Development and optimisation of a recycling process for PET pots, tubs and trays

Report of a series of process development and optimisation trials for PET pots, tubs and trays recycling

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Written by: Richard McKinlay and Liz Morrish

Front cover photography: Washed PET flake (left) and extruded PET (right) derived from post-consumer PET pots, tubs and trays

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Executive summary

Increasing the recycling of household plastic packaging (bottles, pots, tubs, trays and films) is a key aim for WRAP, enabling the conversion of this recycling stream into valuable materials and with the associated carbon benefits. Nearly 70% of all local authorities in the UK are now collecting pots, tubs and trays (PTTs), generating approximately 155,000 tonnes of material each year for recycling. Polyethylene terephthalate (PET) is a significant fraction of the mixed plastics waste stream and an increasing volume of this material is being seen by plastics recyclers in the UK. Despite collection of post-consumer PET PTT packaging developing there are still technical challenges to recycling this stream, as well as a need to develop and establish viable and stable end markets for the material.

The objective of this project was to design and deliver a series of trials to investigate and assess the key processing stages for clear PET PTT recycling. Following on from previous work conducted by WRAP, the focus of the trials was on improving the yield of the process and minimising the production of fines material (<2 mm). The aim was to further develop and optimise the PET PTT recycling process, including sorting, granulation, washing and extrusion. A financial assessment of clear PET PTT recycling was also undertaken to determine the commercial viability of the process.

‘PTT rich’ material was obtained from a UK Plastics Recovery Facility (PRF). The material was generated from a Materials Recovery Facility (MRF), where following separation of key streams such as paper, card, PET and high density polyethylene (HDPE) bottles, a residual stream is left. The PRF processes this residual stream to separate PET and HDPE bottles that were missed by the original sort, and to produce a PTT rich fraction.

Compositional analysis was undertaken on the PTT rich material. A total of 147.8 kg was hand sorted into 17 materials types/categories. The analysis showed that 58.3% of the material was bottles, 32.4% was PTTs, with the remaining 9.3% being other materials. This was a lower level of PTTs than expected, which reflects variation in the composition of the infeed material to the MRF at the start of the sorting process. The material was predominantly PET (94%), with the most significant fractions being clear and light blue bottles (42.9%), coloured PET bottles (15.4%), PET PTT with lidding film attached (16.6%) and clear PET PTT (12.5%). The presence of labels on the PET PTT packaging was also analysed, with 34% of the items being without labels, 40% having a paper label and 26% having a plastic label.

It is important to recognise that the composition of the material is a consequence of the material being sorted from a MRF residual stream. Primary sorting facilities focus on higher value streams such as PET and HDPE bottles and concentrate on removing PET PTT from these streams. The results of this project need to be read within this context.

1 Recoup ‘UK Household Plastics Collection Survey 2015’
If more PET PTTs were collected by local authorities and sorted as a target fraction by MRFs and PRFs, then the composition would change.

A series of processing trials were designed, planned and delivered. The trials took place at the test centres of leading technology and equipment suppliers (TOMRA Sorting, Herbold Meckesheim and Gneuss) and it replicated the whole recycling process from: Near Infrared (NIR) sorting to granulation, washing, drying, flake sorting and finally extrusion.

The first trial aimed to evaluate the use of NIR technology to sort PET PTT and bottles. Three initial optimisation tests were performed to identify the optimum settings to achieve the best balance between purity and recovery. The separation efficiency was very sensitive to changes to the equipment settings, with an increase in purity compromising on recovery levels and vice versa. The material was processed using the optimised settings achieving a suitable purity and recovery. This trial demonstrated that it is technically feasible to separate PET PTTs from PET bottles but it is a difficult separation to achieve. This is due to there being only subtle differences in the infrared spectra of the two types of PET. The result is that the separation efficiency achieved is lower than expected when separating two different polymer types, for example HDPE and PET.

The next trial was the granulation and washing stages of the process. Previous work conducted by WRAP identified that these stages were responsible for the generation of a high level of fines. The trial started by testing both wet and dry granulation techniques, which showed the wet granulation process to be more effective. The NIR sorted material was processed by using a wet granulator and a 15 mm screen. Following granulation the material was passed through a friction washer, a hot wash process (with a detergent and caustic soda at 80°C) and then a second friction washer. There were no problems processing the material through any of these stages. Problems were encountered with the hydrocyclone separator, which became blocked by the material. It was thought this was due to the PET PTT flakes being ‘plate like’ i.e. long, thin pieces. The overall granulation and washing process achieved a yield of 70%. The original input material to the series of trials was contaminated with non-PET material such as PE film and some metal from post-consumer packaging, which is a result of the material being sorted from a MRF residual stream. On a positive note the granulation and washing processes did not generate a high level of fines.

A mass balance for the trial was produced which showed that a high level of fines (51.5%) were generated as a result of the drying process. A centrifugal mechanical dryer was used which appeared to be too aggressive for the PTT material, despite being suitable for PET bottles. This is a key learning from the trials - pinpointing the stage in the recycling process which is responsible for the high level of fines.

The next stage of the recycling process to be trialled was flake sorting in order to remove non-PET contamination, in particular polyvinyl chloride (PVC) and polystyrene.

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(PS). The flake was screened at 2 mm, which is the lowest particle size the flake sorter can process material at. The screening process removed 42% of the material as fines, which is a very significant loss. Following the screening the flake sorter processed the material without any issues and achieved a suitable yield. Again this is a lower yield than would be expected when sorting PET bottle flake and is due to the presence of black plastics and non-target polymers.

The extrusion trial showed that in order to process <2 mm PET PTT fines, a modified extruder design is required. The intrinsic viscosity (IV) of the post-consumer >2 mm flake was boosted to 0.77 dL/g with an upward trend, almost reaching the target of 0.8 dL/g within the constraints of the trial. The IV boosting was also shown to be very successful on post-industrial PET PTT material for which the IV was increased to a target of 0.8 dL/g (to match post-industrial bottle flake). It can therefore be concluded that it is technically feasible to increase the IV of PET PTT to a point where it can supplement post-consumer bottle flake in new products.

