4.8</td>
</tr>
</tbody>
</table>

The results obtained indicate that the expected yield from the wash process is approximately 91%.

13.2 Recycling of Rigid Polypropylene Post-Consumer Packaging

The LINPAC recycling trials of PP were performed under cold wash conditions with caustic (approx. 1% NaOH) and detergents to remove surface based contamination and fats from PP margarine containers. The washed PP flake was then analysed for any potential contaminants and tested for the material Melt Flow Rate (MFR) and therefore determine if the flake was suitable for compounding and further processing into end product applications.

13.2.1 Characterisation and assessment of PP washed flake

Figure 59 summarises the key physical properties of the PP washed flake stream.

- The MFR testing was undertaken to ISO 1133 (230°C, 2.16 kg) standard.
- The flake appearance, colour and odour was assessed by production staff.

![Figure 59. Washed flake results for MFR tests and visual assessment of PP extruded strand.](image)

<table>
<thead>
<tr>
<th>PP Flake</th>
<th>MFR (230°C @ 2.16kg) (g/ 600sec)</th>
<th>Flake Colour Extruded Strand</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>WE3816 (BAG1)</td>
<td>8.4</td>
<td>Various clean colours</td>
<td>Reasonable with gassy appearance</td>
</tr>
<tr>
<td>WE3816 (BAG4)</td>
<td>8.6</td>
<td>Various clean colours</td>
<td>Reasonable with gassy appearance</td>
</tr>
<tr>
<td>WE3816 (BAG7)</td>
<td>8.7</td>
<td>Various clean colours</td>
<td>Reasonable with gassy appearance</td>
</tr>
<tr>
<td>WE3816 (BAG11)</td>
<td>8.6</td>
<td>Various clean colours</td>
<td>Reasonable with gassy appearance</td>
</tr>
</tbody>
</table>

The washed flake samples taken during the washing trials were characterised and were found to be very consistent throughout the washing process trials. The flake appearance and colour characteristic were consistent through the batch and when tested for flow, showed very good consistency in MFR. The subjective odour was to be characteristic of detergent and perfumed bottle content and was consistent through the entire batch. The odour levels were considered to be normal and as expected from these feedstocks.
**Sink / Float Test:**
After the float test there was no evidence of cross-contamination from heavy polymers (e.g. PET, PVC or PS), metals, paper or any other obvious contaminants. The following images show broken bales of polypropylene and washed PP flake.

*Figure 60. From mixed polypropylene packaging to washed density separated flake.*

---

**13.2.2 Formulation for End Markets and Associated Testing (PP)**

**PP Extrusion Trial**
Extrusion trials based upon 100% PP bottle flake (WE 3816) were undertaken on a commercial production Gamma extruder. The trial details were as follows:

1. 100% WE3816 PCW PP bottle flake / MFR as is / jazz colour as is;
2. 100% WE3816 PCW PP bottle flake / MFR as is / coloured black;
3. 100% WE3816 PCW PP bottle flake / peroxide added to MFR 15 / coloured black;
4. 100% WE3816 PCW PP bottle flake / MFR as is / coloured black / impact modified with SBS @ 2% by weight.

Extrusion and compounding was performed under standard commercial PP extrusion conditions at LINPAC Recycling, however the types of compound additives, the type of peroxide, the screw configuration and output details for the Gamma extruder are not provided here due to commercial sensitivity.

**Extrusion Trial Results**
The trial results are summarised in the following table:

*Figure 61. Material property results for extruded recycled PP*

<table>
<thead>
<tr>
<th>Properties</th>
<th>Trial (1)</th>
<th>Trial (2)</th>
<th>Trial (3)</th>
<th>Trial (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (&lt;=0.1%)</td>
<td>0.05</td>
<td>0.07</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>MFR (230°C, 2.16kg) (g/600sec)</td>
<td>6.6</td>
<td>7.0</td>
<td>16.2</td>
<td>7.8</td>
</tr>
<tr>
<td>Notched IZOD Impact strength (KJ/m²)</td>
<td>8.3</td>
<td>8.5</td>
<td>8.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Colour</td>
<td>Jazz (light grey / translucent)</td>
<td>Black</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>Strand Quality</td>
<td>Good (solid / shiny strand)</td>
<td>Good (solid / shiny strand)</td>
<td>Good (solid / shiny strand)</td>
<td>Good (solid / shiny strand)</td>
</tr>
</tbody>
</table>
13.2.3 Summary of Results for Extruded Recycled PP
The trial results were found to be very encouraging. The MFR results for unmodified compounds were only slightly lower when compared to actual flake MFR test results, but the values obtained were similar and consistent. The melt flow rate was successfully raised (approximately doubled) by using organic peroxide, a chain scission additive.

The impact performance measured by notched IZOD (ISO 180/1A, 230°C) was consistent at 8 (kJ/m²), and a 25% increase in impact strength was attained by the 2% addition of a prime SBS impact modifier in extrusion trial 4. Overall, all the extruded strands were found to be of a high quality when visually inspected.

13.2.4 Consideration of Potential End Product Applications
The extrusion trial results revealed that the recycled PP materials could be utilised in a relatively wide range of formulations for a variety of applications. The following list details the most appropriate formulations where the recycled PP material can be utilised based upon maximising the target stream consistent with its technical properties and aesthetic qualities:

- Black PP compound suitable for standard injection moulding applications (e.g. underground water drainage mouldings, mouldings for civil and construction industries). The recycled PP resin can be included at approx 20% by weight in this formulation for these end product applications;

- Coloured (green / terracotta) PP high melt flow compound ideal for injection moulding applications (e.g. horticultural applications such as plant pots, etc) – recycled PP can be included at up to 50% by weight;

- PP Talc filled / UV stabilised compound suitable for large injection moulded articles (e.g. robust external covers) – recycled PP resin can be included at 20% by weight.

Due to the very encouraging results achieved from the extrusion trials, all of the above three options were progressed to full production scale compounding trials. Compounding trial recipes were prepared for the above formulations and trials were scheduled on the relevant production lines at LINPAC Packaging.

13.2.5 Compounding and Characterisation of Recycled PP Resin
Three formulation options were progressed to full production scale and scheduled for compounding on a suitable extrusion line. The chosen three options are summarised below in terms of full scale compounding details:

Black PP compound
Recycled PP resin was blended at 20% by weight with various other post-industrial regrinds from a wide variety of sources. A single screw extruder was utilised for the production of this material. Black masterbatch was added to blend at the feed throat the material was then melted, de-gassed and melt filtered through a fine mesh prior to extrusion through a die to pellet form. The pellet was further cooled, dried and post blended prior to being packed into suitable packaging for dispatch to the customer. The finished product yield was 24 tonnes. The physical properties of the compound are given in Figure 62.

<table>
<thead>
<tr>
<th>Property Units</th>
<th>Test Method</th>
<th>Units</th>
<th>Batch average</th>
<th>Specification range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>ISO 1872/1 – 1986</td>
<td>kg/m³</td>
<td>905</td>
<td>903 - 915</td>
</tr>
<tr>
<td>Melt Flow Rate</td>
<td>ISO 1133 – 230°C, 2.16 kg</td>
<td>g/600 sec</td>
<td>11.2</td>
<td>8 - 15</td>
</tr>
<tr>
<td>Notched IZOD Impact Strength</td>
<td>ISO 180/4A, 23°C</td>
<td>KJ/m²</td>
<td>9.7</td>
<td>&gt; 6</td>
</tr>
</tbody>
</table>

The black compound produced was found to be suitable for a variety of standard injection moulding applications. The amount of recycled PP in this compound was 20% by weight. In summary, the physical properties of the batch were within all stated specification limits.
Green PP high melt flow compound
Recycled PP resin was blended at 50% by weight with various other post-industrial PP regrinds from a wide variety of sources. A single screw extruder was utilised for the production of this compound resin and a green masterbatch was added to the blend at the feed throat. Organic peroxide was added at the screw feed throat. The temperature profile of the barrel surrounding the screw was elevated near the feed section end of the screw to allow the peroxide to activate and react with the polypropylene chains causing chain scission and an increase in MFR. The peroxide addition rate was carefully controlled to ensure a high level of process control to ensure conformance to MFR specification range. 10 tonnes of finished compounded product was produced. The physical properties of the produced compound are given in Figure 63.

<table>
<thead>
<tr>
<th>Property Units</th>
<th>Test Method</th>
<th>Units</th>
<th>Batch average</th>
<th>Specification range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash content</td>
<td>-</td>
<td>% w/w</td>
<td>2.7</td>
<td>0-5</td>
</tr>
<tr>
<td>Melt Flow Rate</td>
<td>ISO 1133 – 230ºC, 2.16 kg</td>
<td>g/600 sec</td>
<td>39.1</td>
<td>35-60</td>
</tr>
<tr>
<td>Notched IZOD Impact Strength</td>
<td>ISO 180/4A, 23ºC</td>
<td>KJ/m²</td>
<td>7.3</td>
<td>&gt; 5</td>
</tr>
</tbody>
</table>

The high melt flow green compound was ideal for injection moulded products requiring fast flowing resins used during the moulding of fast cycle time items such as plant pots used in horticultural applications. The amount of recycled PP resin used in this compound was 50%. In summary, the physical properties of the batch were within all stated specification limits.

PP talc filled and UV stabilised compound
Recycled PP resin was blended at 20% by weight with various other post-industrial regrinds from a wide variety of sources and a UV stabiliser additive was also utilised. A twin screw extruder was used for the production of this compound to ensure increased mixing efficiency to fully homogenise the mineral talc within the PP resin matrix. Colour masterbatch was added to the blend at the feed throat and mineral talc was also added to the feed throat using a separate feed system. Peroxide was added as per compounding trial 2. 24 tonnes of finished product was produced. The physical properties of the compound are given in Figure 64.

<table>
<thead>
<tr>
<th>Property Units</th>
<th>Test Method</th>
<th>Units</th>
<th>Batch average</th>
<th>Specification range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash content</td>
<td>-</td>
<td>% w/w</td>
<td>19.7</td>
<td>18 - 22</td>
</tr>
<tr>
<td>Melt Flow Rate</td>
<td>ISO 1133 – 230ºC, 2.16 kg</td>
<td>g/600 sec</td>
<td>11.5</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Notched IZOD Impact Strength</td>
<td>ISO 180/4A, 23ºC</td>
<td>KJ/m²</td>
<td>5.7</td>
<td>&gt; 4</td>
</tr>
</tbody>
</table>

The talc filled UV stabilised compound was found to be suitable for large injection moulded articles for robust above ground protective housings, typically used in the transport industry. The final compound included 20% of recycled PP resin. In summary, the physical properties of the batch were within all stated specification limits.

13.2.6 Recycled PP Resins - Market Options
The following table summarises several suitable applications and potential market options for the above finished compounds:
### Figure 65. Summary of potential end applications for the manufactured recycled PP compounds.

<table>
<thead>
<tr>
<th>Finished Compound</th>
<th>Application</th>
<th>Market Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Black PP compound (20% recycled content)</td>
<td>Chambers, drainage products</td>
<td>Injection moulded articles for the construction industry</td>
</tr>
<tr>
<td>2) Green PP high melt compound (50% recycled content)</td>
<td>Plant pots and hanging baskets</td>
<td>Injection moulded articles for the horticultural market</td>
</tr>
<tr>
<td>3) PP talc filled / UV stabilised compound (20% recycled content)</td>
<td>External protective covers</td>
<td>Injection moulded articles for the transport industry</td>
</tr>
</tbody>
</table>

### 13.2.7 Moulding of End Products from Recycled PP Resins

The following section summarises the end applications, customer feedback and any moulding successes, observations and failures.

**Black PP compound**

The material was delivered to a large injection moulding company that produces various articles for the construction industry. The specific batch delivered (with 20% PCR material) was run on a large injection moulding line producing a large underground drainage chamber. The moulding itself is a complex part with a requirement for good flow properties, a good surface finish and quality control (QC) tested depth of black colour. The general feedback was very positive with the above requirements being fulfilled to an acceptable standard. The customer has indicated further demand for this material that could result in actual orders in excess of 500 tonnes per annum.

**Green PP high melt flow compound**

The above compound was delivered to a large injection moulding company that produces various articles for the horticultural market. The specific batch was run on an intermediate sized injection moulding line producing a specific plant pot moulding. The moulding requirements are that of very good flow (high melt application) and a quality control (QC) tested colour match. A fast cycle time was also required to allow production target rates to be met.

Again feedback was positive with the above requirements being fulfilled to an acceptable standard. The customer is likely to increase its demand for this material and has agreed to purchase further full loads over the next few months.

**PP talc filled / UV stabilised compound**

The above compound was delivered to an injection moulder to produce large mouldings for external covers. The moulding requires very good dimensional stability, UV protection and good flow properties. Again feedback was positive with the above requirements being fulfilled to an acceptable standard. The customer is likely to increase its demand for this material and has agreed to purchase further full loads over the next few months.

### Figure 66. Examples of end-products manufactured from recycled PP compounds

Various PP injection moulded products manufactured by customers from recycled PP compounds

Injection moulded re-inforcing bar spacer.
13.3 Recycling of Rigid Coloured HDPE Post-Consumer Packaging

Approximately 17 tonnes of coloured HDPE bales (2326W) were processed through the washplant using cold water wash with caustic (approx. 1% NaOH) and detergents. The batch was washed as per standard operational practice with stringent control over input weights, output weights and waste stream outputs to allow an accurate mass balance to be calculated.

13.3.1 Mass Balance (Trial 1)

The following results were obtained from the coloured HDPE washplant trial:

Input coloured HDPE bale weight: 17,520 kg
Output weights and compositions were:

**Figure 67. Coloured HDPE recycling trial mass balance (trial 1)**

<table>
<thead>
<tr>
<th>Waste Stream</th>
<th>Output (kg)</th>
<th>Output (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good HDPE</td>
<td>12,404 kg</td>
<td>71</td>
</tr>
<tr>
<td>Wet waste / paper / residues</td>
<td>2,280 kg</td>
<td>13</td>
</tr>
<tr>
<td>PET / PVC / PS, etc.</td>
<td>2,836 kg</td>
<td>16</td>
</tr>
</tbody>
</table>

The data in Figure 67 was obtained from the washing trial outputs and indicates that approximately 70% of HDPE was recovered. Waste and other losses were found to be 29%. There was a 16% cross-contamination of the HDPE balestock material from other polymers such as PET, PVC and PS.

13.3.2 Washed HDPE Flake Characterisation

- The washed flake quality was characterised during washing trials and was found to be very consistent during the entire trial;
- The flake appearance and colour characteristic was consistent throughout the batch;
- Actual MFR results averaged at 0.4 g/600 sec (190°C @ 2.16 kg) and very good MFR consistency;
- Representative strands were found to be of good appearance and were smooth and solid with no evidence of voids in strands.

The most obvious improvement initiative that could be undertaken would be to minimise the PET from getting into the HDPE stream during the PRF sorting process. PET is a plastic stream of commercial importance and this improvement would benefit both the final good HDPE yield and provide a good source of clean PET.
13.3.3 Summary of results

The waste stream results indicate a high percentage of yield loss due to the heavy mixed plastic contamination (PET / PVC / PS etc). The majority of this plastic stream appears to be PET. Wet waste/paper etc makes up the remainder of the yield loss. The total yield of good HDPE was 71%.

13.3.4 Coloured HDPE Recycling (Trial 2)

A second trial of HDPE was run through LINPAC Recycling plant to further evaluate the data from the first trial. The following results were obtained from the washplant trial:

- Input coloured HDPE weight: 1,201 kg
- Output weights and compositions:

![Figure 68. Coloured HDPE recycling trial mass balance (trial 2)](image)

<table>
<thead>
<tr>
<th>Waste Stream</th>
<th>Output (kg)</th>
<th>Output (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good HDPE</td>
<td>804 kg</td>
<td>67</td>
</tr>
<tr>
<td>Wet waste / paper etc</td>
<td>193 kg</td>
<td>16</td>
</tr>
<tr>
<td>PET / PVC / PS etc</td>
<td>204 kg</td>
<td>17</td>
</tr>
</tbody>
</table>

13.3.5 Washed HDPE Flake Characterisation

The washed flake was characterised and was found to be very consistent throughout the washing process. The flake appearance and colour characteristic is consistent through the batch with very good consistency in MFR.

- Actual MFR results averaged at 0.42 g/600 sec (190ºC @ 2.16 kg) and were to be consistent.
- Representative extruded strands were good in appearance with a smooth surface and had solid cores with no voids.

13.3.6 Summary of Results

The waste stream results indicate a high percentage of yield loss due to contamination present in the balestock in the form of other polymers such as PET, PVC and PS, etc. The majority of this plastic cross contamination stream appears to be PET. Wet waste / paper etc makes up the remainder of the yield loss. The total yield of good HDPE was found to be 67%.

13.3.7 Products Manufactured from Recycled Coloured HDPE Stream

The following images show extruded products such as pipe and conduit manufactured from the recycled coloured HDPE resin that LINPAC Packaging produced. The recycled HDPE was utilised at 100% although proprietary additives were added during the product manufacture to improve product properties.

The recycled coloured HDPE material processed well into this application and there were no quality issues reported during the manufacture of this product. Recycled coloured HDPE is an ideal product for the manufacture of profiles, pipes and other extruded products.
13.4 Recycling of Rigid Polystyrene Post-Consumer Packaging
A further 4.8 tonnes of PS were purchased from another PRF as the 1 tonne of PS recovered during the Valpak PRF (1810W) sorting trials was not enough to run a trial. Compositional analysis was however performed on the bales supplied from the Valpak PRF sorting trials as well as the other PRF.

13.4.1 PS – Mass Balance of PS Bale (1810W)
The PS bale from the PRF sorting trials was hand sorted into plastic types as with the PP bales supplied. The following graph summarises the breakdown after sorting / analysis:

Figure 70. Compositional make up of sorted PS bale from PRF sorting trials
13.4.2 Washing of Baled Plastic – Polystyrene (PS) (Sourced from secondary PRF)

The PS purchased from the secondary PRF was washed as per standard operational practice with stringent control over input weights, output weights and waste stream outputs to allow an accurate mass balance to be calculated. The PS was cold washed with caustic (approx. 1% NaOH) and detergents.

The following results were obtained from the PS washplant trials:
Input weight of PS balestock: 4,800 Kg
Output weights and compositions were:

<table>
<thead>
<tr>
<th>Waste Stream</th>
<th>Output (kg)</th>
<th>Output (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good PS</td>
<td>2,824 kg</td>
<td>59</td>
</tr>
<tr>
<td>Polyolefins</td>
<td>720 kg</td>
<td>15</td>
</tr>
<tr>
<td>PET / PVC / PS / metals etc.</td>
<td>1,256 kg</td>
<td>26</td>
</tr>
</tbody>
</table>

These results suggest that typical bale purity for the PS feedstocks used in these trials varies from 59-69%. The analysis of the PS bales from the secondary PRF indicates that there is a 15% polyolefin fraction, which may be recoverable during a sink-float separation, however there is also a much larger cross-contaminant fraction of 26% in the form of PET and PVC and other forms of PS and metals.
13.4.3 Summary of results

The waste stream results indicate a high percentage of yield loss due to contamination from other polymers such as PET, PVC and also metals was 26% w/w, whilst contamination from polyolefins (PE and PP) was found to be 15%w/w. The total yield of good polystyrene after washing and density separation was 59%.

13.4.4 Washed PS Flake Characterisation

The washed flake appeared to be made up from various clean colours and was of a consistent flake size. There was also some black film present with the rigid flake. A sink-float density test showed some PET contamination within the washed flake (<5% by weight). This would almost certainly be improved with continual running on a larger batch size rather than 1 bale.

Average representative MFR was determined to be 4.3gm/600 sec.

The most obvious improvement initiative that could be undertaken would be to minimise the amount of cross over PET by improving sorting efficiency at PRF sorting trials. PET is a plastic stream of commercial importance and this improvement in sorting efficiency and lower cross contamination would benefit both the final PS yield and provide a good source of clean PET.

13.4.5 Compounding of PS – Extrusion Trial

Extrusion trials based upon utilising 100% PS flake from household packaging waste (WE 3836) were undertaken on a full-scale Delta production extruder at LINPAC.

The trial details were as follows:

- 1) 100% (WE3836) PS bottle flake / MFR as is / coloured black;
- 2) 100% (WE3836) PS bottle flake / MFR as is / coloured black / Impact modified with SBS @ 2% by weight.

Results

The trial results are summarised in the following table:

<table>
<thead>
<tr>
<th>Properties</th>
<th>Trial (1)</th>
<th>Trial (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (&lt;0.1%)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>MFR (230°C, 2.16 kg, g/600sec)</td>
<td>1.90</td>
<td>2.0</td>
</tr>
<tr>
<td>Notched IZOD Impact strength (kJ/m²)</td>
<td>2.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Colour</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>Strand Quality</td>
<td>Poor (rough, gassy strand)</td>
<td>Poor (rough, gassy Strand)</td>
</tr>
</tbody>
</table>

The results for PS compounding were generally disappointing. The MFR results were lower than expected for a typical HIPS grade (normally MFR is 4 – 8). The impact results were also found to be poor – an IZOD result of 2.9 is low. The PS moulded bars were found to be brittle. The use of an SBS impact modifier did not improve the IZOD performance significantly.

The strand appearance quality was also poor with the surface being rough and gassy. The poor results can most likely be attributed to high levels of crystal PS in the balestock and potentially also due to some residual olefins. The PET cross contamination would be able to be effectively removed at the melt filtration stage due to its higher melt point temperature, when compared to PS.
13.4.6 Consideration of Potential End Product Applications

The extrusion trial results revealed that the material could only be utilised in a low percentage in a limited number of formulations due to the above mentioned quality issues.

The following formulation was determined to be the most suitable for the recycled PS material based upon maximising the target stream consistent with its technical and aesthetic qualities. The black HIPS compound is suitable for standard injection moulding applications (e.g. mouldings for outdoor furniture) – recycled PS resin was included at approx 10-15% by weight in this formulation.

13.4.7 Characterisation of Recycled Polystyrene Compound

Black PS Compound
PS was blended at 10 - 15% by weight with various other post-industrial regrinds from a wide variety of sources. A single screw extruder was utilised for the production of this material. Black masterbatch was added to blend at the feed throat, material then melted, de-gassed and melt filtered through a fine mesh prior to extrusion through a die to pellet form. The pellet was further cooled, dried and post blended prior to being packed into suitable packaging for dispatch to the customer. The finished produce yield was 4 tonnes.

13.4.8 Physical properties

In summary the physical properties of the batch were within all stated specification limits. The compound extruded well when recycled PS content was kept to 10-15%. A higher level of recycled content was not trialed.

13.4.9 Recycled PS - Market Options

The following table summarises the applications and market options of the above finished compounds:

<table>
<thead>
<tr>
<th>Finished Compound</th>
<th>Application</th>
<th>Market Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black PS compound (10-15% recycled content)</td>
<td>Furniture supports / hose reels.</td>
<td>Injection moulded articles for outdoor retail products</td>
</tr>
</tbody>
</table>

13.4.10 Moulding of End Products from Recycled PS Compound

The following section summarises the end applications, customer feedback and moulding success of the black PS compound.

The black PS compound was delivered to an injection moulder to produce hose reels. The moulding requires very good dimensional stability, good flow properties and good impact properties. Again feedback was positive with the above requirements being fulfilled to an acceptable standard. The customer is likely to increase its demand for this material and has agreed to purchase further full loads over the next few months.
14.0 Recycling of PET and Natural HDPE from Household Plastic Packaging

Recycling trials of the HDPE and PET materials sorted in the PRF trials were run at the Closed Loop Recycling (CLR) plant and approximately 63 tonnes of baled material was delivered to the CLR Plant in Dagenham from the Valpak PRF.

A full bale was opened and compositional analysis was performed on more than 260 kg of the mixed PET and HDPE infeed. Mixed plastics (3.8 tonnes worth of pre-sorted mixed plastics) from the Sainsbury’s retail waste was also processed as part of these trials. This retail mixed plastics feedstock was also analysed for compositional data before the full recycling trials had begun.

14.1.1 Closed Loop Recycling Trial Methodology

Closed Loop Recycling operate a 35,000 tonne/year recycling facility that specialises in producing food grade clear rPET flake and food grade natural rHDPE pellet. The CLR plant also sells recovered coloured PET and coloured HDPE bales and flake product after they have been sorted from the clear PET and natural HDPE streams respectively. The coloured HDPE material was baled and sent to LINPAC Recycling.

The CLR PET and HDPE recycling trials included the following steps:

- Debaling;
- Fines and dirt removal through a trommel;
- Ferrous and non-ferrous metal separation;
- NIR and optical sort;
- Visual inspection and manual sort;
- Size reduction (granulation);
- Dry cleaning and air classification;
- Hot wash and drying;
- Optical and laser flake sorting;
- Decontamination, extrusion and filtration.

The recycling trial on the mixed PET and HDPE plastics was run under standard operating procedures and under typical commercial throughput rates that CLR normally operate under.

14.1.2 Retail Mixed Plastics Bale Composition Analysis

Analysis was performed on the manually pre-sorted materials from the Sainsbury’s collections. Figure 76 shows the polymer type split of the collected materials. Clear PET makes up more than half of the materials at 53%, with natural HDPE comprising 26% of the material input and other rigid 15%.
Visual observation of the plastic packaging clearly indicated that the clear PET stream was primarily made up of PET bottles and the natural HDPE stream was made up of milk and other bottles. The ‘other rigids’ stream appeared to be primarily PP trays, tubs and punnets.

During the trial the clear PET and natural HDPE were identified using the NIR sensors and separated out and the remaining items (non-clear PET and non-natural HDPE) were rejected and baled. The reject residual outflow stream was analysed and the results are presented in Figure 77.

The out-throw residual material analysis from the retail mixed plastic stream after clear PET and natural HDPE bottles were sorted clearly shows that polypropylene was the most prevalent polymer at 46%. However within the residual stream it was found that there was still a large proportion of PET bottles left. Most of this was due to mistakenly ejected bottles with full body shrink sleeves or bottles that were too close to the items that were being ejected. The third and forth largest reject streams were PVC and PS packaging respectively. The PVC stream was found to be primarily blister pack related whilst PS stream comprised of yoghurt tubs and other packages but also several large tubs for dishwashing liquids.

### 14.1.3 Mixed Plastics Bale Composition Analysis from Kerbside Collection

A typical bale was picked out and a large scale (266kg) compositional analysis was performed. The data obtained from this analysis is provided in Figure 78.
Data obtained from the compositional analysis of a bale (266kg) shown in Figure 78, shows that the overall PET and HDPE material streams entering the CLR facility is 91% pure. This is as high as CLR currently receive from mixed plastic bottle bale suppliers.

Figure 79 provides compositional data obtained after clear PET and natural HDPE were extracted from the ‘input materials’ provides a key analytical finding given that beverage bottles were found to form such a large proportion of the MRF mixed plastics stream.

Figure 80 provides a summary of the Valpak and Sainsbury’s packaging used for compositional analysis.
Figure 80. Summary data for analysis of Valpak and Sainsbury’s materials

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub Category</th>
<th>% of total by weight</th>
<th>Total weight kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALPAK</td>
<td>Plastic film</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Refuse sacks</td>
<td>0.9</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Film packaging</td>
<td>0.9</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Metals</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Cans</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Plastic bottles</td>
<td>39.7</td>
<td>121.3</td>
</tr>
<tr>
<td></td>
<td>PET clear</td>
<td>19.7</td>
<td>61.6</td>
</tr>
<tr>
<td></td>
<td>HDPE natural</td>
<td>7.2</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td>HDPE coloured</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Rigid plastics</td>
<td>Food packaging</td>
<td>1.3</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>PP</td>
<td>0.3</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>PET</td>
<td>1.3</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Food packaging</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>EPS</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>HD</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>PVC</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Non food packaging</td>
<td>0.9</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Other items (VTR tapes)</td>
<td>1.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Netting</td>
<td>Vegetable nets</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Labels &amp; paper</td>
<td>3.7</td>
<td></td>
<td>11.4</td>
</tr>
<tr>
<td>Fines</td>
<td>1.6</td>
<td></td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>261.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sainsbury’s</td>
<td>Plastic film</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Refuse sacks</td>
<td>12.2</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Film packaging</td>
<td>18.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Rigid plastics</td>
<td>Food packaging</td>
<td>3.6</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>PP</td>
<td>18.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>PET</td>
<td>0.9</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Food packaging</td>
<td>12.6</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>HD</td>
<td>1.8</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>PVC</td>
<td>2.7</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Non Food packaging</td>
<td>11.7</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Other items (VTR tapes)</td>
<td>18.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>22.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 80 provides a polymer and packaging type material breakdown of the combined Sainsbury’s and Valpak PRF materials entering the CLR recycling plant.

Figure 81. Summary data for analysis of polymer and packaging type material breakdown of the combined infeed stocks from Sainsbury’s and Valpak PRF materials to CLR
14.1.4 Mixed Plastics Reject Analysis

The reject stream of plastics was carefully analysed to allow improved understanding of the potential contaminants that might be introduced to the streams of HDPE and PET that are intended for food contact quality production. Figure 82 therefore shows the material composition after primary sorting stage.

Figure 82 shows that PET is still the largest component of the input non-bottle stream at 31% after NIR sorting of clear PET and natural HDPE has taken place. The majority of the PET is in the form of sheet/thermoformed packaging such as trays, punnets, etc. Many of these were black CPET trays that cannot be identified by the NIR sensor systems. The film fraction forms the second largest component at 22%. Paper based contamination from liquid cartons and other paper/cardboard streams was found to be approximately 18%. PP formed the next biggest fraction for the rigid non-bottle plastics at 16% of product input and was significantly higher than the rigid HDPE non-bottle fraction. The PP fraction was found to be primarily tray and tub type packaging.

Figure 82. The polymer analysis of the out-throws (e.g. NIR bottle sort reject stream)

The NIR reject stream was then further analysed by polymer packaging format by assessing 317 packaging items. As previously mentioned this analysis was done after all beverage bottles were extracted from the input analysis sample. The bottles referred to in Figure 83 are non-beverage bottles, typically these were PP personal care bottles (e.g. shampoo, body wash, etc).

Figure 83. Composition of NIR rejects stream by packaging format

Trays make up almost half of the NIR rejects at 46%. The majority of these trays were natural or light coloured PP. There were also tubs made up 13% of the reject stream. The majority of these were also PP, with only a few
PS tubs. Blister packs were all primarily PVC based and formed 12% of the 317 items. The majority of these PVC blister packs were all from the personal care and domestic streams, very few were from packaging used in the food and beverage industry.

Multi-layer materials were typically found to be the flexi-packs and pouches. Together these made up approximately 7% of the 317 NIR reject items analysed.

The film fraction from the NIR rejects was low at only 3%, however this is explained by the fact that films were removed by the air classifier prior to the NIR sensor sorting station. The 3% was therefore carryover that was not removed by the air classification system. Figure 84 shows NIR sensor reject out-throws (bottles and non-bottles combined) by polymer type.

**Figure 84.** NIR sort reject stream total out-throws by polymer type (inc. bottles and non-bottles)

Figure 84 clearly shows that polypropylene makes up the largest reject stream (63% by weight) from the trials at Closed Loop Recycling. The NIR sensors positively identified clear and coloured PET and natural and coloured HDPE. All other materials are rejected. Visual and quantitative analysis of these out-throws throughout the trials confirmed that polypropylene was consistently the main component in the balestock after PET and HDPE bottles. This suggests focus on recycling of PP will have the biggest impact on diversion of packaging materials from landfills. A combined PRF + Reprocessor would be able to take advantage of this by recycling the PP too. This would maximise yield and minimise losses from infeed balestock.

Closer analysis of the packaging types of each polymer type out-throw is provided in the following graphs.
Of the polypropylene NIR reject out-throws almost a half were trays. The trays were primarily natural and unpigmented. Other colours such as whites and yellows were also popular. Dark coloured PP was primarily dark blue, black and dark green. PP bottles were primarily natural or white coloured and were typically used in personal care (e.g. shampoo and body wash, etc). PP tubs included clear and coloured ice-cream containers, clear take-away lunch boxes, etc.

PVC packaging rejects (shown in Figure 86) were found to represent approximately 15% by weight. This is significantly higher than what is normally (PVC input from mixed bottles is around 2-3%) found in mixed plastics streams. Since PVC is deliberately rejected as it is a serious contaminant in the recycling of PET. Closer analysis of the PVC NIR reject out-throws found that the majority of the PVC items were sheet products used for packaging of clothing items and other products.
The majority of PVC NIR sensor reject out-throws were in the form of blister-packs. The majority of these came from packaging of domestic, electronic and clothing items. Some blister packs were very large, heavy and thick walled. The sensors were able to separate these packs quite readily due to their size and these large PVC packs did not end up contaminating the PET product stream.

PVC trays were the second largest packaging format within the PVC out-throw stream. Several of these trays were clear and PE lined and used for poultry tray packaging. These trays were of similar size, clarity and sheet gauge to PET trays and need to be effectively sorted as they have the potential to contaminate the primary PET product stream. There were several PVC bottles present within the PVC out-throw stream, these came from imported products used for cosmetic type products such as creams and bath products.

Figure 87 shows the PS out-throws after NIR sorting at CLR.

**Figure 87. PS NIR sensor reject out-throws by packaging format type**

The majority of the PS NIR sensor rejects were trays. The majority of these were coloured and came from confectionary type tray packaging. More than half of these were black. There were two large clear tubs present in the PS out-throw stream. These tubs were used to store dishwashing powder tabs.

Figure 88 shows the types of multi-layer packaging out-throws after NIR sorting at CLR.

**Figure 88. Multi-layer NIR sensor reject out-throws by packaging format type**
The majority of the multi-layer packs were in the form of flexi-packs used to store long shelf life products such as salami’s and other food products. The only multi-layer bottles were tomato sauce bottles.

The following chart in Figure 89 shows that PET packaging such as black CPET and laminated PET trays were also being ejected as out-throws.

**Figure 89.** PET NIR sensor reject out-throws by packaging format type

![PET NIR sensor reject out-throws by packaging format type](image)

The PET trays formed the majority of the NIR reject out-throws of PET. A number of these trays were black CPET trays and several were laminated PET/PE laminated trays. ‘Other’ PET rejects included PET cups and an injection moulded bowl. There was also a PET lid present.

Figure 90 shows the remaining ‘other’ plastic items found as out-throws in the NIR reject stream after clear PET and natural HDPE packaging was recovered.

**Figure 90.** ‘Other Plastic Items’ NIR sensor reject out-throws by packaging format type

![‘Other Plastic Items’ NIR sensor reject out-throws by packaging format type](image)
The majority of ‘other plastic items’ were found to be film or flexible / pouch type products. The films were primarily polyolefinic in the form of thicker walled bags. The pouches and flexible packs were difficult to identify in terms of polymer type and whether or not these were monolayer or multi-layer materials.

In summary, the NIR out-throw reject stream after natural HDPE and clear PET packaging was sorted, contained many other polymers from various packaging formats which have been highlighted. This stream was a residue stream. The analysis also showed that unless sorting of PP improves at the PRF stage, a secondary sort for PP should be considered, due to the large volumes of PP present within the reject stream.
14.2 Natural HDPE Recycling Trials

The next stage of processing the natural HDPE after NIR sorting was visual inspection and manually sorting to ensure that only milk bottle materials were passed onto the granulation and washing stages. This is because a proportion of the natural HDPE material was to be extruded and decontaminated into potentially food contact rHDPE pellet. The remaining amounts were sold as hot-washed natural HDPE flake. The natural HDPE milk bottle packaging was granulated to 8-10mm sized flakes, which were then dry cleaned and hot-washed with caustic (NaOH 1.5%).

14.2.1 Natural HDPE Hot-Washed Flake Results

Figure 91 shows the quality of natural HDPE hot washed flake verse standard CLR natural HDPE flake from mixed bottle input feedstocks. It shows only a very slight difference in colour between flake currently used by CLR to produce food grade HDPE and the flake recovered from the mixed plastics trials.

**Figure 91.** Slight colour difference between standard production HDPE washed flake and washed natural HDPE flake from 'mixed plastics' trials

The natural HDPE flake produced from mixed plastics feedstock appeared to be slightly darker than current production from mixed bottle bale feedstock. It is believed that this is directly related to the fact that the incoming bales from the mixed plastics trials were significantly dirtier than the mixed bottle bales CLR currently receive due to the extra handling involved in this PRF trial which would not normally happen in a conventional pre-processing step. The HDPE feedstock packaging processed well and there were no other major production differences. The majority of the material produced was suitable to sell as hot washed flake for extrusion based products. These are described further in the following sections.
14.2.2 Characterisation of Recycled Natural-HDPE flake

Five quality control samples (200gm) were tested and the average results obtained are provided below in Figure 92. This was done to determine the level of contamination from plastics packaging such as multilayer white HDPE yoghurt bottles that have a carbon black middle layer, to the amount of coloured content from caps and other coloured HDPE packaging as well as key contaminants such as glues and labels.