The results and observations of the processing trials were used to develop an overall recycling process for post-consumer PET PTT. The process follows the stages trialled in this project; NIR sorting, granulation, washing, drying, flake sorting, extrusion and IV modification, with the addition of a preliminary shred (at 300 mm) and a manual sort to remove large items of contamination. All stages of the process have been demonstrated and optimised, with the exception of the drying stage which requires further work and development.

A key conclusion from the trials is that the infeed material to a PET PTT recycling process needs to be improved, with changes being made to the primary sorting at a MRF. A sorting process has been suggested of using two NIR sorters; the first NIR to sort a stream of PET bottles and PTTs and a second to sort PET PTT from PET bottles. There will always be a proportion of PET bottles in the PET PTT stream due to this being a technically difficult separation, but if a better quality PTT stream is produced by a MRF then this would have a positive effect on the process yield.

A financial assessment of PET PTT recycling has been undertaken, using an Excel model, to determine the commercial viability of the process. Data from the series of processing trials was used in the model, as well as additional data from the technology suppliers and from Axion’s own commercial reprocessing knowledge. Three scenarios were modelled and evaluated; the first to assume the PET PTT process is optimised and the production of fines minimised (scenario 1), the second scenario to accept the production of fines at a 50% level and to extrude the fines and flake (material >2 mm) together (scenario 2) and the final scenario to again accept fines production at a 50% level and to extrude the fines and flake separately (scenario 3). The model also considered the production and sale of both PET flake and pellet.

The results of the modelling exercise were that the production and sale of PET flake is unlikely to be commercially viable. This is primarily due to a lack of end markets for PET PTT flake, which means it has no significant value currently. The production and sale of PET pellet from PTTs is more viable. The best approach is scenario 2, to extrude the fines and flake material together, with investment in a recycling facility on this basis.
having a payback period of less than five years and a potential net revenue of £1.7 million per annum. The first approach of optimising the drying process and producing a much lower level of fines is also commercially viable, but with a slightly longer payback period (around six years) and a lower net revenue of in the region of £1.3 million per annum.

A sensitivity analysis was undertaken to determine the impact of changes in the sales revenue from PET pellet. This analysis showed the PET pellet needs to attract a market value of at least £700 per tonne for the recycling facility to be commercially viable, assuming a cost of the feed material at ~£50 per tonne. This might be challenging to achieve in today’s market and against virgin PET prices.

The generation of fines in the PET PTT recycling process is a key issue and the last technical challenge to be overcome. Desk research was undertaken to identify ways to minimise the production of fines material during the drying process and also techniques for recovering the fines so the fraction can be processed. Four equipment suppliers were consulted and asked for ideas on alternative drying techniques. Several suggestions were made and on the whole there was agreement that a very gentle drying process is needed. A mechanical dryer was proposed, with the potential to follow this with the use of a thermal dryer. These suggestions will need to be trialled and evaluated so that an optimum drying process can be identified.

Research into methods of recovering the fines fraction focused on ways to efficiently capture and separate the <2 mm material. Although the fines in the series of processing trials were collected and extruded without any issues, this may not be the case if an existing PET recycling facility processed PTTs. Four potential techniques were identified including a gravity separation table, hydrocyclones and electrostatic separation. Again these would need to be demonstrated and evaluated.

Overall the PET PTT recycling process has been shown to be technically and economically viable. More work is needed to find a suitable drying technique that will minimise the production of fines material. A very gentle drying process should be trialled and assessed, as this further optimisation will improve both the process yield and the economics of the process. Improving the infeed materials is also key to achieving a better yield and a more financially viable process. This includes more targeted collection of PTTs by local authorities and improved sorting at MRFs, so that a PTT rich stream is sorted as target material. This will have an impact on MRFs as additional sorting capacity and equipment will be required. Finally more work is needed to identify and establish longer term and stable markets for PET flake and pellet produced from PTTs, including demonstration trials to build confidence with end users and markets.
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<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMR</td>
<td>Dry mixed recyclables</td>
</tr>
<tr>
<td>ECS</td>
<td>Eddy Current Separator</td>
</tr>
<tr>
<td>EVOH</td>
<td>Ethylene Vinyl alcohol</td>
</tr>
<tr>
<td>IV</td>
<td>Intrinsic Viscosity</td>
</tr>
<tr>
<td>MRF</td>
<td>Materials Recovery Facility</td>
</tr>
<tr>
<td>Pa s</td>
<td>Pascal-second</td>
</tr>
<tr>
<td>PE</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>PET</td>
<td>Polyethylene terephthalate</td>
</tr>
<tr>
<td>PP</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>PRF</td>
<td>Plastics Recovery or Recycling Facility</td>
</tr>
<tr>
<td>PTT</td>
<td>Pots, Tubs and Trays</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>PS</td>
<td>Polystyrene</td>
</tr>
</tbody>
</table>

Acknowledgements

WRAP and Axion Consulting would like to thank the following companies that have supported this project through helping to deliver the processing trials and providing advice and information.

Amut
Gneuss
Herbold Meckesheim
Lintner washTech
Redwave
Sesotec
Sorema
Suez Environnement
TOMRA Sorting
Veolia UK
Viridor
1.0 Introduction

1.1 Background

A key aim for WRAP is to support UK businesses and individuals to realise the benefits of recycling household plastics packaging (bottles, pots, tubs, trays and films). Collection of these plastics is increasing in the UK and reprocessing infrastructure is being established to convert this recycling stream into valuable materials for use in the manufacture of new items, with the associated carbon benefits.

The UK's current plastic packaging recycling target is for obligated companies to achieve a 57% recycling rate by 2020. In order for this to be met the collection and reprocessing of pots, tubs and trays (PTTs) will need to increase. Latest data shows that nearly 70% of all local authorities in the UK are now collecting PTTs, resulting in approximately 155,000 tonnes per year.

Polyethylene terephthalate (PET) represents a significant fraction of the PTT packaging stream. There is already an established infrastructure for recycling PET bottles and if PET from PTTs could also be recycled, further carbon savings could be realised.

Plastic reprocessors in the UK are already seeing increasing volumes of PET PTT, primarily within the bottle stream, but as this fraction increases there is a need to develop and establish economically viable end markets for separated clear PET PTT material. There are also technical challenges that need to be overcome before clear PET PTT can be seen as a widely recyclable fraction of the post-consumer waste stream and more local authorities gain the confidence to collect this type of packaging for recycling.