**Figure 92.** Quality results for hot-washed natural HDPE flake after colour sorting

<table>
<thead>
<tr>
<th>Contamination of Flake Product</th>
<th>HDPE washed flake Trial mix (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural</td>
<td>95.35</td>
</tr>
<tr>
<td>Metals (ferrous)</td>
<td>0</td>
</tr>
<tr>
<td>Metals (non-ferrous)</td>
<td>0</td>
</tr>
<tr>
<td>Carbon black</td>
<td>0.0572</td>
</tr>
<tr>
<td>Adhesion (label + flake)</td>
<td>0.8454</td>
</tr>
<tr>
<td>White</td>
<td>2.3572</td>
</tr>
<tr>
<td>Coloured (green red blue tops)</td>
<td>0.2782</td>
</tr>
<tr>
<td>Coloured (other)</td>
<td>0.3293</td>
</tr>
<tr>
<td>Labels</td>
<td>0.1008</td>
</tr>
<tr>
<td>Glue/Adhesive</td>
<td>0.4284</td>
</tr>
<tr>
<td>Other (ppm)</td>
<td>Angel/Film/Blown PS=569</td>
</tr>
</tbody>
</table>

The overall quality results were found to be satisfactory, although the amount of non-natural HDPE contamination was greater than typically found. When the conventional CLR input materials (bottles only) are used as infeed stock then the final natural HDPE content prior to extrusion is typically 98-99% as opposed to the 95% achieved when natural HDPE was recovered from mixed plastics infeed stocks. This difference is however not considered to be a major obstacle to recycling of natural HDPE from mixed plastics feedstocks, as only slight improvements to sorting may be needed to improve the purity of the final product.

14.2.3 Decontamination, Extrusion and Filtration of Nat-HDPE to Pellet

Five bags of hot-washed Nat-HDPE were set aside for decontamination, extrusion and filtration trials on the Vacurema system. This was done to produce a food grade natural HDPE resin. The remaining material was sent for manufacture of products directly from washed flake. Prior to extrusion, the hot-washed flake was colour sorted using an optical flake sorter.

**Figure 93.** Close-up of the pellet produced from the trial versus current standard production

a) rHDPE pellet from ‘mixed plastics’ trials  
b) current production rHDPE pellet from mixed bottles feedstocks
Several tonnes of material were processed back into pellet via the Vacurema extrusion and decontamination system to produce pellet that could potentially be of food grade quality. Due to the higher levels of packaging from non-food packaging packs, it was believed that the current levels of sorting would need to be improved to produce flake that is >99.0% natural HDPE from food or beverage packaging only.

The Vacurema extrusion trials ran very well and there were no issues recorded. The material was run at commercial throughput rates over 1,000kg/hr. The material was decontaminated under vacuum and raised temperatures to remove potential contaminants and volatiles. The material was filtered and good quality pellet was achieved.

The pellet colour was a shade of ‘grey’ when compared to the standard colour for recycled HDPE pellet, which often has a slight tinge of green present. The material did however pass gas chromatography headspace tests and was considered to be compliant with food contact applications.

### 14.2.4 Natural HDPE Flake End-Product Markets

Over 8 tonnes of the hot washed flake was supplied to Centriforce Ltd for processing into a number of extruded profile products. Centriforce commented that the products ran well as per normal conditions, with only a slight deterioration in colour, e.g. the flake being ‘more grey’. This did not however, cause any problems for Centriforce as the end product was coloured and colour matched as per product specifications. The following images show examples of products that the natural HDPE flake was manufactured into.

**Figure 94.** Products produced by Centriforce Ltd from hot-washed natural HDPE flake obtained from mixed plastics trials

The following picture shows an example of boardwalk made from 100% rHDPE hot washed flake.
The natural HDPE hot washed flake was of sufficiently good quality to be used for long term outdoor products such as beach side boardwalks that require toughness, good weatherability and overall long term product durability. The material would also be suitable for the manufacture of high volume products such as pipes.

14.3 PET Recycling Trials

The PET packaging was positively sorted from the mixed plastics stream using the NIR sensor sorting systems. The materials were then visually inspected and manually sorted in order to remove any non-PET packaging or contamination. The PET stream was primarily all bottles with very few PET trays or other forms of PET packaging products present. Manual sorting staff removed any non-PET packaging. This was done to prevent and reduce the potential of contamination from PVC trays and punnets. The PET packaging was then granulated, dry-cleaned and hot-washed.

14.3.1 rPET Flake Product Results

Post-consumer PET packaging from the mixed plastics trials was processed into food grade rPET flake. The overall colour quality of flake was only slightly lower than standard production and it therefore remained acceptable for use in several end-products for food and beverage packaging such as sheet. The rPET flake produced did contain higher levels of colour than standard production based on mixed bottle feedstock only.

The hot-washed rPET flake material was then passed through the United Resources Recovery Corporation (URRC) thermal flake decontamination process to fully decontaminate the rPET flake into food contact quality rPET flake. The materials produced are shown in Figure 96.
Figure 96. Comparison of the food grade rPET flake from ‘mixed plastics’ trials vs. standard flake from mixed bottle feedstock

Figure 96, shows that the flake from the ‘mixed plastics’ trials was slightly darker in colour. The rPET flake end-product also contained a higher level of coloured PET. It is believed that an increase in the content of coloured PET is directly related to the much higher levels of coloured PET in the trial input balestock.

14.3.2 Characterisation of Recycled PET Flake

All flake produced via the URRC PET recycling process under standard operating conditions is certified as food grade quality rPET flake. The flake produced was analysed for overall quality. The following table provides a summary of results obtained from rPET samples from the mixed plastics trials. The high level of PVC was attributed to the higher level of trays in the infeed that could have escaped detection due to their small size and similar appearance to PET.

Figure 97. Quality analysis of the food grade rPET flake produced at CLR from ‘mixed plastics feedstocks’

<table>
<thead>
<tr>
<th>Quality Assessment</th>
<th>rPET flake sample results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flakes colour target sample YI</td>
<td>10.42</td>
</tr>
<tr>
<td>Flakes colour target sample L</td>
<td>60.39</td>
</tr>
<tr>
<td>Flakes colour target sample a</td>
<td>-1.89</td>
</tr>
<tr>
<td>Flakes colour target sample b</td>
<td>4.12</td>
</tr>
<tr>
<td>Flakes difference ΔR</td>
<td>2.88</td>
</tr>
<tr>
<td>Flakes colour aged sample L</td>
<td>70.39</td>
</tr>
<tr>
<td>Flakes colour aged sample a</td>
<td>-0.84</td>
</tr>
<tr>
<td>Flakes colour aged sample b</td>
<td>7</td>
</tr>
<tr>
<td>Flakes colour aged sample YI</td>
<td>17.56</td>
</tr>
<tr>
<td>IV-value from MFR</td>
<td>0.78</td>
</tr>
<tr>
<td>Moisture content</td>
<td>0.17</td>
</tr>
<tr>
<td>pH rise</td>
<td>-0.535</td>
</tr>
<tr>
<td>---------------</td>
<td>--------</td>
</tr>
<tr>
<td>Foreign materials:</td>
<td></td>
</tr>
<tr>
<td>PVC polymer (1st 2 SAP mix)</td>
<td>121</td>
</tr>
<tr>
<td>PVC polymer (2nd 2 SAP mix)</td>
<td>67</td>
</tr>
<tr>
<td>Metals (ferrous)</td>
<td>0</td>
</tr>
<tr>
<td>Metals (non-ferrous)</td>
<td>0</td>
</tr>
<tr>
<td>Polyolefins (PE/PP)</td>
<td>0</td>
</tr>
<tr>
<td>Label film residues</td>
<td>0</td>
</tr>
<tr>
<td>Other (wood etc)</td>
<td>0</td>
</tr>
<tr>
<td>PET coloured (exc. white, l.blue)</td>
<td>2.463</td>
</tr>
<tr>
<td>PET white (%)</td>
<td>0.2536</td>
</tr>
<tr>
<td>PET light blue (%)</td>
<td>6.1204</td>
</tr>
<tr>
<td>Adhesive (glue) (%)</td>
<td>0.37165</td>
</tr>
<tr>
<td>Adherents + flake (%)</td>
<td>1.2325</td>
</tr>
<tr>
<td>Limonene (ppb)</td>
<td>4.8</td>
</tr>
</tbody>
</table>

The quality parameters were considered to be acceptable except for the level of PVC. After the URRC decontamination process, the material was suitable for the manufacture of food contact PET packaging provided the PVC present as carbonised black particles could be removed by melt filtration.

### 14.3.3 Clear rPET Flake - End Market Opportunities

A number of manufacturing trials were run utilising the rPET flake including the production of sheet and actual thermoforming of cups. Two trials were run:

- Sheet extrusion and thermoforming into cups;
- Sheet extrusion and thermoforming into punnets, and salad bowls.

The overall feedback was positive with good quality sheet extrusion being able to be achieved. From a processing point of view the rPET flake had very good Intrinsic Viscosity (IV) of 0.78 when compared to standard PET flake IV, which is generally also in the range of 0.78. The PVC levels were found to fluctuate and ranged from low to reasonably high at almost 400ppm. Limiting PVC contamination was the key issue to achieving high quality rPET flake suitable for sheet and thermoforming applications.

The key issues encountered in both extrusion trials were:

- High levels of PVC contamination (resulting in black specs and volatiles/bubble formation);
- Black specs in final product (typically small specs of around 0.5-1.5mm);
- Darker colour then 'usual';
- Higher levels of solid contaminants.

In order to overcome some of these quality issues, improved infeed quality is needed, better sorting levels are required both for removal of PVC and for coloured products. Overcoming the higher levels of PVC in the end-product flake is possible via finer melt filtration screen packs during extrusion.
14.3.4 End-Markets for Coloured PET
All coloured PET bales were sent for further recycling and reprocessing. The end-product manufactured from coloured PET was green PET strapping. PET strapping is commonly used for strapping of products on shipping pallets.

It can be concluded that the quality of the rPET flake that the quality is acceptable for the manufacture of a number of products. The levels of contamination in rPET from mixed plastics sources are slightly higher then when mixed plastics bottles are used as feedstocks. Improved sorting along all the recovery stages is the key to achieving a high quality end-product.

15.0 Recycling of Household Plastic Film Packaging
The handling of the film fraction within the mixed plastics stream probably presents some of the biggest challenges for viable large scale recovery. The key challenges involved in recycling of mixed film from household plastic packaging include:

- Density and polymer type separation of film packaging from household sources is complex and whilst the majority of films are polyolefinic many films are also multi-layer. Some film recycling plants in Europe utilise NIR based sorting systems and density separation techniques to mainly remove non polyolefinic materials, however most common sorting method is manual sorting;
Effective devolutilisation is necessary due to evolution of volatiles from the degradation of inks present on heavily printed film packaging such as bread bags and crisp packets. Solvent based inks in particular have been found to decompose and produce gaseous volatiles during reprocessing (extrusion);

A further challenge is the removal of metallised layers from products such as crisp packets.

If the recycled film resin is to be used back into thin gauge film applications high levels of melt filtration and screening is needed for the removal of any solid contaminants. There is currently only limited post-consumer film recycling occurring in the UK as opposed to recycling of film from post-commercial or industrial sources, which is focused on agricultural films and industrial film recycling such as shrink wrapping film.

There are existing film recycling plants in the UK which tend to specialise in particular on reprocessing of industrial films but often rely extensively on hand pre-sorting. Overall, there is a perception that household mixed plastics film recycling is a difficult business with low profitability.

15.1 CeDo film recycling trials and methodology

More than 36 tonnes of mixed polymer post-consumer packaging film waste was sourced from three different MRFs which were in different geographical areas. The material was presented in standard bales and contained all types of flexible packaging waste including crisp packets, carrier bags, cellophane, stretch wrap and bin liners.

(see following images)

Figure 100. Baled film from a UK MRF that actively collects post-consumer domestic film

The film material fraction was collected from a UK MRF that actively collects post-consumer domestic film. The film was then shipped to project partner CeDo Film’s Geleen recycling facility in the Netherlands for analysis and processing. The CeDo film recycling facility produces in excess of 40,000 tonnes of compounded pellet for film extrusion per annum. Significantly, a large proportion of their finished pellet contains an element of post-consumer film product, currently sourced from within the EU.

CeDo is keen to source UK film if high enough quality can be achieved. It currently source films from Austria as the input quality of the films is considered higher due to lower levels of cross-contamination from other non-film materials.

15.1.1 Film Recycling Trial Objectives

The key objective was to determine the recyclability of the film fraction of domestic mixed plastics feedstock from the UK on a commercial scale. Film extrusion of the recycled pellets produced was then carried out to determine suitability for commercial application.
15.1.2 Film Recycling Methodology

A number of stages were carried out for the recycling trials and subsequent product trials:

Stage 1 – Pre-trial visual compositional analysis;
Stage 2 – Pre-trial wash plant and extruder condition setting;
Stage 3 – First stage recycling and extruded strip assessment;
Stage 4 – Second stage refinement and extruded strip assessment;
Stage 5 – Recyclate production;
Stage 6 – Mass balance determination;
Stage 7 – Film extrusion trials.

Stages 1 to 6 took place at the CeDo (Geleen) recycling plant, whilst stage 7 took place at the CeDo (Telford) film blowing plant. Figure 101 displays the schematic for the CeDo Recycling complete recycling line (Sorema), including out throws.

Figure 101. CeDo film recycling line schematic

15.1.3 Pre-trial visual compositional analysis of film balestock

CeDo Recycling examined the Valpak supplied bales to gain a subjective view of the material quality and pre-determine the line set up necessary to contend with the feedstock. Qualitative bale assessment resulted in the observation of a significant proportion of film and non-film items that would be rejected due to the resultant processing problems that would ensue. In principle the bales contained predominantly PE based films but notably with the following:

- Polypropylene films – changes processing and quality of PE films due to being immiscible in HDPE, but can be blended if other resins such as LLDPE or LDPE are blended with PP;
- Highly metallised films and other laminates – at CeDo these components need to be filtered out if resin is to be used back into film applications;
- Heavy or flood printed films – result in the creation of volatiles, which hinder recycling;
- Carrier bags containing > 10% calcium carbonate filler – film can become heavier than water and sinks resulting in increased losses and lower yields;
- Paper and board – can clog reprocessing equipment and fibre will burn and degrade during extrusion if not removed;

- Cans, bottles and trays – metal cans need to be removed due to potential damage; bottles and trays introduce non-PE polymers;

- Bags within bags within bags – this results in unknown contamination entering the recycling plant.

As a result, of principally the presence of metals and metallised films it was decided that a manual sort using two operators would be needed on the in feed conveyor to the wash plant.

CeDo set up a bale breaker/guillotine that fed a horizontal conveyor with an overhead metal detector. The operatives were instructed to remove rogue materials such as metal and paper objects, heavily printed and metallised film from the belt prior to entry to the wash plant. The need to remove metal was to protect the granulators used to shred and cut the film at the wash plant entry.

**Figure 102.** CeDo manual pre-sort and removal of heavily printed and metallised films

![Image of CeDo manual pre-sort and removal of heavily printed and metallised films](image1)

a) The film in-feed conveyor  
b) The collected out throw rejects

**Figure 103.** The types of film materials removed by the manual sorting operators

![Image of film materials removed by the manual sorting operators](image2)

During the trials in order to understand the mass balance, each bale processed had its out throw individually collected and labelled for subsequent assessment.
15.2 Pre-trial wash plant and extruder condition setting

The process of washing and subsequent extrusion filtration and pellitisation and albeit any in-line activity relies on a number of buffering and mixing silos to allow sufficient material to process at circa 700-750kg/hr without interruption.

The standard feedstock contains little or no material that needs to be removed, as such the single operative on the in-feed conveyor manages the entire in-feed process, bale feed to bale breaker, guillotine operation and conveyor management. This allows a consistent in-feed of greater than 700kg/hr to the grinder/granulator stage of the wash plant.

Since the UK supplied domestic mixed plastic feedstock needed two operators and a high level of sorting to remove unsuitable material, it was necessary to assess the throughput achievable and therefore adjust/amend the method of wash plant accrual of material and subsequent discharge to the extruder. The reason for this is that there are three silos prior to the extruder that are required to be filled to a minimum level prior to release. With an in-feed of approx 700kg/hr these are normally kept relatively full and run sequentially to the extruder in a continuous manner. The issue with the trial was that due to a maximum in-feed of circa 125-200kg/hr of sorted product with two available operators and a minimum extruder speed of 300kg/hr needed to generate sufficient head pressure to allow pelletisation, there was going to be a shortfall of material. As such it was decided to run the process as a batch process where the extruder was run in short bursts as the various silos became full, the extruder was shut down once the supply was exhausted and then re-run when supply was sufficiently refreshed.

15.3 First stage recycling and assessment

The extruder is fitted with a automated belt filter system that can use a variety of mesh sizes. To start with, to ascertain primary quality a minimum filter size of 200 microns was selected.

Following on from the hand sorting the film feedstock entered a grinding hall where size reduction took place, this is a dry granulation process (Geleen also uses wet granulation). The material was then blown through to a silo for holding, prior to movement to a friction washer where the majority of primary entrained dirt was agitated together with wetting out of paper labels etc. This was all completed underwater. The film/water stream then entered two stages of density separation using two separate cascaded float/sink tanks. Float sink tank A gave rise to two out-throws, a mid-suspension and a sunk, the outflows B1 (mid-suspension) and B2 (sunk) mainly consisted of non-olefinic plastics (PVC, PET etc and some paper). The second float/sink tank also removed the non-olefins but also chalk filled olefinics from carrier bags plus a higher degree of paper than tank A. The out-throw was labelled as Waste C.

Figures 104. Typical out throws washplant residue wastes (samples B1, B2 and C).

![Waste B1](image1)
![Waste B2](image2)
![Waste C](image3)

For the mass balance CeDo dried the wet out throws to understand the removed mass at each of the above stages.

Following on from the density separation the material entered two cascaded centrifuges where high volumes of water were removed together with particles suspended within the water. At this stage CeDo had no visibility of the out throw as it enters a common water reprocessing system. From the centrifuges the material entered a mixing silo, before subsequent movement to a drier, which removed any final moisture down to <2% water by
weight. After the drier the dried film flake was transported to an extruder mounted mixing silo for subsequent delivery to the extruder.

The 160mm vented single screw extruder is fitted with a screw crammer that forces the low bulk density dried film flake into the throat of the extruder. The machine is capable of 1,200kg/hr, but typically runs at 700-750kg/hr under normal production conditions.

Due to the low throughput from the wash plant the extruder was set to run at 350kg/hr, the lowest possible to allow pelletisation to take place. Coincidentally this also allowed for maximum degassing residence time through the extruder vent. The size of the vacuum vent was not determined, however a single standard sized vacuum vent was used to devolatilise the volatiles created from remaining heavily printed films.

During the first stage extrusion trial a filter mesh of 200microns was used. Observations at the water ring pelletiser were of grey opaque gassed pellet, copious amounts of visible fumes were also noticed (abnormal) indicating high residual volatile content carried through post-devolatilisation. Figure 105 shows the water ring and surrounding levels of fume emissions.

**Figure 105.** Water ring and visible fumes from film ink degradation

At this stage the line was halted whilst the resultant pellet was extruded through the Brabender lab film blowing line. 100% sample pellets were extruded through the lab line. The material was not capable of being blown into a film, the as it was full of coarse grainy particles and also fractured frequently. At this stage the product was deemed unsuitable for conversion into a finished item. Figure 106 displays a comparison between the normal film CeDo produce and the first stage extrudate.
At this point it was decided that in order to cope with both the devolutilisation requirements and contamination, a move to 90micron filter screens was necessary coupled with running the recycled material a second time through the extruder. This would filter twice at 90microns and allow double devolutilisation of the washed feedstock. Although it became apparent that in its present format the costs of such a material could be non-commercial, it was necessary to assess this to the best of CeDo Recycling’s capability and to produce a recycled material that might eventually prove commercially viable. This therefore led to second stage trial refinement trials and assessment.

15.4 Second Stage film recycling refinement and assessment
Fresh washed film flake material was extruded twice at 350kg/hrs using 90micron screens. At the second pass noticeable fume was still present indicating that volatiles were still evolving at the water ring and still remaining within the extruded material albeit at a lower level than the first pass.

As before the material was extruded at 100% through the CeDo lab line, a blown tube was formed with noticeably fewer holes in the film and fewer incidents of bubble collapse size losses than previously. The resultant film although still coarse to touch was significantly better than the first extrudate attempt.
The film was still relatively susceptible to tearing and poorer in quality than is normal for conventional thin gauge blowing, so to demonstrate commercial possibilities it was decided to run a blend at 50% addition with standard LLDPE post consumer recyclate. The results were very promising with acceptable lab scale film being produced using 50% U.K. mixed plastic waste content.

15.5 Recyclate production
CeDo had received 36 tonnes of material to trial, however at the very low rate of an average of 150kg/hr throughput it was going to take approx 10 days to run through the 36 tonnes. It was therefore decided to run for one and half days to produce sufficient material for subsequent extrusion trials. This was double passed (extrusion) product with 90micron filtration.

CeDo produced 2,758kg of double passed recyclate in the time available under the same conditions as the second stage trial.

15.6 CeDo Film Recycling Trials Mass Balance
A mass balance determination was required to determine the yields and losses associated with recycling post-consumer films from UK. This constituted both a primary feedstock constituent assessment plus a full breakdown of the feedstock, through the recycling process to finished recycled material.

A single bale was weighed and found to be 251kg in weight. This was subsequently manually split apart and sorted by CeDo in the UK. The sorting operation simply split the bale into three constituent fractions – polyethylene, polypropylene and all other films that were not identified to be polyolefinic. Each fraction was collected individually and then subsequently weighed. The results are displayed in Figure 108.
Figure 108. Primary feedstock constituents

<table>
<thead>
<tr>
<th>Weight (251kg)</th>
<th>Polyethylene</th>
<th>Polypropylene</th>
<th>Other (plastic, paper, board, metallic objects, 3D plastic objects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>195</td>
<td>33</td>
<td>23</td>
</tr>
<tr>
<td>Fraction (%)</td>
<td>77.7</td>
<td>13.1</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Figure 108 displays the full mass balance of the system.

Figure 109. Mass balance of the film recycling trials

<table>
<thead>
<tr>
<th>Overview</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock Mass (kg)</td>
<td>4,364</td>
</tr>
<tr>
<td>Recyclate Yield (kg)</td>
<td>2,758</td>
</tr>
<tr>
<td>Efficiency (recyclate % v feedstock mass)</td>
<td>63.2</td>
</tr>
<tr>
<td>Waste (kg)</td>
<td>1,606</td>
</tr>
<tr>
<td>Waste (%)</td>
<td>36.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complete Mass Balance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detail</strong></td>
<td>kg</td>
</tr>
<tr>
<td>Recyclate</td>
<td>2,758</td>
</tr>
<tr>
<td>Steel Wires (Removed from bales)</td>
<td>19.5</td>
</tr>
<tr>
<td>Waste A (Manual sorting)</td>
<td>532</td>
</tr>
<tr>
<td>Waste B₁ (Float sink A mid suspension) Dry</td>
<td>38</td>
</tr>
<tr>
<td>Waste B₂ (Float sink A sunk) Dry</td>
<td>147</td>
</tr>
<tr>
<td>Waste C (Float sink B) Dry</td>
<td>105</td>
</tr>
<tr>
<td>Vacuum unit (solids, including leakage) Dry</td>
<td>68.5</td>
</tr>
<tr>
<td>Screen changer</td>
<td>204</td>
</tr>
<tr>
<td>Fines</td>
<td>27</td>
</tr>
<tr>
<td>Subtotal (A)</td>
<td>3,899</td>
</tr>
<tr>
<td>Unmeasurable losses (Waste D and E centrifuges, entrained water, devolved volatiles etc) (B)</td>
<td>465</td>
</tr>
<tr>
<td><strong>Total (A) + (B)</strong></td>
<td>4,364</td>
</tr>
</tbody>
</table>

CeDo typically experience a 55-65% efficiency on it’s standard post consumed agricultural film feedstock, however the resultant waste is predominantly soil, sand and stone plus residual water, this is very easy to remove with the appropriate equipment and no manual sorting.

The 63.2% efficiency achieved for the UK mixed plastic film trials required two operatives to remove just over 12% of the in feed material due to the presence of contaminants such as metals, etc. Secondly the removal of highly metallised film and laminates during manual sorting also had an influence on the final quality of the recycled film. Leaving this fraction in would have contributed to poorer quality output and higher frequency of screen changes (due to aluminium fine fragment content) and thus further reduce process inefficiency. Aluminium film layers can be difficult to screen out and cause issues in thin gauge films, but are not an issue if the recycled resins are used in thicker walled or thicker gauge applications. Where possible these films were removed, however due to the high levels of heavily printed films, removal was not possible under commercial sorting rates and large amounts of this material ended up in the final film product.

15.7 Film Extrusion Trials

Film extrusion trials took place at CeDo in Telford, U.K. Pellets made from recycled UK post-consumer packaging films from the trials were sent from Geleen for the UK film blowing trials. Prior to the trials the MFR and basic consistency of the recycled film pellets were tested. The MFR was tested as per ASTM D1238-73(A). An average
result from three tests gave an MFR of 0.68g/10mins. As well as MFR for film it is important to understand the ratio of PE to PP in the final pellet. PP tends to results in poorer film blowing characteristics plus due to the immiscibility between PE and PP also leads to poorer physical properties.

Testing of the recycled film resins using Thermal Gravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) indicated that the material was polyolefinic in nature with immeasurable proportions of other polymers. Polyethylene was present in excess of 85% with polypropylene making up the polymer balance, the recylcate contained less than 3% solids (mainly from Titanium dioxide, calcium carbonate and carbon black). These results were indicative of a product that had potential film application from a purely polymeric viewpoint.

The pellet colouration and observed gassed pellet can be seen in figure 110.

**Figure 110.** Example of double passed mixed plastic film recyclate from CeDo film recycling trials showing colour variation and evidence of gases (visible voids in pellets)

15.8 End-Product Market Opportunities

A Sainsbury’s ‘Basics’ 16micron flush top star sealed refuse sack product was selected for trials. The extrusion line was in a standard unmodified format for the trials and consisted of a 51mm co-extruder, fitted with a 120mm die and 1.2mm die gap. Cooling air for blown film was provided by a cooling ring feeding ambient unchilled air. Fresh filter screens (minimum hole size 180microns) were fitted immediately prior to the trial. The line produced a single lane product and was converted in-line on FAS bag making and winding equipment.

The trial programme set out to replace the bought in PCR and internal reprocessed resin with the double passed mixed plastics recyclate at 10%, 20% and 30% additions. The trials would also run the film if possible at 100% to determine suitability. The control mix replicated the standard mix running at the time of the trial. The control mix and the trial mixes were all made up by hand to accurately control the component ratios. The films were all run with a 1.2m frost line height. Product was successfully produced using the 10% and 20% mixed plastics recyclate. The trials containing mixed plastic recyclate processed acceptably at 10% and 20% but noticeably the frequency of contamination increased as the percentage increased. This contamination was not seen in the control. At 30% the incidence of the contamination and excessive ‘lensing’ meant aborting this sample and trial as the line was unstable and losing bubble size due to deflation because of continuous hole formations in the bubble at an unacceptable rate. The contamination can be seen in figure 111.
In order to determine the absolute processability of the mixed plastics recyclate we ran a further exercise where the inside layer of the product was run with 100% rHDPE supplied from the bottle recycling industry and 100% on the outside with the mixed plastic recyclate. The results clearly demonstrate that the rHDPE gave a coherent inside layer with the mixed plastic recyclate presenting itself as a highly foamed polymer net on the outside layer. The volatiles present in the resin appeared to significantly foam the material resulting in a complete loss of strength. Figure 112 displays films at 0% desiccant, 2% and 3% desiccant.

The use of desiccant at 3% is excessive. CeDo typically run at 0.75% (65% CaO masterbatch) to protect against lensing. Moisture content of the pellet was typically 0.3%, and whilst this was above average it is still not excessive. The origin level of moisture has not been explored further at this stage. It was controllable at low additions of the mixed plastics recyclate to a mix of other recycled material and chalk mixes. Within the foamed film (0% desiccant) the contamination could be seen running on the periphery of the foamed cell. The addition of desiccant significantly helped with the absorption and stabilisation of the present volatiles within the melt stream thereby giving a more stable polymer melt and film.
Trials produced with 10% and 20% recycled material from the trial were tested alongside the control for dart impact and tensile properties. Tensile strength and elongation were tested on a 25mm test strip at 500mm/min draw speed.

Figure 113 details the tensile and impact results.

**Figure 113.** Recycled film resin tensile test and impact results

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mean Thickness (microns)</th>
<th>Impact F50% Dart (g/micron)</th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Elongation @ Break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Machine Direction</td>
<td>Transverse Direction</td>
<td>Machine Direction</td>
</tr>
<tr>
<td>0% Control</td>
<td>15.5</td>
<td>4.5</td>
<td>14.3</td>
<td>13.9</td>
</tr>
<tr>
<td>10% MDP021 Recyclate</td>
<td>15.6</td>
<td>4.5</td>
<td>15.6</td>
<td>12</td>
</tr>
<tr>
<td>20% MDP021 Recyclate</td>
<td>16</td>
<td>5</td>
<td>15.25</td>
<td>13.25</td>
</tr>
</tbody>
</table>

The results indicate that the addition of the trial material had little effect on mechanical strength and impact performance. Testing of highly recycled film systems is affected by the presence of contamination. Where possible the testing is completed outside of visibly imperfect film areas.

Samples of film containing 10%, 20% and 30% of Sainsbury’s Basics refuse sacks product were produced. Figure 114 shows an example of final roll of black refuse sacks.

**Figure 114.** Example of the refuse sacks produced from 30% UK recycled post consumer film

15.9 Summary and Conclusions from CeDo Film Recycling Trials

Recycling and subsequent film extrusion of the film fraction sourced from UK household mixed plastics required manual sorting to remove metal objects such as cans, metallised film and other non-film residues prior to processing through CeDo Recycling’s wash plant and extruder. Initial results indicated very high volatile content in the first pass material, which showed itself as gassed pellet. Lab extrusion produced highly ‘lensed film’.
Subsequent second passing of the material through the extruder resulted in a material (at 50% loading with standard PCR) that could be processed into a film product.

Recycling rates were slow at 350kg/hr through the extruder. Subsequent film extrusion of the double passed recyclate demonstrated that up to 20% of the recycled plastic material could be included as part of a blend to produce 17micron refuse sacks. Resultant film was fit for purpose but uneconomic to produce.

15.10 Conclusions

- Recycling of UK household post consumer packaging film sourced from a MRF into a film application is possible at levels not exceeding 20% in low gauge (16microns) refuse sack, however;

- At CeDo feedstock was required to be manually sorted to remove metallic and other items prior to wash plant entry;

- Excessive volatile content necessitated double pass extrusion degas and filtration;

- Residual volatile still high in finished pellet even after double passing;

- Wash plant delivered well washed and predominantly polyolefinic flake to the extruder;

- Recycled material yield was 63.2%, impressive for a mixed plastics waste feedstock;

- Production rates of 150kg/hr are uneconomic coupled with high labour input for pre-sorting and the requirement to double pass;

- Production costs are uneconomic at 150kg/hr to produce a product with projected value of circa £350/tonne in today’s market. Good quality PCR suitable for film can be purchased from German or Austrian sources for circa £450-£500/tonne at March 2009 Polymer prices hence commercialisation is unlikely using this route;

- Principally the recycled film produced from the trials consisted of >85% polyethylene, 3% inorganic solids and the balance of polypropylene, this reflected the primary bale constituent study which found 13.1% PP;

- The PP was processed together with the PE. Compositional analysis was performed to understand the % of PP within the PE final product matrix. The brittleness of PP is often overcome by ensuring that LLDPE/LDPE is present together with HDPE;

- Film extrusion at levels up to 30% produced a commercially saleable refuse sack product with no adverse attributes v standard production blends;

- Commercialisation of the domestic mixed plastic waste will require significant further development to overcome the difficulties presented by the contamination and volatiles generated from printed films;

- Further work is recommended to overcome the existing hurdles found in these trials, namely:

  - Automated sorting of feedstock or a process that can handle the feedstock unsorted;

  - Devolatilisation of the material in a single pass at throughputs approaching/exceeding 1000kg/hr; and

  - Markets to absorb the recyclate available if full market potential of circa 190,000 tonnes is realised (63.2% of the 300,000 tonnes estimated UK mixed plastics film waste).
15.11 Recommendations

Recommendations after film recycling trials at CeDo were:

- Investigate automated sorting solutions or equipment capable of processing the film waste without the need for sorting i.e. can handle metallised material;

- Source equipment and trial devolatilisation equipment capable of delivering robust, simple processes that can process the mixed plastics film waste at high throughputs;

- Complete market survey of realistic contenders/products to absorb the potential large quantities of available recycled film.
16.0 Recycling of Domestic Post-Consumer Film - Best Practise Investigation

The CeDo Geleen trials clearly demonstrated that mixed plastic film could be reprocessed, but that further investigation was needed to ascertain current best practice in this area and find solutions for the problems caused by the high percentage of volatiles and gases present during extrusion.

16.1 Sorting of Film at MRF source

The first bottleneck in production at CeDo Geleen came at the very beginning, when the bales of mixed plastic film were split by hand and found to contain large percentages of paper, cardboard, metal and aluminium cans. For the film trial extension, it was therefore decided to re-sort the material in a mini MRF environment, taking out the main contaminants and re-baling the product ready for further processing trials. This exercise served the dual purpose of removing obvious contaminants and resulted in a clear understanding of time and effort needed for a hand sorting operation concentrating on film. Transport of unused bales at CeDo was arranged from Geleen and approximately 15 tonnes of material was returned for primary sorting and processing trials.

The film hand sorting trial was carried out by Plaswash Ltd. To ensure the right types of product were selected, a representative from CeDo manufacturing plant in Telford was also on hand, as were Nextek. The following images show the original MRF supplied kerbside collected films bales being split and the materials being sorted.

Figure 115. Bale splitter in operation

The following pictures show manual sorting of the film stream at Plaswash Ltd.
The out-throw was examined and was found to contain a very similar composition to the bales sorted at Geleen with lots of heavy ink filled products and metallised films in evidence:

Many products carried poor or no identification regarding polymer type or suitability for recycling. As a result the parameters used were ‘if in doubt reject’. An untrained operator, or temporary worker at a MRF would not have much chance of identifying this polymer or it’s suitability for recovery.

It quickly became very obvious that sorting by hand was very labour intensive and slow. Although the resultant bales were of a high quality, the costs attached rendered this alternative totally unviable as the table below shows:
As each bale weighed no more than 370kg this equates to a sorting cost alone of £450 per tonne with a maximum throughput of around 500 kg per hour. However, the MRF sort belt was often stopped to prevent commingled materials piling up and to give the operators a chance to empty bags that had been stuffed with other waste like paper or card based packaging. Therefore, this cost is conservative given the time spent re-baling and logistical costs associated with double handling.

The obvious conclusions were that automated sorting facilities of the film fraction or a recycling process that didn’t need pre-sorting were needed to make reprocessing of film viable. By desktop research and talking with machinery providers, we were able to locate a large scale manufacturer in Germany (Relux Umwelt GmbH) currently adopting these techniques. All of the material (sorted and unsorted) was then routed to Relux in Magdeburg Germany for further trials in their manufacturing facility.

16.2 Relux Umwelt GmbH

Relux is an independent group of companies specialising in logistics and waste recovery. As part of the group strategy, they have invested in a recycling plant in Magdeburg Germany, specialising in the recovery and reprocessing of plastic film from post consumer sources. This company was chosen as a benchmark comparison because the factory was commissioned especially for film recycling and has only been fully operational within the past year.

Relux is currently manufacturing reprocessed PE extruded pellet derived from kerbside collections in Germany, and it’s DSD source of material is yellow bag product, which is usually clean and only lightly contaminated.