WRAP has conducted previous work to investigate the development of end markets for the clear PET PTT fraction. This identified three key issues associated with PET PTT recycling, such as:

- A standard mixed PTT fraction is expected to attract a gate fee at a Plastics Recovery Facility (PRF). This is for material without PET bottles and with low levels of contamination. If there are PET bottles present in the fraction then the material may have a positive value;
- Clear PET PTT is a much more brittle material than bottle grade PET, as the material has a lower Intrinsic Viscosity (IV) which reduces mechanical strength. The recycling process generates significant yield losses due to fines material (<2 mm) being produced. It is thought the granulation and washing process developed for PET bottles is too aggressive for PET PTT and needs to be modified; and
- More thorough flake sorting is recommended as part of the PET recycling process, in order to remove contamination such as polyvinyl chloride (PVC) and polyolefins (polyethylene (PE) and polypropylene (PP)).

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4 Recoup. "UK Household Plastics Collection Survey 2015"
5 WRAP. "Developing End Markets for PET Pots, Tubs and Trays"
This project focused on further development and optimisation of the PET PTT recycling process by designing and delivering a series of trials to investigate and evaluate the key stages of sortation, granulation, washing and extrusion.

1.2 Aims and objectives
The aim of this work was to deliver a series of processing trials to further develop and optimise the PET PTT recycling process.

The objectives of the project were to:
- Design a series of processing trials to investigate the key stages of sortation, granulation, washing and extrusion for post-consumer PET PTT;
- Deliver a series of trials to develop and optimise the recycling process for PET PTT, with a particular focus on minimising yield losses and production of fines materials;
- Produce an economically viable clean PET recylcate that can be used in end market applications such as extrusion, moulding and compounding;
- Evaluate and determine an optimised process for PET PTT recycling; and
- Undertake a financial assessment of the optimised process to determine its viability.

A decision was made early in the project to process both clear and coloured PET PTT material during the series of trials, as this was thought to be a more realistic approach to recycling this waste stream at the current time. It may be possible in the future to focus on clear PET PTT once the economics of the recycling process have improved and the necessary collection, sorting and recycling infrastructure established.

2.0 Methodology
The project was delivered through practical compositional analysis, processing trials, desk based research and a financial and technical evaluation.

2.1 Compositional analysis
A source of post-consumer baled PTT was identified and purchased from a leading UK waste management and recycling company. The material purchased was used for both the compositional analysis exercise and the series of processing trials. The material was obtained from a Plastics Recovery Facility (PRF), which processed a MRF residual stream in order to obtain PET bottles, high density polyethylene (HDPE) bottles and a PET PTT stream.

Analysis of 147.8 kg was undertaken to determine the composition of the material. The bale was broken open and the material hand sorted into 17 material categories including clear PET PTT, coloured PET, black PET, PET bottles, glass, paper and metals. Each category of material was weighed and the data analysed to determine the composition. Samples from three different bales were taken to give a more representative sample for analysis.
2.2 Processing trials
A series of processing and optimisation trials were designed to evaluate and optimise each key stage of the PET recycling process; sorting, granulation, washing, flake sorting and extrusion. The trials were delivered at the test centres of leading technology suppliers: TOMRA Sorting Solutions\(^6\), Herbold Meckesheim\(^7\) and Gneuss\(^8\).

2.3 Technical evaluation and financial assessment
A technical evaluation was undertaken following delivery of the series of processing trials. The purpose of the evaluation was to determine a complete recycling process for clear PET PTT, optimised where possible. This was done by reviewing the results of the individual processing trials, in order to identify the overall process flow, key processing stages and equipment.

Alongside this, a high level financial evaluation was undertaken using an Excel model to determine the financial viability of the clear PET PTT recycling process. The model includes the costs and revenues associated with recycling clear PET PTT, using data obtained from the processing trials, the technology suppliers and supplemented by Axion’s own commercial knowledge of plastic reprocessing. The financial model was run to evaluate the viability of the process, through calculation of key indicators including payback period. In addition, a sensitivity analysis was performed to evaluate the viability of the process through three scenarios, with changes to key costs and revenues.

2.4 Desk based research
In addition to the series of processing trials, desk based research was conducted on two key technical issues related to clear PET PTT recycling. The first was minimising the production of fines material (<2 mm) and secondly techniques for recovering fines as a separate product stream. This research was delivered through internet research, as well as direct contact with technology and equipment suppliers.

\(^6\) www.tomra.com
\(^7\) www.herbold.com
\(^8\) www.gneuss.de
3.0 Results

3.1 Compositional analysis

Table 1 shows the composition of the PTT material. The sample was made up of 58.3% bottles, 32.4% PTTs and 9.3% other material. There was a higher proportion of bottles in the material than expected; typically the PRF PTT stream contains in the region of 45% bottles, as suggested by data collected on an on-going basis by the PRF.