A total consignment of 12,180 kg of materials was shipped to Magdeburg after the Plaswash hand sorting exercise. As the trial needed to examine processing options on a large scale, the batch consisted of sorted and unsorted bales, together with some example bales consisting of the reject fraction separated during the hand sorting process. At Relux a decision was made to run the sorted and unsorted materials together in a mixed pattern as it would not be possible to keep the materials apart and it was therefore better to make one agglomerated compound that has been sorted for solid metal contaminants and non film packaging plastics. Because of this > 70% of the infeed stock was not sorted for metallised films and heavily printed films and the final agglomerate still contained these materials. It was decided that these materials should be present if the true capability of the devolatilising systems was to be tested.

The reject material bales (from the Plaswash sorting trial) were examined visually by Relux production staff together with Nextek. The conclusion was that very little useful product would be retained if these bales were processed. In addition, the potential risk to machinery posed by this concentration of contaminants was very high and the decision was therefore made to scrap these bales before starting the shredding process.
16.2.1 Relux Plant Capacity and Structure

The Magdeburg site currently operates a five day working week, with 3 x 8 hour shifts per day. This gives the plant the capacity to deal with a total annual input of approximately 15,000 tonnes of plastic film.

Each shift comprises seven operators, plus two maintenance engineers and a supervisor. Including administration, loading and stores a total of 35 people are employed. Based on this 5 day x 3 shift pattern, the business has an output capacity of around 12,000 tonnes (80% average yield), meaning around 3,000 tonnes or 20% is waste and excess water.
16.2.2 Magdeburg Site Operations

Relux take in baled waste film products from a variety of sources. As previously stated their preferred source is the DSD ‘yellow bag’ German post consumer product. These bales are supplied by a German MRF conforming to a specific baled film standard. This ensures that the reprocessor gets a consistent quality with a known maximum level of contaminants. The material bales are stored outside exposed to the elements and therefore collect moisture during transport and storage. The bales are identified and segregated according to origin.
Once a batch is selected for processing, bales are transported into the factory via a bale lift truck. The bale is split, baling wire removed and the whole bale lifted into a shredder. This is designed to reduce the film into 'ribbons' of approx 120mm long.

**Figure 124.** Whole bales of film loaded and shredded to 120mm long slits in the shredder

This shredded ribbon is transported by means of a chevron conveyor to the first sorting process, which is a large vibrating bed designed to shake off any fines, earth or small contaminants. These wastes are segregated and directed to roll-on bulk container skips situated outside of the main factory, located in an open shed which minimises any extra water absorption from the weather.

The second sort happens directly after this, when the remaining materials are dropped onto a 800mm wide flat conveyor, which passes under an NIR sorting machine. This principally looks for very dense materials like wood and PVC but if needed can be configured to identify other generic polymers. Inspection for other polymers is currently not performed as the purity of the German bales is considered to be sufficiently high and rigid polymer contamination is not often observed. The main reason for the initial coarse ribbon shredding is to make the identification by the NIR sorting system easier.

Any suspect materials rejected by the NIR sorting system are diverted into the outside bulk containers. Following the NIR sorting, the remaining ribbon is fed into a second dry shredder, where it is reduced in size to a maximum 60mm length. Following this, water is introduced and the mix conveyed by a slow turning screw auger to a third shredding machine. Waste in the form of fines and organics, etc. from the screw auger process is diverted, with the water being reprocessed for continual use.
Relux has also installed a duplicate line to run alongside the main film shredding line. This second line does not have the large shredder at the beginning, nor a NIR sorter.

This line was designed for products with a greater density and rigid plastics so the shredding unit starts at the 60mm size and does not have NIR sorting. The idea of this line is that it inter connects with the film line by means of the screw auger mechanism, thereby allowing in line mixing for the agglomerate. The line then follows the same pattern as line 1 described in the following section.

This feature means that other film waste streams can be accommodated by mixing in known feed stocks at percentages which allow the mixed product to be processed. The addition of another NIR sorter on this line would enable specific polymer types to be positively sorted, but Relux feel this is not needed at present as it’s original conception was for the handling of a single polymer source.

As an example, they currently feed in coloured HDPE bottles to bolster the stiffness of one of their standard products which is subsequently extruded and used in the manufacture of MDPE low pressure pipe. The third shredder reduces the wet ribbon to a 20mm maximum size flake, which is then fed directly into a sink float separation tank. At this point any materials with a density of more than 0.96 are separated and diverted to the waste stream. There are no chemicals used in the washing process, only an anti-foaming agent and recycled water. Once again, at this stage, rejected materials such as fines and other plastics are collected as a waste stream and diverted into the exterior bins.

Relux do not currently analyse this waste, as they are able to send these residues out to a company within their group that converts this waste into a uniform particle size before converting it to fuel for energy from waste by incineration.

The washed flake then enters the Herbold film recycling system. It is conveyed to a mechanical drier, then a cyclone separator, before being compressed, at which point 90% of the moisture has been removed. Photographs of part of the actual installation are shown below.
The following images show the residue recovered from sorting stages, shredding and washing. Water is drained and removed from the residue fines with a screen. The residue is then sent for energy recovery.

During the initial phase of processing, the pre-sorted Plaswash bales were introduced first. As they had already had a lot of potential contaminant removed, the bales were very rich in supermarket carrier bags. The film used to manufacture these carriers is of a very low gauge and as a result the flake was more like fluff. This caused a build up of product within the mechanical drier and the pre-cyclone buffer silo. Relux felt this problem was not major and would be overcome during a normal production cycle by mixing some heavier film into the run, thereby reducing the percentage of carrier bags.

The next step involves a gas fired thermal drier, which reduces the moisture level to < 1% before the material is conveyed to the agglomerator, where it is compacted and formed into loose agglomerate of 4mm to 6mm. There were some concerns raised prior to the trial that this additional procedure would aid de-gasification, thereby invalidating any extra extrusion trials, but at this plant there was no evidence of any gas being removed at this stage of the process.
The resultant agglomerate was then tested to find out the existing mineral levels by means of a standard ash test, (see table and photos below) which showed that this batch had a range of 7.5% mineral filler – consistent with the ratio of carrier bags contained in the mixed plastic materials processed at CeDo.

<table>
<thead>
<tr>
<th>Weight before flame</th>
<th>Weight of Residue</th>
<th>mineral content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.46 g</td>
<td>0.11 g</td>
<td>7.5%</td>
</tr>
</tbody>
</table>

Following agglomeration, the material is pneumatically conveyed to storage silos, which feed bulk bags for onward transportation or processing further into pellet in the Relux extrusion hall. The material at this point has been dried and densified, meaning that each bulk bag can hold 600 to 800 kg of a single agglomerated compound.

16.2.3 Residual Waste

Relux has an inter-company outlet for all the waste produced at the plant. This is Relux Brennstoffproduktion GmbH which, specialises in the production of composites for use with burning solid waste for fuel.

As all the residual materials (inc. heavy polymers with density >1) are collected automatically and collated in large containers, detailed analysis was not possible during this trial.
However, the input materials were exactly as used in the CeDo trials and further investigations with the Relux parent company would help determine calorific values. This would be especially useful in working out the economics for an on-site CHP solution for the residual elements.

Interestingly, Relux were of the opinion that their own treatment plant (details below) was the only one in Germany that would take this type of waste, as the moisture content was too high for standard incineration.

16.2.4 Relux Brennstoffproduktion GmbH

The company is situated in Premnitz / Brandenburg. It operates a treatment unit for the production of secondary raw material fuel supplying cement works and power plants. High demands on quality of substitute fuels are being made by the users. These demands are established in different contracts. The most important parameters are the calorific value and the content of chlorine, heavy metals and humidity.

Recyclable waste materials are plastics, packing materials, composite materials consisting of paper and plastics, textile fibres and carpets.

The recycling process consists of several steps. At first large-scale materials like carpets and bales will be coarse shredded. After a premixing the combination in the second and third shredder crushes the waste material in the necessary particle size. The quality control system, a self-monitoring and external surveillance guarantees the consistent good quality of the produced fuels.

RELUX Brennstoffproduktion develops new high quality substitute fuels for future application fields. The plant is operated with an official authority permit. The annual recycling capacity is 80,000 tonnes.

16.2.5 Mass Balance

The breakdown of the total amount of material processed (10,920 kg) in the agglomeration phase is illustrated in the following chart:

Figure 131. Production mass balance from Relux washing and agglomeration trials

The result was very encouraging, with process waste amounting to only 17% of the input total, including an allowance (145kg) for materials lost during changeover. This compares very favourably with the normal expectations of the plant when processing German yellow bag film, when they typically get an average waste ratio of 30%. This better than expected ratio is partially due to the pre-sorted materials included in the trials, but overall the impression of the operators was that this type of material was at least on a par with their normal production input.

Although there was some pre-sorting that occurred at Plaswash, more than 50% of the film was not sorted for metallised and heavily printed films. The materials were well mixed during the washing and granulation trials at Relux, thus ensuring that the final agglomeration of the product contained a mixture of all films.
16.3 Relux Extrusion Trials

Once the product has been dried and densified by agglomeration, it is ready to be converted into pellet in their own extrusion hall. The bulk bags are taken into the mixing section where the agglomerate forms the basis of a standard recipe.

The WRAP project team were very keen to investigate production of pelletized product, especially in light of the results from the CeDo film trials. Relux were chosen as one of the venues for the devolatilisation trials on the basis of their current equipment and experience with German based mixed plastic films. The other 4 companies that specialise in extrusion and recycling of films and have significant experience with devolatilisation of plastic materials are listed below.

Latest devolatilisation processes and technologies were investigated and the agglomerate from Relux was also sent out to the following companies for devolatilisation, extrusion and filtration trials.

- Erema GmbH – Austria;
- Extricom GmbH – Germany;
- Gneuss GmbH – Germany;
- MAS GmbH – Austria.

All five companies believed that they had a robust process for commercial recycling of films which may contain high levels of gas and volatiles. The processes selected had to have a minimum throughput capacity of 1 tonne per hour and be in an accessible format to prospective PRF operators. Reports on all of these trials are described in the following sections.

As the Relux extruder has a normal operating range of 1 tonne to 2.5 tonnes per hour and had material readily at hand, they were included in the trials. Although they have an excellent Brabender mixing section, capable of producing recipes with added UV stabiliser, master batch, talc filler and additional polymers such as HDPE etc, it was decided to run the mixed plastic agglomerate ‘raw’ so that the true mixed plastics batch properties could be examined and the finished product trials and material characterisation could be accurately recorded. The agglomerate was fed into the extruder pneumatically as shown in Figure 132.

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**Figure 132.** Feeding the agglomerate into the Leistritz extruder

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The picture below shows the Leistritz twin screw extruder that was used to produce the Relux grade of recycled film from post-consumer UK packaging film.

**Figure 133.** The 135mm Leistritz twin screw extruder with three devolatilisation zones

![Leistritz twin screw extruder](image)

The Leistritz extruder has a twin screw specification, 135mm screw size with 3 in built de-gassing units. The long length of the barrel maximises resonance time during processing. Although this has a maximum output of 2.5 tonnes per hour, normal running speeds are around 1.5 tonnes per hour for basic low to medium density polythene based product.

Although the rest of the equipment in the extrusion hall was bought new, the extruder was bought as a second hand machine, proving that there is availability of used equipment for a potential reprocessing operation. The extrusion processing parameters were set as normal production; with a temperature profile based on past successes using PE based agglomerate sourced from domestic waste. A total weight of 1,940 kg of agglomerate was introduced at the beginning of the trial. No additional colours or masterbatches were included.

**Figure 134.** Leistritz film extrusion system

![Leistritz film extrusion system](image)

Setting up time was minimal and once the line is running, the process is fully automatic, so apart from periodic quality checks and removal of full bulk bags, there is very little direct labour input.
At the end of the line, is an automatic Britas filter screen changer assembly. This operates on a continual replacement roll basis and has variable filter mesh size settings.

The extruder feeds the plastic melt through the filter zone, which is hermetically closed by two seal pistons. The contamination closes the screen area and affects an increase in pressure. When the adjustable pressure limit is reached, the valve closes the melt channel and both of the seal pistons open so that the screen belt can be moved along. During this time the extruder can operate continuously and the accumulator piston is pressed down. When there's a new screen belt in the filter zone the seal pistons close and the filter zone is hermetically closed again. Next the valve opens and the accumulator piston slowly moves upwards and empties the accumulator. As soon as the accumulator piston has reached its uppermost position the screen changing procedure is completed.

The normal Relux filtration setting is 200 microns, the trial commenced on that basis, because further on in the trials, we wanted to see a direct comparison between the UK mixed plastics and the German ‘yellow bag’ derived product. Smaller mesh sizes are available for the system. This last step in the sorting cycle aims to remove any last remnants of contaminants such as aluminium, wood, adhesive labels, inorganic fibres, etc.

The agglomerate did not need any extra cramming mechanism or additional hopper vibration to feed smoothly into the throat of the extruder. As the image below confirms, the output figure for the trial averaged 1,100 kg per hour. Based on past experience of post consumer film waste, they would expect to achieve 1,500 to 2,000 kg per hour. The readout from the auto screen changer control panel also confirmed that the level of contaminants was in the normal range expected and no blockages or build up of pressure occurred during the trial period.

The final total of pellet produced 1,795 kg was packed into two bulk bags. This means a material loss due to starting losses and material change over, of around 145 kg or 7.4%. This is a relatively high percentage due to the small absolute amount of material which was extruded and in a normal production run of 10 tonnes or more, the waste ratio expected is in the range of 1.5% to 3%.

Samples were taken throughout the trial for further analysis and a data sheet of this reprocessed material detailing main characteristics is appended to the report. The bulk bags of reprocessed pellet were segregated and labelled with production date and batch number ready for onward shipment to project partner CeDo for conversion to finished film products. Pellets were also cut in half to expose an internal cross section, and the results of this further visual examination were also very positive (see following images).
The finished reprocessed pellet was very consistent in terms of size and shape. It had a dark green/grey colour and exhibited no external signs of gassing or volatile degradation.

In conclusion, the agglomerate seemed to process very well, with minimal disruption to normal operational procedures. Relux stated that they would have no problem in selling this product into the German market, especially to injection moulders and pipe extruders at their standard commercial pricing rates.

The Relux technical staff did think that to produce film from 100% recycled resin pellet in this raw state was probably ambitious, but they saw no barriers to refining the product for the film market by mixing with additives or another polymer source.

16.4 CeDo Blown Film trials of Relux Resin

Two bags of recycled film resin from the trials at Relux were sent to Cedo for blown film trials. The pellet looked to be free of volatiles. CeDo prepared a recipe blend of PE based resins and added the Relux recycled resin at 10%.
The trials indicated that at 10% addition rate the amount of lensing was limited and the film had good tear strength and good properties. Several rolls were run and the product processed well at 10%. The film bubble was stable throughout the 10% addition trial. CeDo then increased the addition rate to 20% and 30% subsequently. The material started to severely degrade at 20% and at 30% addition had completely lost all strength and started to foam.

CeDo then ran natural 100% HDPE / 100% Relux Recycled Film Grade as a coextruded film product to determine the level of material decomposition. The recycled material layer was to severely degrade and the material had lost all melt strength. This is shown in Figure 139.

It is believed that the recycled films contain residual levels of inks from flexible film packaging such as crisp packets and heavily printed films such as bread bags. These forms of packaging are often printed with solvent based inks that appear to easily decompose and degrade during thermal reprocessing.

Although, the recycled resin has been through a twin screw extrusion system with three devolatilising vacuum vents, it appears that residual chemicals from inks remain in the material. The vacuum venting achieved during
recycling extrusion removes any volatiles that are created during that process, however if the material is reheated again such as during blown film extrusion then it creates gases and volatiles. The volatiles are significant as they foam and break down the polymer material at higher addition rates.

16.5 Gneuss Ring Extruder Devolatilisation Trials

Following on from the trial at Relux, 1.1 tonnes of agglomerate was shipped to Gneuss Kunststofftechnik GmbH in Germany for devolatilisation trials.

16.5.1 Gneuss Trial Background

Gneuss have patented technologies for extrusion and melt filtration which are both well suited to handling film with high levels of volatiles. The MRS extrusion method is based on a concept, which has 8 mini satellite screws seated in recessed chambers, counter rotating around a main single screw. This increases the surface area of material exposed within the process dramatically. The screw is a modular construction, so different set ups can be achieved according to the polymer profile being processed.

The Genius filtration method is a rotary system, which is fully automatic and self cleaning. This gives a very good consistency of melt pressure, temperature and viscosity with a comparatively short dwell time for both the melt and contaminants on the filter screen.

Gneuss were chosen to take part in the best practise film recycling trials to demonstrate the effectiveness of novel technologies such as ring extruders and screen changing set ups. They have recently installed a complete 90mm line in Chile to reprocess PE film from feedstock used at dockside to store fish. The customer is successfully re-integrating this product at a ratio of 25% back into a film product for supermarkets.

16.5.2 Gneuss Trial Results

Relux supplied 1.1 tonnes of agglomerate was supplied in two bulk bags. This agglomerate exhibited a fairly strong odour, typical of post consumer washed film flake. Gneuss used a trial extruder, which has a main screw size of 70mm. Material was starve fed into the extruder, but in a full size set up the extruder would be fed by a positive mixing feed or directly from bulk bags. Manufacturing directly from flake would not be possible without additional cramming equipment. Even then, the throat size of the extruder does not lend itself to flake feeding.

Although this trial line only has a capability of outputs of 100 kg per hour, the results of the trial are easily scaleable and could be compared with recent commercial installations by Gneuss. To ensure the trial could be continued at a commercial scale, all of the available material was processed over a 2-day period.

The vacuum section on the barrel is very large in comparison with standard extruders, this means that less vacuum is needed on the vacuum pump to remove volatiles as they are naturally forced out by the counter rotating process. The vacuum was set at 25 millibars. Initial melt temperature was set at around 250°C at the die. This gave best appearance results for the resultant strand.

Figure 140. Photo showing extrusion of film resin along with the screen changer and vacuum venting on the Gneuss ring extrusion system
The filtration section was a fully automatic Gneuss Genius model with 10 screen packs. Purging losses through back flushing were calculated at 2 to 3%. The trial was split into 2 parts, 50% processed with 100 micron filtration screens and 50% with 200 micron screens. Changing the screen packs is possible while the extruder is in full production and takes about 25 minutes in total.

**16.5.3 Gneuss - 100 micron filtration trial**

The strand produced was very consistent with no outward signs of contamination or gassing. The surface was of a satin appearance. The pellet exhibited low odour, especially when compared with the original agglomerate. There was a slight ‘smoky’ smell, but no wash-plant type residual odour at all.

Plate compression samples were taken of the strand and of the out-throw flush from the filter. When the out-throw plugs were examined, there were pieces of metal contamination noticeable. Under the microscope these were confirmed as aluminium, with particle sizes of around 500 microns.

The plate samples of the finished strand exhibited no signs of contamination, the colour of the pellet was grey/green, as expected in the absence of colour masterbatch or additives.

Output at this level of filtration was limited to 50kg per hour for this size of extruder, so the decision was made to increase the output by decreasing the level of filtration to 200 microns.

![Figure 141. Photo showing backflush of contaminated film resin from the screen changer and final product strands](image)

The picture showing the extrusion of the resin strands in Figure 141, shows that after filtration and devolatilisation the material appears to have excellent melt strength. This suggests a lack of volatiles (e.g. bubbles) in the resin as the material is not decomposing. The findings from the extrusion trials were that the strand extrusion was stable and that strands did not break suggesting very good filtration and lack of any solid contaminants and/or bubbles from volatile gases.

**16.5.4 Gneuss - 200 micron filtration trial**

The initial strand produced was of a similar appearance, and also had very low odour. The changing of the mesh size did dramatically increase output, from 50kg per hour to 80 kg per hour. However, this caused some problems with the strand itself, which became too hot and as a result started to retain excessive gas within the finished pellet. The pellets also became distorted in shape.

The die plate was changed to increase the number of strands and by this method production was maintained at 80kg per hour for the rest of the trial. Once the additional strands were available via the new die plate, the pellet settled down to an identical version of the earlier 100 micron trial.
Both sets of pellets were segregated and identified for onward shipment to CeDo Telford for finished product trials. Samples of pellet and plug out-throws from each stage of the trial have been retained for future testing.

16.6 CeDo Blown Film Trials of Gneuss Resin

CeDo carried out a trial on the Gneuss recycled resin to test the volatile level of the 100 micron filtered product. To do this CeDo ran a two layer co-extrusion line, inside layer running 100% rHDPE and the outside 100% of the 100 micron filtered Gneuss material at approx 20 microns film thickness.

Previously lensing was present in the outside layer of recycled films when film was blown from the CeDo Erema line and also on the resin made during the Relux extrusion trials. In the Gneuss materials there was a significantly lower level of lensing. To test for moisture or other volatile species CeDo added 2.5% of Calcium Oxide desiccant masterbatch, which removed 100% of the lensing so the Gneuss system coupled with Herbold washing resulted in recylcate capable of film extrusion when run with desiccant. CeDo then ran this into a number of film products.

CeDo has also tested the 200 micron film. Again lensing was present at higher amounts, with 2.5% desiccant and a low level of lensing was still present. Noticeable in the 200 microns sample was the regular presence of non-homogenised material which was visible in both the neck of the bubble and the film itself has a 'smeared' area of the film. In the past CeDo have found this to be troublesome when the product is run in a full blend rather than in discrete layers. CeDo has reported that the product cleanliness was excellent for both filtration levels.

Clearly the intensive surface area and distributive mixing process of the planetary ring extruder machinery coupled with 100 micron filtration works well. Going forward, the use of additives such as desiccant will probably still be required to give a 'lense' or porosity free product.

The stranding process used by Gneuss usually also gives a pellet with more moisture ingress than a water ring or underwater so again this may be an upgrade at Gneuss that could be completed to reduce the moisture further.

16.7 Extricom Ring Extruder Trials

Extrusion trials were performed at Extricom GmbH in Germany. The trials were performed on a 12 screw ring laboratory extrusion system running at 150 kg/hr using a 3mbar vacuum system. Two bulk bags of agglomerated recycled film materials were delivered to Extricom from the Relux washing and granulation trials.

Extricom had reported past experience with running trials where it was important to create effective devolatilisation and mixing of materials. Extricom have not run UK based film packaging however believed that the key issues to resolve with film recycling is the removal of ink based volatiles and paper fibre volatiles from degraded paper based labels. Extricom also reported that experience from previous trials found that mixing of materials within the barrel is a very important part of effective devolatilisation. They have also reported that previous work performed on recycling of film packaging suggests that film reprocessors should consider stabilisation additives to improve performance during blown film operations. Ring extrusion systems are novel extrusion technologies that are believed to offer enhanced mixing and degassing opportunities.

16.7.1 Principles of Ring Extruder Operation

The Extricom Ring Extruder (RE) has the following key features:

- Machine setup and processing tasks in principle identical as twin screw extruders;
- 12 shafts symmetrically arranged in a ring;
- Co-rotating and closely intermeshing screws;
- Outer barrel and stationary inner core enclose screws with gaps similar to today's twin-screw technology;
- Intensive cross mixing of the 12 melt pools;
- Low specific energy input;
Multiple compression and decompression of the melt during the transition from screw to screw;

Shear flow in the screw channels;

Elongational flow in the intermeshing areas;

Longer residence time in the intermeshing sections.

**Figure 142.** The Extricom RE 12 ring extruder showing modular set-up of the screws and barrel

The following sections describe the key features of the ring extrusion system. The 12 screws rotating around a stationary core create very extensive surface area, which allows for high levels of exposure to vacuum and therefore extensive devolatilisation. The system has 3 venting sections, which are placed at the top and at the sides of the extrusion system.

**16.7.2 Extricom Ring Extruder Venting/Devolatilisation**

**Figure 143.** Schematic of the vacuum venting on the ring extruder

Specific Venting/Devolatilisation parameters:
- Large cross sectional area for emersion of volatiles
- Frequent surface renewal
- Small melt pools with high surface/volume ratio
- Short diffusion paths
- Large film surfaces at:
  - inner surface of the barrel
  - outer surface of the core
  - core of the screws
- Small melt pools with improved surface/volume ratio

The following pictures clearly show the very large surface area that is available on this system to effectively devolatilise plastic materials.
The following diagrams using finite element analysis show examples of dispersive mixing within the Extricom Ring Extruder and in particular the areas of intensive mixing in the melting pools. The diagrams show that there is intensive cross mixing across the 12 melting pools.

**Figure 145.** A Finite Element Analysis (FEA) showing the cross mixing of the polymer melt (Source: Extricom GmbH)

The following figure shows the FEA analysis on a cross-sectional view of the polymer mixing as well as heating zones where heat is transferred into polymer. The action of the 12 screws creates a large amount of shearing and this provides the majority of the heating requirements for this system.
16.7.3 Extricom Trial Results

Agglomerated material from Relux was sent to Extricom to reprocess into pelletised resin that would then be sent to CeDo for blown film trials and technical assessment. The trial was run on a laboratory machine that was able to process 150kg/hr under continuous conditions under an applied vacuum of 3 millibar. The laboratory machine was fully automated and is scaleable to a full a production machine, which could have outputs of 1-2 te/hr depending on the model used.

The material was fed into the ring extruder and was able to be processed well. Material was processed for several hours and samples were taken and blown into film onsite at Extricom. Several hundred kilograms of the agglomerated material was run, at which point the trial was stopped due to material unrelated filtration issues.

The material extruded well and appeared to be degassing very well. Small amounts of gas could still be seen at the die-face. The resin produced during these trials appeared to be slightly lighter then that of film produced in other trials. It appears that the inks are being removed together with the volatiles. The agglomerate feedstock was analysed and was found to be similar in appearance and composition to that supplied in all other trials.

Processed and filtered material was stored in a bulk bin. Some of this material was taken to a laboratory film line to process the produced resin at (i) 20%, (ii) 50%, and at (iii) 100%.
The resin blends were blown into film very well at all ratios and even at 100% it was possible to keep a stable bubble at a thin gauge. Visual analysis of the film showed that there did not appear to be any issues with lensing even at 100%.

16.7.4 Conclusions

The Extricom system is capable of recycling mixed film and the quality of the resin produced was considered to be very high. Visual check of the glass panels on the vacuum panels clearly showed that very high levels of volatiles were being removed. The resin and film produced also appeared to be slightly lighter to that produced during other trials. The film was able to be blown to a thin gauge film and did not show any lensing and the bubble remained stable over a 20 minute film trial. Results from trials using the Extricom RE 12 ring extruder show that high quality film resin production from mixed post-consumer film is possible.

16.8 Erema Film Recycling Trials

Two bags of agglomerated material were sent to Erema from the Relux washing and granulation trials. For recycling of post-consumer mixed packaging film feedstocks Erema used an EREMA TVE system (Figure 149) to have effective volatile removal.

The agglomerate used for the trial is shown in Figure 150.
16.8.1 Erema Film Recycling - Trial Objectives

Erema have extensive experience with recycling films and also with recycling of mixed film stocks, including work on heavily printed films. Feedback from Erema is that degassing of heavily printed films is key to successful recycling because the inks on films create extensive gassing due to degradation during extrusion. The key objectives for the trials at Erema therefore were:

- Effective degassing (devolatilisation) - this is due to the fact that many of the films are heavily printed with solvent based inks; and
- Effective filtration (90-120 micron) as the objective is to take the pelletised materials back to blown film applications.

16.8.2 Erema Film Recycling - Trial Results

The laboratory EREMA TVE system was started with the agglomerated material feedstocks and run at a 360kg/hr throughput rate. The extrusion system ran well and the operating conditions remained consistent.

The laser filtration system needed to be used during this trial because of the level of contamination. The pressure on the Laser Filter started to rise immediately during a 15 sec stop of the scrapers from 155 bar to 230 bar.
It was concluded that the laser filter was most suitable for the filtration of this feedstock as the contamination levels were considered to be too high for a screen changer unit.

The produced resin was taken to a blown film line and extruded into film at 100%. The film did not show any signs of lensing on a small laboratory film line.

16.8.3 Erema Film Recycling Trial Conclusions

The material ran well on the Erema extrusion system and appeared to devolatilise well. The laser filtration system was needed to effectively remove the solid contamination from the agglomerated film stocks. The filtration was successful and during the trials on a laboratory blown film line there was no problems due to any solid contamination defects. The film that was produced from the Erema pellets did not show any lensing, which had good tear resistance and was of good colour quality.

16.9 MAS Film Recycling Trials

Two bags of agglomerated materials were sent to MAS in Austria for recycling. The materials came from the Relux film granulation and washing trials and were sent to MAS in agglomerated format. The MAS extrusion system is unique as it is the first available conical co-rotating twin screw extrusion system, which allows for excellent mixing and due to the screw profile configuration that MAS have developed it is believed to be highly effective on film devolatilisation.

**Figure 152.** MAS conical co-rotating twin screw extrusion system

16.9.1 MAS Film Recycling – Trial Objectives

The key objectives for this trial was to effectively devolatilise volatile residues from the degradation of inks and pigments during extrusion. The secondary objective was to filter the materials to a level that the final pelletised product could be used back into blown film applications.

16.9.2 MAS Film Recycling - Trial Results

MAS ran two sets of extrusion trials. The filtration trial was made with a manual type melt filter with a screen with diameter 130mm. The material had too much contamination inside so that the lifetime of the filter screens (with 110 micron) was too short for a longer test run. This was especially the case with the trial with 110 micron the small filter area limited also the output of the NCT 55 extruder.
From the pelletised materials a film with both pellet qualities was produced, e.g. with 400 micron and with 110 micron filtration. The film produced on the blown film line appeared to process well and did not show any lensing.

**16.9.3 MAS Film Recycling Trials – Conclusions**

The film recycling trials at MAS on the conical co-rotating twin screw extrusion system were successful and appeared to give very good devolatilisation. Special mixing elements were placed on the screw to maximize degassing potential during this trial. The pellet produced has minimal odour and when blown into a film on a laboratory line there were no problems at 100%.

It was found that very good filtration was needed to remove the amounts of solid contamination from the agglomerated film feedstocks. The pelletised resin was taken onto a laboratory blown film line and processed into film. Overall, the film quality appeared to be very good.
16.10 Best Practise Film Recycling Trial Conclusions

A number of leading technologies were utilised to extrude, filter and devolatilise post consumer packaging film waste from UK. It appears that technologies such as the ring extrusion systems can successfully produce high quality recyclate film resins from mixed infeed film stocks. Filtration of the films has been a key issue and results obtained that films should be filtered between 90-110 micron to achieve the best possible film quality.

Devolatilisation was found to be effective on the ring extrusion systems from Gneuss and Extricom, whilst the MAS conical co-rotating extrusion systems and the TVE system from Erema also appeared to give very good results.

Film recyclers may need to use additives such as stabilisers and desiccants to control lensing, however it can be concluded that it is technically viable to recycle UK post-consumer film waste from domestic sources. The recycled resins can be used in a number of markets including film products such as refuse sacks and industrial films.

The development of the film resins with low volatiles suggests that further development work is needed to create film products with high recycled polymer content.

17.0 Energy Recovery – End-of-Life Management of Residual Wastes

During all of the reclamion and recycling phases of the sorting and reprocessing trials, no matter how efficient, there was always some residual element of material left over that could not be recovered within that trial phase.

In this project there were two distinctive forms of residue. Firstly there was a residual material stream left over after sorting trials at the PRF facility. This residue stream was baled and sent to DELA in Germany as they have a PRF with 7 NIR sorting units, which allows for extensive sorting and automated re-sort capability. The remaining residues after re-sorting trials at DELA were then used by DELA for energy recovery.

There was also a substantial amount of residue from reprocessing trials. This residue was in the form of washplant fines, paper fibres, dirt and other unknown fines. This residue stream of washplant fines is currently impossible to be sorted into a plastic vs. non-plastic stream as the particles are typically too small (0-3mm) for sorting.

The management of both of these residue streams is described in the following sections.

17.1 UK PRF Sorting Residues

Materials at the UK PRF were rejected before de-baling if more than 10% paper contamination was clearly evident. This was done because the sensors in the automatic sorting equipment would become covered with paper and thereby the sensors would eject all good product, thereby reducing the overall quality of the output. Following images are of residual materials baled from the trial out-throws i.e. after NIR positive sorting for PP, PET, PS, PVC and PE. After sorting 15.75 tonnes of residue remained. This included 13 tonnes of residue and over two tonnes of mixed PVC. A number of companies were approached to determine if they could reprocess the PVC stream, however none were willing to take the material.
17.2 PRF Sorting + Reprocessor Trials: Yields and Residue Streams

The composition of the residue from the sorting trials of rigid plastics at Valpak was mainly PET (25%), paper (23%), PP (20%), HDPE (7.5%), PVC 5%, film (1.5%) and PS (1.5%) and the balance being minor components. The details are shown below.

The actual data collected for the inputs, outputs, yields and residual amounts measured during the trial is presented in the table below. The data is a guide to the residual fractions created at each stage of a PRF process. This data provides the basis for the models that have been developed by Axion Consulting in the section on the economics of mixed plastics recycling. The data allows the characterisation of the modelling coefficients for the estimation of yields for primary inputs and the secondary materials derived in the processing steps.

It should be noted that some of the baled products (PET coloured bottles and HDPE coloured bottles) grew in size due to the incorporation of other plastics by erroneous sorting.
Figure 157. The recycling performance of the mixed plastics primary and secondary input materials and residues under the various processing methods during the commercial scale trial.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Initial Input</th>
<th>Processed</th>
<th>Waste</th>
<th>Final Output</th>
<th>Yield %</th>
<th>Waste %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre sort mixed in homeless shelter</td>
<td>123.94</td>
<td>14.95</td>
<td>67.67</td>
<td>85.49</td>
<td>14.10%</td>
<td></td>
</tr>
<tr>
<td>PF rigid process to flakes</td>
<td>35.54</td>
<td>14.03</td>
<td>35.71</td>
<td>94.01</td>
<td>6.99%</td>
<td></td>
</tr>
<tr>
<td>PF rigid process to flakes</td>
<td>7.39</td>
<td>6.01</td>
<td>7.39</td>
<td>94.01</td>
<td>1.99%</td>
<td></td>
</tr>
<tr>
<td>PF rigid process to flakes</td>
<td>4.39</td>
<td>2.27</td>
<td>2.27</td>
<td>99.99</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>PF residues to flakes</td>
<td>19.63</td>
<td>1.10%</td>
<td>19.63</td>
<td>0.01%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>PF residues to flakes</td>
<td>3.85</td>
<td>7.95</td>
<td>3.85</td>
<td>18.64%</td>
<td>81.36%</td>
<td></td>
</tr>
<tr>
<td>PF baleable clear flakes</td>
<td>15.37</td>
<td>1.00%</td>
<td>15.37</td>
<td>99.99</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>PF baleable clear flakes</td>
<td>15.37</td>
<td>1.00%</td>
<td>15.37</td>
<td>99.99</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>PF baleable clear flakes</td>
<td>7.07</td>
<td>1.00%</td>
<td>7.07</td>
<td>99.99</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>Total baleable</td>
<td>22.44</td>
<td>1.00%</td>
<td>22.44</td>
<td>99.99</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>PF baleable clear flakes</td>
<td>22.44</td>
<td>1.00%</td>
<td>22.44</td>
<td>99.99</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>PF baleable clear flakes</td>
<td>22.44</td>
<td>1.00%</td>
<td>22.44</td>
<td>99.99</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>Total baleable</td>
<td>22.44</td>
<td>1.00%</td>
<td>22.44</td>
<td>99.99</td>
<td>0.01%</td>
<td></td>
</tr>
</tbody>
</table>

This data has been used to model the yields generated within a PRF of 80,000 tonnes processing capacity. The following table shows the yield of plastics and the residues at various stages of processing for the PRF with input split 70/30 between rigid plastics and film.

Figure 158. The simulation of yield of baled plastics, flake and pellet from 80,000 tonnes per annum of mixed plastics.

<table>
<thead>
<tr>
<th>Total Amount of Input</th>
<th>Bales with film sorted</th>
<th>Yield</th>
<th>Flake</th>
<th>Yield</th>
<th>Pellet</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>80000</td>
<td>80000</td>
<td>80000</td>
<td>80000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>66509</td>
<td>83.1%</td>
<td>46116</td>
<td>57.6%</td>
<td>44013</td>
<td>55.0%</td>
<td></td>
</tr>
<tr>
<td>13491</td>
<td>16.9%</td>
<td>33884</td>
<td>42.4%</td>
<td>33987</td>
<td>45.0%</td>
<td></td>
</tr>
</tbody>
</table>

The projection of the trial data to a large scale plant that produces the maximum amount of pelletised product shows that the ultimate yield is 55% and the cumulative waste is 45%. This is in contrast the higher yields shown for baled products however these will contain a degree of contamination and moisture that needs to be removed as the plastic is refined prior to the next processing step.