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight (kg)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pots, tubs and trays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear PET trays and tubs</td>
<td>18.53</td>
<td>12.5%</td>
</tr>
<tr>
<td>Clear PET beverage cups</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Clear PET non-food packaging</td>
<td>0.84</td>
<td>0.6%</td>
</tr>
<tr>
<td>Clear PET PTT with lidding film attached</td>
<td>24.54</td>
<td>16.6%</td>
</tr>
<tr>
<td>Coloured PET trays</td>
<td>3.98</td>
<td>2.7%</td>
</tr>
<tr>
<td>Black PET trays</td>
<td>5.16</td>
<td>3.5%</td>
</tr>
<tr>
<td><strong>Sub-total</strong></td>
<td><strong>53.05</strong></td>
<td><strong>35.9%</strong></td>
</tr>
<tr>
<td>Bottles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear and light blue PET bottles</td>
<td>63.41</td>
<td>42.9%</td>
</tr>
<tr>
<td>Coloured PET bottles</td>
<td>22.74</td>
<td>15.4%</td>
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<tr>
<td>Other plastic bottles</td>
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<tr>
<td><strong>Sub-total</strong></td>
<td><strong>86.15</strong></td>
<td><strong>58.3%</strong></td>
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<tr>
<td>Other non-PET packaging (incl. PE and PP)</td>
<td>0.00</td>
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</tr>
<tr>
<td>Film/flexible packaging</td>
<td>1.82</td>
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<tr>
<td>Glass and stones</td>
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<tr>
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<td>1.34</td>
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</tr>
<tr>
<td>Organics</td>
<td>0.33</td>
<td>0.2%</td>
</tr>
<tr>
<td>Fines (&lt;20 mm)</td>
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<tr>
<td>Other</td>
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<tr>
<td><strong>Sub-total</strong></td>
<td><strong>8.6</strong></td>
<td><strong>5.8%</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>147.80</strong></td>
<td><strong>100.0%</strong></td>
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As can be seen in Figure 1 the sample was 94% PET material (139.2 kg), with the majority being clear and light blue PET bottles (42.9%), coloured PET bottles (15.4%), PET PTT with lidding film attached (16.6%) and clear PET PTT (12.5%).
The document discusses the development and optimization of a recycling process for PET pots, tubs, and trays. It includes figures showing the composition of PET and examples of hand-sorted PET PTT and PET bottle fractions. The figures illustrate the types of materials found in PET packaging, such as clear and light blue PET bottles, PET pots or trays with lidding film attached, coloured PET bottles, and others.

**Figure 1** Composition of PET

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Clear and light blue PET bottles</td>
<td>10%</td>
</tr>
<tr>
<td>PET pots or trays with lidding film attached</td>
<td>25%</td>
</tr>
<tr>
<td>Coloured PET bottles</td>
<td>15%</td>
</tr>
<tr>
<td>Clear PET trays and tubs</td>
<td>5%</td>
</tr>
<tr>
<td>Black PET trays</td>
<td>5%</td>
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<tr>
<td>Coloured PET trays</td>
<td>0%</td>
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<td>Fines (&lt;20 mm)</td>
<td>0%</td>
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<tr>
<td>Film/flexible packaging</td>
<td>0%</td>
</tr>
<tr>
<td>Metals</td>
<td>0%</td>
</tr>
<tr>
<td>Other</td>
<td>0%</td>
</tr>
<tr>
<td>Paper</td>
<td>0%</td>
</tr>
<tr>
<td>Clear PET non-food packaging</td>
<td>0%</td>
</tr>
<tr>
<td>Organics</td>
<td>0%</td>
</tr>
<tr>
<td>Clear PET beverage cups</td>
<td>0%</td>
</tr>
<tr>
<td>Other plastic bottles</td>
<td>0%</td>
</tr>
<tr>
<td>Other non-PET packaging (including PE and PP)</td>
<td>0%</td>
</tr>
<tr>
<td>Glass and stones</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Figure 2 and Figure 3** show examples of the hand sorted PET PTT and PET bottle fractions.

**Figure 2** Hand sorted clear PET PTT material
The presence and type of labels on the items of packaging was also analysed as can be seen in Figure 4. The analysis was undertaken on the clear and coloured PET PTTs and found that 40% of the packaging items had a paper label, 26% had a plastic label, with the remaining 34% having no labels. Knowing the type and level of labels present helps to determine the type of washing required. In this case due to the high level of labels it suggests a hot wash is required to remove the glue that will be present.

Figure 4 Presence and type of labels
It should be noted, that since PET PTT material is not currently a target material of value, little effort is made by the industry to recover this material to a high standard. In contrast, there is a demand for high purity PET bottle bales, and so MRFs and PRFs sort accordingly.

Therefore, if there were a demand for PET PTT bales of a high purity, then the composition would very likely be different to that measured and analysed in this project. In addition, if more local authorities collected PET PTTs and actively targeted them at the kerbside through householder communications then again the composition would vary.

As a result, the purpose of this project was to demonstrate the technical feasibility of processing this type of material, but the findings cannot correlate directly to what is likely to occur in the future if changes were made to the collection and primary sorting of PET PTT material.

3.2 Processing trials
A series of processing trials were delivered at test centres of technology suppliers TOMRA Sorting, Herbold and Gneuss. The material was processed at each individual trial stage and then transported to the next trial, to replicate the material following through an overall recycling process. Figure 5 shows the overall flow of processing trials that were delivered.

3.2.1 PTT and bottle NIR sorting trial

**Trial equipment**
The first trial in the series was an NIR sorting trial held at TOMRA Sorting's test facility in Mülheim-Kärlich in Germany. The purpose of the trial was to evaluate the efficiency of NIR technology to separate PET bottles and PET PTTs. The NIR signal from a PET PTT is slightly different from that of a PET bottle as different grades of PET are used to manufacture the packaging.

A TOMRA Autosort unit was used for the trial, with a 1m conveyor belt and a belt speed of 3m/s. Figure 6 shows a schematic of an NIR sorter.

**Trial material**
Approximately 6.5 tonnes of PET ‘PTT rich’ material was obtained and transported to the TOMRA Sorting test facility (Figure 7).

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Figure 5 Flow of PET PTT processing trials

1. PET bottles and trays
2. TOMRA: NIR sortation to remove bottles from trays
3. Herbold: Granulation trials to minimise fines
4. Herbold: Washing to remove contamination but reduce material loss
5. TOMRA: Flake sorting to remove PVC
6. Gneuss: Extrusion and IV modification
Optimisation of NIR sorter
Initially three small scale optimisation trials were carried out on the NIR unit (~20 kg per sample); this allowed the engineers to test and evaluate different settings, to visually assess the material and optimise the equipment settings by changing the sensitivity of the unit.

Figure 6 Schematic of NIR sorter

Figure 7 Close up of PET ‘PTT rich’ material

Image provided by TOMRA
On visually assessing the trial material it was clear that it contained a lower proportion of clear PET PTTs than expected, due to variation in the feed material to the PRF. This was confirmed by the compositional analysis undertaken, which measured the clear PET PTT level to be 32.4% as reported in Section 3.1. Optimisation tests showed that with a single pass, a compromise was required between purity and recovery as is usually the case with NIR separation. The unit was optimised to give a satisfactory recovery and purity to enable further testing.

**Trial results**

The final optimisation settings were chosen as the optimum balance between recovery and purity levels and were used to process the bulk of the trial material (6.42 tonnes). The material processed without any issues. Three samples were taken during the trial, which were hand sorted to calculate the composition of the material. The three compositions were used to calculate an average composition for the trial material and PET PTT and PET bottle sorted material.

The purity and recovery observed were satisfactory for the trial and clearly demonstrate the ability of NIR to sort PET tray from PET bottle material. In total 2.2 tonnes of PET tray rich material was recovered. This contained 61% PET tray material as opposed to the infeed which contained only 28% tray material.

**Figure 8 Sample of PET PTT product**

The trial demonstrated that PET bottles and PET PTT can be separated using existing NIR technology. It is a technically difficult separation as there is only a subtle difference in infrared spectra between PET PTTs and PET bottles. This results in the sorting efficiency being lower than is typically expected for a NIR sorting unit separating two different polymers, for example HDPE and PET. This will also mean that the PET PTT sorted material is likely to always contain a proportion of PET bottles. In order to improve purity or recovery levels further there would need to be a second pass of the material through the NIR sorting unit.
Identification of multi-layer PET PTT

The trial carried out with TOMRA focused only on separating PET PTT from PET bottle. This practical trial did not consider the potential to separate ‘multi-layer’ from ‘mono-layer’ PET PTT. When considering multi-layer structures, it must be appreciated that this is a very broad term, and may refer to a structure that is an A-B-A all PET structure where the middle layer is made from recycled PET. It could also however refer to a structure that has a polyethylene layer or an Ethylene Vinyl Alcohol (EVOH) layer which is a very different structure. The reason for removing structures with non-PET components would be that it would help to ensure a high quality, clear rPET can be produced.

Four of the major European NIR technology providers were contacted to discuss the separation of multi-layer PET packaging. One of the companies was not confident that the NIR technology would have the ability to carry out this degree of sortation, however the other three companies felt that the more different material that is present, the more possible the detection.

Research carried out on flexible packaging sortation\textsuperscript{11} has shown that flexible laminates with different structures (for example PET/PE, Polyamide (PA)/PE and PE/polypropylene (PP)) can be detected very effectively and that the NIR signal is affected by not only the surface layer of the packaging.

To further consider the separation of multi-layer PET the term must first be defined clearly and research should be carried out into what packaging structures are on the market and in what quantities. Since the separation between PET bottles and PET PTT using NIR technology has been shown to be sensitive, it is likely that introducing an additional processing step to sort the material further would result in a reduction of yield and an increase in costs. Therefore the economic benefits of sorting multi-layer packaging from mono-layer packaging must be considered more fully and a conclusion reached on if it is a necessary and viable processing step.

\textsuperscript{11} Project REFLEX
3.2.2 Granulation and washing trial

**Trial equipment**
Following the NIR sorting trial the material was transported to Herbold’s test centre in Meckesheim, Germany. The purpose of this trial was to demonstrate and evaluate the granulation and washing stages of the recycling process. It was thought from previous WRAP work that the high level of fines was due to the granulation and washing process, so the trial aimed to maximise the yield achieved and minimise production of fines during these stages of the overall recycling process.

For the granulation trial a SMS 45/60 wet edition granulator was used. This equipment can be operated wet or dry and uses an open guillotine rotor, giving the minimum possible friction which is needed for brittle PET material. Both 15 mm and 20 mm screens were used for the initial granulation optimisation trials.

The washing trial used a hot wash process to remove glues and contamination such as fats, oils and grease. The process uses a detergent and caustic soda at 80°C, followed by a friction washer to remove the contamination by forcing the material through a screen with a 2-3 mm mesh. **Figure 9** shows the inside and outside of the friction washer equipment.

![Figure 9 Inside (top) and outside (bottom) of friction washer](image)

The material was then processed through a hydrocyclone to remove PE and PP. Finally, the flake was dried using a mechanical centrifugal dryer. **Figure 10** shows the overall granulation and washing process with the key process stages as described above.
**Trial material**
The material used for the trial was the NIR sorted PET PTT, with a composition of 61% PTT and 39% bottles. Approximately 1.7 tonnes of material was transported to the Herbold test centre. This is the same material as is shown in Figure 8.

**Trial results**
The first part of the trial involved evaluating both wet and dry granulation techniques. A small sample (approximately 100 kg) was granulated using the two techniques, with both 15 mm and 20 mm screens. The results were that a wet granulation technique produced less fines than dry granulation. The larger screen size (20 mm) generated less fines as expected but the granulated material would be too large for the planned extrusion trials, so could not be used for this optimisation process. Figure 11 shows the size distribution of the granulated material and Figure 12 shows samples of the four sets of material.
Based on these results a wet granulation technique with a 15 mm screen was used to process the bulk of the material (1,746 kg). No processing issues were encountered during this part of the trial. If the extruder could be fed with larger particles, then a 20 mm screen could be used for size reduction, however this was not possible during this study.

Following the granulation process the material went through a friction washer, a hot wash and a second friction washer. The material again processed without any issues.

Problems were encountered during the separation stage of the process. The hydrocyclone became blocked, which was thought to be due to the different geometry of the PET PTT flake compared to PET bottle flake. The PTT flake is ‘plate like’, with a large diameter to thickness ratio resulting in large, thin flakes. Due to the blockage, modifications were made to the hydrocyclone, during which some material was lost before the system was corrected.

The overall yield of the granulation and washing process was 70%. The loss of material was mainly at the friction washer after granulation and at the separation stage to remove polyolefin material. **Figure 13** shows the overall process flow and mass balance for the granulation and washing trial.
Figure 12 Granulated PET PTT using wet and dry techniques and 15 mm and 20 mm screens
The results show the PTT had relatively high levels of contamination resulting in a loss of material and a 70% yield overall. This is due to the PET PTT stream being produced from a residual stream from a MRF and is not classed as target material. The yield from the granulation and washing process could be improved if PTT was a target fraction at the collection and primary processing stages, as a better infeed material with a greater proportion of PTT and lower levels of contamination would have a positive impact on the process yield.