The level of waste and residues in these trials was higher than may be expected in an integrated operation since the material recycling trials were done at many different locations and the plants were not necessarily optimised for mixed plastics feedstocks and it can therefore be suggested that if this was done at one integrated PRF + Reprocessor plant then there would be greater efficiencies and lower material losses.

The waste generated within these trials could have been reduced if sorting of the packaging was optimised. Some of the residual products from each individual process would certainly be utilised in other processes within the PRF, e.g. PET bottles in the coloured HDPE bottle fraction were shown as waste, but would be actually utilised by the PET recovery operation in an integrated operation.
The analysis of the individual processes involved in a PRF operation during this trial converting the materials into a flake stage, shows that the unavoidable, 'unusable' waste could have been 9 tonnes less or 5% lower than the actual residues achieved in this trial by the recovery of materials through more efficient sorting.

By applying the same analysis to the integrated PRF + reprocessor where the yields from sorting could be maximised to 97% recovery levels, the yield of the operation would improve from 55% to 60%. There would be a double benefit from this strategy as the cost of waste would be reduced by 5% and the revenue from finished products would be increased by 5%. Further details are provided in the 'Financial Assessment Report'.

The overall moisture content of the product at receipt also needs to be taken into consideration, especially when processing film, where production statistics at Relux built up over a number of months show regular moisture levels in baled film of 20%. This moisture does not incur disposal costs and to a large extent is recovered and used during the process. However, this fraction is not always measured accurately by other processors and the tendency is for it to be lost within the general waste assumption.

Even allowing for integration of processing facilities, extra sorting and recovery of moisture, there is still a considerable amount of residual waste generated during most recycling operations. A prospective PRF operator would need to explore this area in detail in order to maximise returns and minimise disposal costs.

17.3 Reducing waste via Material and Energy Recovery (PRF Sort Residue Stream)

Relux and other parts of the German recycling group e.g. DELA were able to take in residual fractions created by other plastics processors. In particular, DELA was created to recycle and recover mixed rigid plastics and as the plant has a high degree of NIR sorting automation. The final remaining residual waste after sorting and re-sorting at DELA is then turned into Refuse Derived Fuel (RDF) and exported as a fuel for cement kilns or is used as a component for the composite fuel manufactured by Relux Brennstoffproduktion. The project investigated this model, as it is currently providing an integrated solution in Germany.

17.3.1 DELA Operational Structure

DELA was started two years ago in Beckum Germany with the aim to produce high quality sorted polymer specific baled product, which can then be exported or sold on to other plastic processors. After extensive resorting the final residue stream is shredded (size reduced) and forms RDF based waste for energy. Apart from an initial visual inspection of bales and occasional removal of large metal components (by hand), all sorting is automatic and performed by seven NIR units.

The business currently operates with 12 staff including administration and technical, five days per week with two shifts per day. The plant can handle most types of mixed plastics and is designed to have maximum throughputs of 15 tonnes per hour. In reality, with the level of personnel, diverse material mix and current economic climate, they are operating at five to six tonnes per hour.

17.3.2 DELA Mixed Plastics Reclaim Plant Outputs and Efficiency

The material recovery rates at DELA were found to be significantly greater than any of the MRFs surveyed during the MRF/PRF sorting part of the project. When handling mixed plastics from German waste sorting plants, DELA claim to regularly achieving 85% recovery rates for polymers such as PET, PP, and PE, with the residue balance typically converted to RDF.
At the end of the pre-sort virtual PRF phase of the project, there was a balance of 15.75 tonnes ‘residual’ product (including the PVC sorted product), which could not be sent on to processors in the UK. In addition, there were bales of retail take-back product co-mingled with paper and cans that were inadvertently mixed by the waste contractor. DELA agreed to put some of this residual through its plant to ascertain the level of possible product recovery and also the RDF that could be obtained and therefore give a guide to the reclaimable energy value of the residual fraction from a PRF.

The following pictures show the quality of the PET and HDPE packaging that was recovered by DELA from UK PRF residue materials. This shows that further recovery of highly pure plastics is possible. DELA was able to achieve this recovery due to a sophisticated seven NIR sorting plant, which allows for extensive resorting and recovery. This results in minimal losses and improves the yields for a PRF.
The plant was cleared so that no contamination of the trial was possible from previous production. Approximately 21.1 tonnes were put through on the day, including 5 tonnes of retail co-mingled fraction, which was processed first. Although there was a lot of paper in this fraction, the DELA PRF sorting system coped well. The main concerns that DELA had were potential damage to shredding equipment from metals and the lowering of the RDF calorific value, due to the paper content.

The metal separation equipment managed to remove most of the metal cans, however, there were some non-packaging items found (e.g. a car battery and bicycle handlebars) in the retail waste.

The main shredder used by DELA is a large Vekoplan machine, which coarsely shredded to a 300mm size particle to enable good product flow to the next stage. An 80mm shredding phase takes out any small particles which are routed via NIR sorters to the RDF shredder which reduces size to 10mm.

The trial throughput of the commingled retail fraction was about 5 tonnes per hour, slower than normal, but this was due to the higher level of present paper contamination.
The sorted product storage bins were examined after the trial and as previous trials had shown, the quality of HDPE and PET recovered was very high. There was also a mixed polyolefin (PO) fraction made up of PP and coloured HDPE. The recovered RDF, was generally of a poorer quality (in terms of energy) than normal, due to the high paper content. The estimated effect on the energy content due to the paper was a reduction of calorific value in the RDF residue from 30 MJ/kg to 20 MJ/kg. This quality would not normally be acceptable to DELA’s premier grade customers, but would be an acceptable grade for second tier operation. In addition, the quality of the sorting was also very high; there was a very low ratio of cross contamination across polymer types due to the high level of re-sorting, to the extent where it was difficult to find any PET items in the HDPE bins and vice versa.

**Figure 163.** Mass balance of recovered polymer materials from the UK mixed plastic co-mingled retail residue stream after ‘re-sorting at DELA’

**Figure 164.** Mass balance of materials recovered from the UK mixed plastic co-mingled PRF residue stream after ‘re-sorting at DELA’

### 17.3.3 DELA Mixed Plastics Residue Recovery Plant

The residual materials from both trials were then visually analysed and assessed by DELA staff for viability of use as RDF fuel. The following picture shows paper and some polymer residues that could not be recovered for recycling.
Metal and other contaminants were separated out and ejected by the NIR sorting units. The recovered metals were then separately stored for later shipping to a metal reprocessor.

The following picture shows the quality and quantity of natural HDPE recovered from the UK mixed retail residue stream after paper and metal packaging was automatically removed by NIR sorting units.

The balance of the residual fraction from UK was processed. This trial proved the benefits and recovery efficiencies of NIR sorting in this plant even when heavily mixed and contaminated UK residue streams were presented. This indicates that with the correct sorting set-up high recovery rates are possible with automated NIR
systems and this results in minimal product losses and therefore increased yields. An example of coloured PE fraction recovered from the DELA recovery sorting trial.

**Figure 167.** Recovered coloured HDPE from UK PRF residue stream

![Recovered coloured HDPE from UK PRF residue stream](image)

During the PRF residue sorting trial, the plant ran at normal commercial outputs, because there was little paper or metal contamination. It was noticeable that black trays, either in PP or PET, were not being recognised and these nearly always ended up as RDF. The quality of the RDF was inspected and found to be of sufficient quality to pass to premier customers, with no reduction expected in calorific value. Natural HDPE recovered during trial 2 (UK PRF residue recovery sorting) is shown in Figure 168. It was found to be of very high purity with negligible cross-contamination from other polymers and other materials.

**Figure 168.** Recovered natural HDPE from UK PRF residue stream

![Recovered natural HDPE from UK PRF residue stream](image)

The overall total of plastics recovered for resale, (bearing in mind that this was the residual waste from the UK MRF/PRF trial and was destined for landfill), was a further 34% by weight of mixed plastics suitable for recycling.
was recovered. This included the natural HDPE stream, the PET bottle stream and the mixed coloured PP/PE stream. The following picture shows an example of a black tray not identified by NIR.

**Figure 169. Unidentified black tray packaging**

The following picture clearly demonstrates that by re-sorting only residue packaging; non-packaging plastics and non plastic materials were sent to energy recovery by creating an RDF type material after four hours of re-sorting trials.

**Figure 170. RDF for energy recovery from UK PRF and retail residue stream**

17.3.4 **DELA Re-Sort and Energy Recovery Trial Conclusions**

The retail take-back fraction will cause even the most efficient processors many problems unless metals and paper can be kept separate throughout collection and storage. However, this is primarily due to poor collection method.

Automatic sorting efficiency varies from processor to processor, however NIR sorters are extremely accurate and give very efficient giving excellent purity within the stream chosen. Black trays cannot currently be identified by NIR sorting methods.
There are existing markets for energy from waste residual product, with maintaining calorific values and transport the major challenges to be overcome. When using this plant as a model for efficiencies in sorting within a PRF, residual waste can still be effectively reduced by a third.

17.4 Potential of Combined Heat and Power (CHP) for Treatment of Washplant Residues

If diversion from landfill is the main driving factor, then the washplant fines residue streams from PRF + reprocessors plants could be utilised in pyrolysis plants that are designed to recover energy from residual wastes. Currently there are no such working plants or systems in the UK, but several are being planned.

The washplant residues warrant further investigation, as currently only landfill and SRF options are potential disposal treatments. A typical PRF + reprocessor could have around 7,500 tonnes of this type of material available each year. As part of this project the residue from the washplant at CLR was chosen for further evaluation. Washplant residue is typically a mixture of paper based fibres (from paper labels), glues, dirt, with some plastic fines (typically 0-3mm dust/fines) from the granulation process. The plastic component of this residue is very difficult to separate and reuse into any applications. Due to the contamination from organic matter and the small size of the fragments and fines it was not possible to establish an accurate material based composition.

This form of residue is currently unavoidable due to packaging design/materials used and reprocessing methods that result in some losses.

The wash-plant waste from CLR was collected for assessment of potential energy recovery options. Currently this form of residue is destined for landfill from the majority of plastic reclamation facilities in the UK.

The chemical nature of the product was examined to ensure it qualified as a non hazardous waste for landfill and therefore for energy recovery. As the materials were mainly from food packaging waste and as the main element was paper, it was determined that this material mixture could be used for energy recovery. A chemical assessment of the washplant residue was performed and the material was found to be safe for both disposal options landfill and gasification.

The washplant residues were densified by means of mechanical pelletisation. This also had the benefit of extracting remaining moisture and of converting the mushy waste into easily handled pellets. The following diagram shows residue materials entering a mill and pelletised residue exiting.

**Figure 171. Agglomeration and pelletisation of fines and residues from CLR washplant**

A CHP pyrolysis technology supplier (Kedco Ltd) was approached to perform an energy potential assessment of this materials. Kedco manufacture a range of Combined Heat and Power (CHP) modular systems. CLR delivered a 1 tonne bulk bag of wash plant residue to a pelletizing company. Although they are principally contract manufacturers of slug pellets and animal feed, the equipment was ideally suited to processing materials of this type, as shown in the following image.
The picture clearly shows the high level of paper fibres present in this stream. The paper fibre typically comes from paper based labels on plastic packaging, which are removed during the granulation, dry cleaning and washing stages of reprocessing.

The pelleting trial was a qualified success. In a normal production environment they were confident that they could run the product at 1 tonne per hour. They suggested a bespoke die was needed, giving a slightly larger pellet but with more compression, which would give more consistency and densify the product still further.

A new PRF site will have a considerable demand for power and heat, so generating some of that energy and heat from residue waste such as washplant fines may be an effective way to derive extra value from the residual stream.

17.4.1 CHP Treatment (Kedco Ltd)

The existence of heat demand in hot wash plants at integrated PRF sites, may provide the potential for a Combined Heat and Power (CHP) system to be used to produce electricity and heat from washplant residues. This would have the benefit of creating energy from a material stream that is destined for landfill. With CHP schemes, if heat is obtained after power generation then energy efficiency of 70% to 80% can be consistently achieved. Samples of the pelletised residues were sent to Kedco for assessment trials using a 75 kWe CHP system. For example, 50 kWe system typically uses 1 tonne of dry biomass per 24 hours and produces enough electrical energy to power 50 homes and enough heat to displace 8,000 cubic feet of natural gas. A 75 kWe modular plant has a capital cost in the region of £0.5 million depending on exchange rates and configuration required. An example of a 50kWe system is shown below in Figure 173.
This system was used to produce energy from the washplant residues in Ireland. The following data shows the assessment of flue gases and also the calorific value obtained from pelletised washplant residues.

**Figure 174. Assessment of flue gases and energy values from gasification of washplant residues**

**Certificate of Analysis**

+ Kodco-The Biosolence Energy Company
  John Brennan
  Unit 5
  Fortgate Business Park
  Co.Cork
  Monkstown
  IRELAND

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The assessment of flue gases was that there were no harmful substances emitted to the atmosphere. Assessment of energy calorific values found that the material had slightly higher energy values than typical biomass feedstocks. For example dried wood chips typically provide approximately 5MWh/tonne, compared to a calorific value of 5.8-6.4MWh/tonne for the washplant residues. Given the fact the majority of this residue is paper/organics based than this suggest that this feedstock could be used for energy recovery. The washplant residues had a calorific value of approximately 20-23 MJ/kg, this is substantially lower when compared to the calorific value of plastics such as PP, PS or other polyolefins which typically have calorific values of 40-50MJ/kg. For example the calorific value of PE is 46MJ/kg and PS is 44MJ/kg (Source: 'Plastics Engineering, Manufacturing & Data Handbook', pg 57, by Dominick V. Rosato, Plastics Institute of America, Nick R. Schott). The low value is attributable to the high paper/organics composition levels in the washplant residues.

A visual assessment of several samples of the dried washplant residue indicated that a typical composition of non-plastics (e.g. paper/organics) is likely to be approximately 60-70%, with the remaining 30-40% being fines from plastic labels, glues and plastic fines from the granulation process.

**18.0 Plastics Reclamation Facility + Reprocessing (PRF+) Analysis**

During this project there have been many opportunities to assess the nature of the challenge facing new businesses that will seek to use these materials. The key issues and observations are made below.

**WRAP Commercial scale mixed plastics recycling 153**
This large scale mixed plastics trial processed large quantities of plastics at commercial rates at existing reprocessing operations. Different parts of the 150 tonnes of mixed plastics procured were processed two or three different ways to fully investigate the commercial aspects of production. As the project progressed and was extended into additional investigations of the recycling of films, there were 26 different organisations involved and 20+ separate manufacturing processes to monitor, all within a six month period.

The definition of mixed plastics has been defined by WRAP as ‘non bottle rigid and films’. As has been shown in this project, the meaning has been interpreted by householders and MRFs in a broader sense that indeed incorporates the presence of bottles.

**Retail Take Back Scheme**

The project proved that there was a willingness from consumers to utilise this facility and that the quality of product recovered was very high. Contamination from other recycling streams was very low at the collection point, but the economies of collecting relatively small weights of plastics alone by compactor or compartmented trailer, travelling over a widespread area needs to be addressed. Further investigation is needed into on site compaction at point of collection and collection with optimised logistics.

**Composition of Materials in Mixed Plastics Streams**

The materials that have been collected within this project were sourced from three MRFs that had differing local collection and recycling strategies resulting in different compositions. This was especially apparent with the way plastics films were treated since they presented a significant challenge to the sorting of recyclable materials. Films were often a major contaminant in paper due to the way these 2-D materials behave in sorting operations with 3-D rigid plastics being easier to separate as group from planar materials. Consequently the films are removed early in most recycling operations and do not usually make up high percentages of the rigid mixed plastics stream in most collection systems.

Earlier studies on ‘Domestic Mixed Plastics’ by WRAP in 2008 showed that film makes up 30% of the mixed plastics waste stream. Although films are always present, the level encountered in the waste stream would depend on collection strategy and householder response. This meant that this study needed to incorporate films into the collection and recycling phases. This was done through separate sourcing and processing stages that are described within this report. The techniques for separating films from rigid plastics are well known (ballistic separators, air knives, air sifters etc.) so it is feasible to treat films and rigid plastics separately within the processing sections of this project without deviating too far from the way a commercial plant would process the materials if they were sourced as a completely commingled stream.

Given that MRFs are likely to remove films at the early stages of recycling the PRF is likely to receive baled film from the MRFs as an input to any processing operations.

The detailed composition of the film stream is outlined within this report and consisted mainly of mixtures of LDPE, HDPE and PP with significant presence of metallised and heavily printed films.

**Film Can be Recycled on a Commercial Scale**

The project demonstrated that there are existing techniques available for processing mixed plastic film. A PRF may be able to improve the quality coming in by the introduction of a film specification that would assist the MRFs. Near infra-red sorting is a useful option for film recycling providing the initial size reduction is designed to suit the process.

The development of the new film processing techniques means that new products can now be developed to exploit the opportunity to use higher levels of recyclate.

The compositions of the mixed plastics without films is shown below for the materials with and without bottle fraction.
Composition of Mixed Plastics without bottles

Figure 175. Composition of mixed plastics without bottles and without film

The above table shows the analysis of the mixed plastics stream with the film fraction removed with and without the presence of bottles.

The presence of bottles has a significant effect on the composition of the mixed plastics stream. The analysis shows that PET and HDPE bottles both clear and coloured represent 57% of the total. The other crucial feature is the high level of PP present especially in the absence of any bottles where it represents nearly 60% of the total with a very varied mix of other plastics at levels lower than 10%.

This observation means that any PRF will most likely separate PET, HDPE, and PP as fractions for recovery into high quality flake and pellet. PS and PVC will most likely be collected and baled due to their much lower levels of incidence and market value. The PVC is often present as flattened trays and folded sheet for small boxes and has been identified at Closed Loop Recycling as a key source of contamination for PET. This has resulted in all trays being diverted away from the food grade PET stream resulting in the loss of material from this high value destination. This emphasises that as the recycling of mixed plastics increases in popularity, there will be more pressure to exclude the minor polymers from food and other packaging.

Polymer Types and Identification

During the various compositional analysis carried out within the trial, many different types of packages were found that had no type of polymer identification. Non-food packaging was especially noted for this omission. A widespread use of the identification protocol would enable faster training and more effective separation.

PRF Recycling Process Operations

As a result of the detailed studies of each operation conducted with in this large-scale trial it is possible to design a technical model of a single facility that takes in the mixed plastics collected by municipalities and recovered at MRFs as a single mixed stream. The model that has been developed is based on the material input encountered in this large-scale trial that has been described earlier i.e. it includes bottles as well as the film and other forms of packaging.