At the start of the project it was thought that the high levels of fines generated by the PET PTT recycling process was due to the washing and granulation technique. This trial has shown that granulation and washing are not generating a significant level of fines (less than 5%). The results of the mass balance show that it is the drying process that has generated the excessive level of fines material (<2 mm). Figure 14 shows the size distribution of the particles after each stage of the granulation and washing process.
As can be seen above there is a slightly lower percentage of fines at the hot wash stage than the wet granulation stage as some of the fines generated by the wet granulation process will have been removed by the friction washer, although this difference is unlikely to be significant.

Figure 14 shows that just over 50% of the material was classified as fines after the drying process. This is a very significant level of fines production. The fines were not removed as waste but were in the product stream. A mechanical centrifugal dryer was used for the trial which had been designed for PET bottles and was thought to be suitable for PET PTT, but the high level of fines generation shows that the drying process is still too abrasive for PTT material. This is a key result and learning of the trial; to pinpoint the stage in the recycling process where fines are being generated is very useful. The drying process for PET PTT will need further optimisation work and some ideas have been suggested for other drying techniques in Section 3.3.5.

### 3.2.3 Flake sorting trial

**Trial equipment**
The next trial in the series took place at TOMRA Sorting’s test centre in Mülheim-Kärlich, Germany. The purpose of the trial was to evaluate a flake sorting process to remove non-PET material. There are concerns about the presence of both PVC and PS in the PET PTT stream and PET recyclers need these contaminants to be removed.
The trial used a TOMRA Autosort flake sorter, which works through a combination of NIR and camera sensors, characterising particles by both shape and polymer type. A schematic of the flake sorter can be seen in Figure 15.

**Figure 15 Schematic of flake sorter**

![Schematic of flake sorter](image)

The NIR cannot detect the polymer type of black plastics but the camera sensors in the sorting unit can see and eject black particles. This is due to the particles being detected in flight rather than on a belt as there is a contrast between the particles and surrounding empty space.

**Trial material**

The material used for this trial was the washed flake produced by the previous granulation and washing trials. A total of 560 kg of flake material was transported to TOMRA's test facility. The washed PET PTT flake can be seen in Figure 16.

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12 Image provided by TOMRA
On visual inspection of the material it was apparent that there was a high presence of fines (<2 mm). The Autosort flake sorter can only process material greater than 2 mm, so the flake needed to be screened. The material also had a slight residual moisture content, which is likely to be due to the presence of fines material which hold more water than larger sized particles. There was also some aluminium present so the flake material was processed through a zig zag air separator to dry the material and also an Eddy Current Separator (ECS) to remove the metal contamination.

**Trial results**
As explained above, the flake material required some additional processing before being passed through the flake sorter. The overall process can be seen in Figure 17.

Following screening of the material to remove the fines, optimisation tests were run on small samples of the flake (~2 kg) in order to determine the optimum settings for the flake sorter. The bulk of the material was then processed using these settings.
The flake sorter uses a recycle loop to process the reject stream. This is standard operation in the unit although for the purposes of the trial the recycle loop was fed manually. **Figure 18** shows how the two-pass system works.

**Figure 18 Flake sorter configuration**

A full mass balance was carried out for the trial, which can be seen in **Figure 19**.

**Figure 19 Overall flake sorting trial mass balance**

The results show a significant loss of material at the initial screening stage, when 42% of the material was removed as fines. **Figure 20** and **Figure 21** show the fines material that was separated.
Following this there was only a minimal loss of material through the zig zag air separator and ECS, 1.4% in total. A mass balance of the flake sorter was also calculated, which can be seen in Figure 22.
The flake sorter achieved a yield of 72%. This is a lower yield than would be expected when processing PET bottle flake, which is typically less than 95%. The reason for the fairly low yield is the presence of black plastics and non-target polymers in the material rather than due to the sorting machine efficiency.

Figure 23 shows the product and reject streams, with the reject stream containing more opaque material, however some target material was removed due to ejection efficiencies and an over-sort due to high contamination levels.
This trial has demonstrated that sorting of PET PTT flakes is achievable but the yield attained is fairly low. This is due to the PET PTT stream being produced from a residual MRF stream, so contains lower grade material.

It would not be possible to operate the recycle loop under commercial operating conditions with the current composition of PET PTT flake, due to the high contamination levels. A second flake sorting unit would be required to process the reject stream material.

The sorted flake has been analysed for chlorine levels. Since chlorine accounts for 50% of the mass of PVC, the PVC content can be estimated from the chlorine levels. The results of the chlorine analysis are given in Table 2.

**Table 2 Chlorine analysis of flake sorter outputs**

<table>
<thead>
<tr>
<th>Material</th>
<th>Chlorine content</th>
<th>Estimated PVC content</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2 mm PET PTT sorted flake product</td>
<td>0.02%</td>
<td>0.04%</td>
</tr>
<tr>
<td>&lt;2 mm PET PTT flake</td>
<td>0.04%</td>
<td>0.08%</td>
</tr>
<tr>
<td>&gt;2 mm flake sorter reject</td>
<td>1.25%</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

The analysis shows a clear effect of the flake sortation process in the removal of PVC. The flake sorter reject material had a significantly higher level of PVC (estimated to be 2.5%) than the sorted flake product (estimated to be 0.04%). Interestingly the fines had a very low PVC content, and this material was not flake sorted. It could be the case that the PVC does not break up as much as the PET PTT and so is less likely to be recovered as fines. This also indicates that the fines material could be extruded without flake sorting.

### 3.2.4 Extrusion and intrinsic viscosity boost trial

**Trial equipment**

The final trial in the series utilised the Gneuss MRS extruder with an intrinsic viscosity (IV) jump reactor. The extruder is designed for PET processing, in particular for the production of food grade recycled PET derived from post-consumer bottles. The extruder uses an innovative screw configuration to maximise the surface area of the polymer in the melt phase, thus making de-gassing more effective. Figure 24 shows an image of the jump reactor.
The molten polymer exiting the extruder is then fed into an IV “jump reactor”. Jump reactor is the name given to the IV boosting reactor developed by Gneuss. Conventionally the PET is extruded into pellets and then the pellets are treated in a solid state reactor to remove the volatiles and increase the IV. IV needs to be increased to allow the recycled PET to be used back into thermoformed applications, otherwise there are limited end markets for the recycled polymer.