The key steps that would be found in a in the PRF are listed below with comments on some of the steps in the PRF. The model allows the estimation of the equipment, space and utilities for such a facility at the different stages such as baling of bottles, production of flake and production of pellet.
1. Input facilities:
This would include the separation of films from rigid plastics this is often done by hand however the use of Ballistic separators and film sifters are the preferred option.

2. Film Processing
   a. Shredding to 120 mm ribbons
   b. NIR sorting of the film pieces
   c. Shredding to 60 mm ribbons
   d. Mechanical or wet cleaning
   e. Shredding to 20 mm ribbons
   f. Sink and float separation
   g. Mechanical and thermal drying
   h. Agglomeration
      i. Extrusion, Melt Filtration and Pelletisation
   j. Bagging and storage

3. Rigid/Bottle Plastics Separation
   a. Bale breaking and singulation
   b. Preliminary fines and dirt removal via trommel
   c. Sorting by NIR sorting into Plastics types i.e. PET, HDPE, PP, PS and PVC
   d. Sorting by Optical sorting into Clear and coloured streams for PET, HDPE, PP
   e. Baling of PS and PVC
   f. Grinding of rigid/bottles to Flake 10mm
   g. Washing (Hot) of clear PET and natural HDPE
   h. Washing (cold) coloured PET, PP and Coloured HDPE
   i. Colour sorting of clear PET and natural HDPE flakes into clear and coloured streams
   j. Decontamination, Extrusion Melt Filtration and Pelletisation of clear PET and Natural HDPE.
   k. Extrusion, Melt Filtration and Pelletisation of PP, coloured PET and HDPE.
   l. Bagging and storage

These operations have been used to develop the estimates of capital, processing costs and economic performance in the 'Financial Assessment Report' by Axion.

**PRF Residues**
A PRF with 80,000 tonnes per year input capacity will generate around 36,000 tonnes per year of residue. This will impact on the economics and environmental effectiveness of a PRF if the only solution is landfill. The German model investigated during the project has solved this problem by shipping everything they reject to a group company that produces a composite fuel for cement kilns.

Current UK market price for cement kiln fuel is around £5 per tonne, but a specification needs to be established for residual plastics materials that energy-from-waste producers will be prepared to take.

Densification of washplant fines waste creates a fuel for an on-site CHP plant for the PRF. The energy efficiency of such a system economics of such a system would be enhanced if there was a nearby outlet for the extra heat generated, again underlining the importance of the geographical location of the PRF.

**Recycling efficiency of the materials in the mixed plastics trial**
During the processing of the mixed plastics the yield and losses of each fraction was measured throughout each trial to assess the efficiency and yield of the recycling process and the level of contamination present in the mixed plastics.

The losses to waste during the first processing step at Valpak into individual fraction of the rigid plastics without film was 14%.

The conversion of the rigid plastics to pellets lost a further amount that varied between 25% to 40%.

The losses during the processing of the film to finished pellet by two different methods were 37% reflecting the greater level of moisture (typically 20%) and contamination in the thin materials.
Axion has used this data to model the sorting and recovery efficiency of the mixed plastics fractions for plants of various sizes in the section on the economic analysis for PRFs that use similar technologies.

The sorting efficiencies of each stream can be used to model the yields of any mixed plastics plants with similar inputs of materials i.e. film, rigid plastics and bottles.

The projection of the trial data to a large scale plant that produces the maximum amount of pelletised product shows that the ultimate yield is 55% and the cumulative waste is 45%. This is in contrast the higher yields shown for baled products however these will contain a degree of contamination and moisture that needs to be removed as the plastic is refined prior to the next processing step.

**Purity and Quality of sorted Plastics**

The quality tests and parameters for the sorted plastics are detailed in other sections of this report. In general all the materials produced resins that could be used as replacements for virgin resins either at full strength or as blends with virgin resins once the contaminants were removed. The level of contaminants varied from 37% to nearly 50% for the film and the various rigid plastics over the whole of the sorting process. The lowest losses were seen for the bottles where the losses were of the order of 35% due to the simplicity of identifying the base plastics by automatic and manual sorting. Other materials such as PP and PS were contaminated with other plastics and suffered greater waste levels when sorted to a commercially adequate level of quality. The losses in the film fraction processing were of the same magnitude (37%) due to the relatively generous capacity of the LDPE fractions to accommodate the presence of other plastics such as HDPE and PP, otherwise the losses would be higher.

**Recycling Process Throughput Rates**

The trial monitored the existing throughput rates of the participating processing operations within the project to establish a true benchmark for PRF performance within each element. Full details are reported within each relevant section, but are summarised below to demonstrate that the trials were conducted at rates that would be considered to large scale and similar to those encountered within a large PRF.

**Film Fraction Processing Rates**

The baled film was initially handled by CeDo in Holland, which has an existing production facility with an annual output of 24,000 tonnes PE reprocessed product.

The normal outputs for CeDo were minimum 1 tonne per hour through shredding and wash-plant and 750 kg per hour for extruding pellet. The imbalance created by the quicker shredding process was taken up by buffer silos prior to the extrusion process to ensure continuous production.

When the MRF supplied film material was manually sorted on site using 2 operators to eliminate major obvious contaminants, input to the shredding process was reduced to 125 to 200 kg per hour. This was insufficient to feed the extruder continually. In addition, the extruded pellet required a double pass through the extruder to degas the volatiles within the plastic melt. This reduced output further, to a maximum 300 kg per hour (see CeDo report section for further details).

As this figure did not meet the benchmark for normal production or the projected output for a PRF handing film, the project investigated alternative methods. A trial of intensive hand sorting was carried out at Plaswash, with moving conveyors and re-baling. Although the quality was high, the maximum throughput achieved in any one hour was around 400 kg (see film report section of this report).

The trial at Relux demonstrated that sorting rates of 1 to 1.5 tonnes per hour were achievable using NIR sorting and a Herbold mechanical recycling plant which size reduces the film to agglomerate. Devolatilisation of the pellet, when produced on alternative technologies, was successfully achieved at commercial rates, with demonstrated outputs of 1100 kg per hour recorded using a twin screw extruder (see film best practice section of this report).

**Rigid Fraction Processing Rates**

The PRF operating at 80,000 tonnes per annum will need to deal with an input of 25,000 tonnes per year of non-bottle, other rigid, plastics. This equates to a total throughput of 3.5 tonnes per hour.

The trial showed that existing throughputs in the LINPAC recycling plant for PP, coloured HDPE and PS all ran at similar throughput rates. De-baling, visual-inspection, shredding and sink/float sorting ran concurrently averaging throughputs in the wash plant section of 800 to 1,000 kg per hour.
Processing to pellet had average throughputs of 750kg per hour per extruder. The PRF model includes provision for processing the total recyclable fraction of these rigids including extruding to pellet, which will equate to 10,600 tonnes per year with an average throughput of 10.5 tonnes per hour. The wash plant and extrusion facility would be integrated with the processing of the bottle fractions of HDPE and PET to ensure maximum utilisation of equipment.

**Bottle Fraction Processing Rates**

The PRF will expect to receive a lot of mixed bottles within the ‘mixed plastics’ input. The composition of the input material from this trial indicates that around 31,000 tonnes per annum of bottles could be expected. At Closed Loop Recycling, Dagenham, material was received in bales, which were fed into an automated facility that includes NIR sorting machines and manual sorting. The plant is configured to handle an input of 35,000 tonnes per year. Throughputs of bottle to flake during the trial averaged 1.25 tonnes per hour over the whole trial. The sorting line ran at 5 tonnes per hour and the flake sorters ran at 2 tonnes per hour.

The PRF + reprocessing model for 80,000 tonnes per annum would require throughput rates for sorting of 5 tonnes per hour to process the estimated 31,000 tonnes of bottles.

HDPE and PET flake would be colour sorted at maximum throughputs of 1 and 2 tonnes per hour respectively. Flake would be allocated to one of 4 specialist extruders in the PRF, designed to process pellet to the polymer and purity required. Each extruder will be configured to run the materials at the predicted outputs i.e. film 2.0 t/hr, clear PET 1.5 t/hr, PP 1.2 t/hr, natural HDPE 0.7 t/hr and coloured PET 0.6 t/hr. These projections demonstrate that the trials conducted in this study were comparable or scalable to those that would be encountered in a large scale PRF.

**Technical Performance of Recycling Equipment**

The recycling equipment used in each trial represented full scale commercial processes using the most modern equipment and manufacturing techniques available in UK and Europe.

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**Figure 176.** From household plastics packaging waste to new products
Conclusions

Overall Project Conclusions

- There is potential for MRFs to be modified to accept and process mixed plastics from kerbside and retail collections. In some cases modification may be minimal.

- The majority of mixed plastics (films and rigids) can be reclaimed and reprocessed into replacements for virgin resins in a wide range of products.

- A combined ‘PRF + Reprocessor’ will have intrinsic efficiencies of operation in machinery utilisation and waste reduction

This project has conducted extensive investigations into the three questions at centre of this study on the recycling of mixed plastics. They were:

- How can plastics be sorted from other materials at a MRF?

- Does collection of plastics at retail outlets, such as supermarkets, have a role to play?

- How can mixed plastics be sorted by polymer type and reprocessed to produce high quality raw materials?

The results for the reprocessing of the highly contaminated films have been particularly significant as it is now possible to thoroughly devolatilise printed films that would have been previously considered unprocessable and discarded to landfill. This has been achieved by applying the technology derived from high performance food contact recycling processes to these materials.

Another result has been the recycling of polymers that have not commonly featured in the recycling of post consumer packaging materials i.e. PP and PS, into a wide range of commercially distributed moulding materials.

Equally important has been the achievement of food grade quality for resins based on clear PET and natural HDPE. Even though these products are based on very tight input and processing conditions based on bottle feedstocks, the inclusion of mixed plastics materials has not prevented the high standards from being achieved.

The better understanding of technical viability of mixed plastics recycling has revealed a potential pathway to the recycling of much more post consumer packaging beyond the plastic bottles and films currently being recycled.

This understanding will evolve further as commercial operations are established to exploit this large resource of plastics materials that have currently had limited end-of-life destinations. While the technical benefits to the environment and businesses involved in the production, use and recycling of these materials are now better understood, the implementation will strongly depend on the economic attractiveness of these operations and this explored in greater detail in the Financial Assessment Report prepared as part of this study.

The conclusions of this study are based on the discussions found in earlier sections of this report and are summarised below.

MRF Conclusions

**MRFs can recover large quantities of mixed plastics of at least the same magnitude as the plastic bottle stream from commingled domestic sources.** On average throughputs of 12 tonnes per hour in the MRFs were observed and the trials recorded 60% capture efficiencies for mixed plastics

**MRFs can sort mixed plastics (films and rigids) and this does not impact on the quality of other material streams.** Product quality from all MRFs was generally very high and the inclusion of mixed plastics did not adversely affect the value and quality of the MRFs existing material streams. Consistent level of feed on conveyors ensured high capture rates and quality of outputs with manual or automatic sorting. Paper quality observed during the trials was high, with only 0.2% of contamination recorded; although there was slight contamination from rigid plastics in aluminium and steel it was not considered high enough to reduce the accepted quality to end market customers.
MRFs need to remove films early in the separation process to minimise potential problems with sorting downstream. The report recommends the removal of film at the earliest stage possible and outlines low capital cost solutions for achieving this. Those MRFs not requesting plastic film still received plastic film as contamination and were required to separate it, especially where recycle was collected in plastic sacks;

**MRFs can use automated sorting techniques to improve purity of materials recovered.** Automated NIR sorting solutions were compared with manual alternatives and were found to provide higher recovery rates at the commercial throughputs. The sorting of all mixed plastics by Near Infra Red technology at a single stage should be considered.

**Retail Collection Conclusions**

Retail mixed plastics take back schemes provided excellent product quality with minimal cross-over from non-plastics packaging such as paper, glass, steel. Retail take back scheme provided cleaner plastics with minimal organic contamination when compared to MRF sourced materials. If plastics packaging can be kept separate from paper and other materials it can be sent directly to a PRF and high value polymers like PET, HDPE and PP can be readily recovered.

The mixed plastics returned to retail sites contained a high percentage of bottles. Although consumers were specifically asked for ‘mixed plastics’, (excluding bottles), the consumers did not differentiate between a plastic bottle, a plastic tray or a multi layer squeezable pack and 57% of all plastic returned was bottle packaging.

**PRF Conclusions**

The inclusion of film and glass in collections did not affect the operation of the PRF. Although glass and film were included in material collected from households it did not find its way through to the PRF and therefore had no affect on PRF performance.

**NIR sorting systems have difficulty identifying polymers that are black, causing higher rejection rates** Of the total residual material at the PRF, black plastic items amounted to 12.4% representing a significant loss of materials that could otherwise be usefully recovered.

**In general automated sorting equipment has higher capture efficiency for plastics than a manual sort facility.** The capture efficiencies for plastics at two manual sort system MRFs were 57% and 59% respectively. The capture rate for the PRF during the benchmarking trial using NIR sorting was estimated at 78%.

**Polystyrene can be lost passing through the MRF system** Polystyrene tends to be brittle and this is likely to be the reason for this loss, after baling PS packaging breaks into fragments and is lost together with other fines at the MRF stage.

**PRF + Reprocessing Conclusions**

Recycling of rigid mixed plastics in the UK is technically viable at commercial production rates. The major polymer groups were successfully sorted at commercial throughput rates using standard Near Infra Red (NIR) automatic sorting machines. They were then reprocessed at commercial scale operations in specialist plastic manufacturing sites within the UK.

Recycling of films on conventional film recycling equipment is difficult due to the level of contamination and the amount of printing. The complex mixture of materials found in films means that sorting is required before processing. Manual sorting systems are typically slow and costly. Even if these materials are processed via washing and sink-float steps, the recovered plastics typically contain high levels of volatiles and odours limiting their re-use in film products to less than 30%. The volatiles and odour have attributed to the presence of high levels of printing on the films.

**Recycling of films can be significantly improved through the use of advanced sorting and processing technologies.** The rate of sorting and processing of films can be enhanced by the use of shredding and automatic sorting equipment to improve quality and reduce contamination. The use advanced extrusion technology including melt filtration and high-level devolatilisation can produce plastic materials that have greatly reduced volatility and odour allowing the material to be re-used at levels of 50%.
The reprocessed plastics were successfully substituted for virgin materials in end-product applications.

- Polypropylene was recovered and blended into three different commercial moulding compounds at levels of 20% to 50% with varying specifications and successfully manufactured in final products for the transport, materials handling and horticultural industries that met all target specifications.

- Coloured HDPE was converted to pellets that were used to make pipe and conduit products at re-use levels of 100% while meeting all product specifications.

- Polystyrene from this trial and external suppliers of post consumer polystyrene was converted to pellets which was blended at 15% into a formulation for moulding hose reels meeting all performance requirements.

- Bales of mixed HDPE and PET bottles and rigids were sorted with automatic Near Infra Red (NIR) and manual sorting followed by granulation and washing.

- The natural HDPE packaging was converted to flakes and extruded into food contact quality HDPE pellet that could be used in food grade film and bottle applications. The HDPE flake was also extruded into a range of profiles used in outdoor applications meeting all performance requirements.

- Clear PET was reprocessed to food grade PET flake and extruded into sheet and thermoformed into food grade products. Coloured PET was segregated and end products successfully manufactured into PET materials handling strapping.

There are existing markets for the majority of the recycled plastics. All of the recycled resins were successfully integrated into end market applications at a range of recycling rates that varied from 15% to 100% replacing virgin polymers with no adverse effects on product performance. The use of the recycled plastics in blends allowed the specific properties of the packaging resins to be adjusted to the performance properties of end market applications.

New technologies such as ring extrusion systems can successfully produce high quality recycle film resins from mixed plastic film input. The trials successfully demonstrated a number of different extrusion technologies to extrude, filter and devolatilise mixed and heavily printed film material from UK post consumer streams.

A combined PRF + Reprocessor on one integrated site will have operational efficiencies and less residual waste through increased recovery yields. The maximum material recovery achieved by separated processing sites was 55% of total input while it is anticipated that an integrated PRF + Reprocessing site could achieve 60%.

Residues from sorting and reprocessing have high calorific values (greater than wood), which can be utilised for energy recovery The report describes technologies currently used to maximise reclamation of polymers from residual materials through the improved sorting performance and how The utilisation of wash plant waste to make an ideal fuel for a CHP plant is also explained.

19.0 Glossary of Terms

Air Classification - A system where items may be separated based on their various trajectories through an air stream.

CAPEX - Capital Expenditure.

Capture Rates- The proportion of a targeted material that has been collected rather than disposed of.

CHP - Combined Heat and Power.
Closures - Bottle tops, lids etc.

CPET - Crystalline Polyethylene Terephthalate.


End of Line material - Those materials that have not been positively sorted and separated as material travels through a MRF. Contains various co-mingled material streams which may be further processed.

Infeed material - The household recyclables derived from kerbside refuse collection schemes that are delivered to MRFs for separation. Consists of co-mingled material streams.

Gravimetric Assessment - A weight based measurement.

HDPE - High Density Polyethylene.

Input material - The household recyclables derived from kerbside refuse collection schemes that are delivered to MRFs for separation. Consists of co-mingled material streams.

LCA – Life Cycle Assessment.

LDPE - Low Density Polyethylene.

Mass Balance - Analysis of a process by considering the balance of mass flows through it.

Mixed Plastics - All non-bottle plastic packaging sourced from the household waste stream and includes rigid and flexible plastic items of various polymer types and colours.

m/min - Metres per minute.

MFI – Melt Flow Index

MFR – Melt Flow Rate

MRF - Materials Recovery Facility.

NPV - The present value of an investment’s future net cash flows minus the initial investment.

OPEX - Operating Expenditure.

PCR – Post Consumer Recyclate

PET - Polyethylene Terephthalate.

PP - Polypropylene.

PRF - Plastics Recovery Facility.

Product - Separated and sorted recyclable material streams such as HDPE, paper etc. These are baled and transported to downstream reprocessing plants.

PS - Polystyrene.

PVC - Polyvinylchloride.
Pyrolysis – Heating of plastics in the absence of oxygen causing the polymer molecule to fragment into liquid and gas fractions.

Residual material - The waste product from a MRF. This material is often subsequently landfilled.

Retrofit - Reconfiguration.

SRF - Solid Recovered Fuel.

Tonne/annum - Tonnes per annum.

Te/hr - Tonnes per hour.