The benefit of the IV jump system is there is a continuous flow of material from the extruder into the reactor, and the energy within the molten polymer is not lost when the material is pelletised. The material exiting the IV jump reactor is pelletised.

The extrusion and IV jump unit are equipped with viscosity monitoring equipment. The viscosity of the material exiting both the extruder and the reactor is continuously measured. It is important to note that during extrusion, the IV reduces, and then in the reactor the IV is increased. Figure 25 shows how the IV is expected to change within the extrusion and reaction unit.

**Figure 24** Gneuss jump reactor

![Gneuss jump reactor](image)

**Figure 25** IV profile during extrusion and reaction

![IV profile diagram]
The extrusion unit used for the trial is designed to give a throughput of 200 – 300 kg/hr. It should be noted that the extruder used for the trial is designed for post-consumer bottle material, and if an extruder were to be designed for post-consumer PTT material there may be some difference in the feeding and screw design to account for the differences in material (namely the shape and size).

In addition to the extruder and IV jump reactor, a crystalliser was used to crystallise some of the trial material (the post-industrial flake and the <2 mm PET PTT fines from the flake sorting trial). Crystallising the material prevents the thin amorphous material from becoming ‘sticky’ when introduced to heat in the feed to the extruder which can cause blockages. This is not needed when processing bottle flake as this tends to be thicker, more rigid pieces which are less susceptible to creating blockages. Crystallisation was not needed for the >2 mm flake as the material contained some bottle flake along with the PTT material which would help prevent blockages.

**Trial material**
Three materials were used for the extrusion trial (Figure 26):

- ≈2 tonnes of post-industrial PET PTT re-grind was used to set up the extruder. The material was supplied by a packaging convertor in the UK and is size reduced out-of-specification material that is usually fed back into the process.
- ≈500 kg of washed post-consumer PET PTT >2 mm flake product from the previous flake sorting trial; and
- ≈500 kg of washed post-consumer PET PTT <2 mm fines from the flake sorting trial.

**Figure 26 Feed material for extrusion trial**

Prior to the extrusion trial, the post-industrial flake and the <2 mm fines were processed through a crystalliser to crystallise the PET PTT material to prevent blockages in the extruder. This was needed as the extruder infeed and screw have been designed for bottle flake rather than PTT flake. In practice the extruder could be designed to take the PTT material without requiring crystallisation (for both the flakes and the fines). Figure
Figure 27 Post-industrial PET PTT before (left) and after (right) crystallisation

27 shows the postustrial PET PTT flake before and after crystallisation; the crystalline material is opaque.

**Trial results**

The extrusion and IV jump reactor has a residence time (the time taken from feeding the material into the extruder until it exits the IV jump reactor) of approximately 40 minutes. The post-industrial material was used to set up the extrusion process to ensure the correct settings were being used to modify the IV of the material. A target IV was set at 0.8 dL/g as this is the IV of PET bottle flake. This relates to a viscosity of approximately 1,800 Pa s (Pascal-second).

Since IV is a static measurement, it is not possible to measure the IV in line. However, it is possible to measure the dynamic viscosity (also measured in Pa s) which can be related empirically to the IV. A continuous log of the extruder settings and the viscosity of the PET before and after the IV jump reactor was recorded.

The process of setting up the extruder with the post-industrial flake took several hours. After the process was at steady state and the target IV was reached, the post-consumer <2 mm fines were fed into the reactor. The bag into which the output pellet material was collected was changed after 40 minutes to ensure the sample was derived only from the trial material and was not a mixture of the post-industrial and post-consumer material. Once the <2 mm fines were consumed, the >2 mm flake was processed and again the bags were changed at an appropriate time to ensure a sample of pellet derived only from the PET PTT flake was obtained.

Some processing issues were observed with the <2 mm fines. Due to the high bulk density of the material it resulted in overfeeding of the extruder. The effect of this was that the vacuum extraction port became filled with material, resulting in less efficient devolatilisation (removal of volatiles). This problem was associated to the design of the
extruder, and if the fines were to be processed commercially the design of the extruder could be modified to prevent such issues from occurring.

There were no processing issues noted with the post-consumer >2 mm PET PTT flake, or the post-industrial PTT material.

**Figure 28** shows the output viscosity from the IV jump reactor over time. The sections have been split up to show which material was exiting the reactor. It should be noted that the higher the IV, the higher the viscosity.

The IV was also measured on a sample of the pellet. **Table 3** gives the average reactor input viscosity (which was very consistent), the achieved reactor output viscosity and the IV measured on a sample of pellet.

<table>
<thead>
<tr>
<th>Material</th>
<th>Reactor input viscosity (Pa s)</th>
<th>Achieved reactor output viscosity (Pa s)</th>
<th>Reactor output IV (dL/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-industrial flake</td>
<td>400</td>
<td>1,800</td>
<td>0.800</td>
</tr>
<tr>
<td>Post-consumer flake</td>
<td>250</td>
<td>1,500</td>
<td>0.770</td>
</tr>
<tr>
<td>Post-consumer fines</td>
<td>150</td>
<td>1,000</td>
<td>0.690</td>
</tr>
</tbody>
</table>

The data shows that the post-industrial flake had a consistent output viscosity in the region of 1,800 Pa s. Due to the material not being contaminated, it was possible to quickly optimise the IV reactor to give the desired output viscosity. The IV of the pellet derived from the post-industrial flake reached the target of 0.8 dL/g.
This result demonstrates the technical feasibility of increasing the IV of recycled PET derived from PTT. Providing a post-consumer PET PTT flake could be made to a high purity with a consistent particle size, then the increase of IV to allow the PET to be used in place of post-consumer bottle flake is feasible.

However, when processing the post-consumer fines, the output viscosity dropped significantly. This could be as a result of non-PET contamination (such as PVC) which although at low percentages, can still have an effect. This non-PET contamination is however not present in the post-industrial material. In addition, due to the extrusion issues encountered with the fines (over feeding) this had a knock on effect of reducing the residence time within the reactor and also would have reduced the devolatilisation efficiency. This is shown by the input viscosity to the reactor being so low. The result of the combination of these factors meant that a target viscosity of 1800 Pa s could not be reached. With additional time and material and an extruder more optimised to the processing of fines, it is likely that the IV could have been modified further by optimising the IV jump reactor.

When processing the post-consumer flake, there was a clear trend of increasing IV as the reactor was reaching steady state. The input viscosity to the reactor was higher for the flake material than the fines, although it was lower than the post-industrial material, likely due to residual contamination. Since the reactor requires such a large volume of material it is difficult to fully optimise the system in a trial environment. Gneuss felt that further, continued operation could lead to being able to achieve the desired output viscosity for the post-consumer PET PTT.

The trial has demonstrated the technical feasibility of increasing the IV of recycled PET from PTT to a target of 0.8 dL/g when using post-industrial material. When using post-consumer material increasing the IV is more challenging and the entire extrusion process needs to be optimised which is not feasible in a trial environment, however the data is very promising.

3.3 Evaluation of PET PTT recycling process

3.3.1 Overview of process development and optimisation
The purpose of this series of processing trials was to further develop and optimise the recycling process for PET PTT. Previous work has been conducted to establish a recycling process but there remained technical issues to be resolved. The trials delivered within this project have recycled a PET PTT material stream, sourced from a MRF and PRF and by processing the material through six stages; PET PTT and PET bottle separation using NIR sorting technology, granulation, washing, drying, flake sorting and finally extrusion with IV modification.

From the practical trials delivered, it has been demonstrated that it is possible to sort PET PTTs from PET bottles using NIR technology. The trials have also shown that PTTs can be successfully granulated and washed, with the generation of fines being minimised up until the point of drying without further process optimisation. Drying is
the processing stage where excessive fines are produced, even when using a drying technique designed for PET bottles.

**Figure 29** presents a proposed process flow for PET PTT recycling based on the processing trials carried out in this project. The processing trials delivered gave a strong indication to the technical feasibility of all processing stages aside from the drying stage.

**Figure 29 Proposed process flow for PET PTT recycling**

The initial shredding and pre-sorting stage will be necessary to break up the baled material prior to the main processing steps. A simple single shaft shredder is recommended to reduce the material to a particle size of 300 mm. The pre-sortation stage would be a simple manual sort to remove any large items of non-target material such as large pieces of metal, non-PET plastic and wood. It is unlikely these items would be present, however experience has shown even in sorted plastic bales large non-target items can be present which can damage downstream processing equipment.

The remainder of the PET PTT recycling process is based on the trials demonstrated in this project; NIR sorting, wet granulation, hot wash and separation, mechanical and thermal drying, flake sortation, extrusion and finally IV modification.

As mentioned above following this project it is only the drying stage that now requires further optimisation. Discussions have been held with several suppliers of washing equipment and suggestions have been made of potential methods that could be used to reduce the moisture levels sufficiently (to below 1%) without generating excessive fines; these options are discussed in Section 3.3.5. An alternative approach would be to assume that the production of fines material is unavoidable and to process the fines; this option is considered in the financial assessment in Section 3.3.3.

Establishing end markets and applications for recycled PET PTT is still a key requirement. It is unlikely that a market can be found for a recycled PET with a low IV, which has been
one of the barriers to recycling PET PTT in the past. Therefore, IV modification to increase the IV is included as a final stage in the overall recycling process, as can be seen in Figure 29. In addition, it is likely that the colour of the recyclate will be ‘off-white’ and therefore coloured material applications such as non-food contact thermoform application (for example horticultural trays) may be the most feasible end use.

3.3.2 Improving the infeed material of PET PTTs
This project has shown that improving the quality of the feed material for a PET PTT recycling process is key, in terms of improving the yield achieved and reducing levels of contamination. The presence of PET bottles in the feed material is not detrimental to the processing of PET PTT material. It is within the interests of waste management companies to separate a high purity PET bottle product (>95% bottle), as there is an established demand for this material. The separation between PET PTTs and PET bottles using NIR technology is sensitive and technically challenging. The process is limited to producing either a pure PET bottle fraction or a pure PET PTT fraction, and cannot do both. Therefore, it is inevitable that there will always be a mix of PET bottles and PET PTTs, along with some non-target contamination.

Defining the likely mix of PET bottle and PET PTT material is difficult and ultimately depends upon the feed composition to the primary MRF sorting process and therefore the target materials collected by local authorities. At the time of this study, PET PTT material is not a target material for many local authorities and MRFs and as a result is sorted to the MRF residue stream or mixed plastics product stream. In practice, the mix achievable if PET PTT was targeted for local authority collection and at the MRF is not yet known.

The volume of PET bottles and PET PTTs placed on the market is estimated to be fairly similar; in 2014, 397,000 tonnes of PET bottles were placed on the consumer market versus 278,000 tonnes of PET PTT\footnote{Plastics Market Situation Report Spring 2016, WRAP}. Therefore, in theory, the quantity of PET bottles and PET PTT within the feed to a MRF could be more or less equal. However, this would represent a significant change in householder behaviour, and it is likely that initially the quantity of PTTs collected will be significantly lower than quantity of bottles collected, until new recycling habits are formed and the volume of PTTs collected increases.

Figure 30 shows how a PET PTT material stream could be separated at a MRF processing dry mixed recyclables (DMR).
The front end processing stage would likely consist of a trommel, ballistic separator and/or windshifter, magnet and ECS to produce a mixed 3D plastics stream.

The mixed 3D plastics stream could then be separated using NIR sortation. The first NIR unit could be set up to eject all PET materials and ejecting other polymers (HDPE, PP and PS), and then a second NIR unit could eject PET bottles in order to meet the >95% purity requirements of PET bottle recyclers (this material could be sorted further to remove coloured PET). Assuming an infeed where there is initially a 2:1 ratio of bottle:PTT, it is reasonable to assume therefore that a PET PTT material could be separated that is 70% PTT and 30% bottle (excluding contamination).

If contamination is assumed on a dry basis to be 5% (this would be residual metal, paper and polyolefin packaging (PE and PP)) and on a wet basis the material is 5% moisture and 10% labels, dirt, and FOGs (fats, oils and grease), then the infeed composition used for the financial assessment modelling in Section 3.3.3 can be assumed to be that shown in Table 4.

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Figure 30 MRF sortation process to recover PET PTT
It is important to note this is a different infeed composition than was processed during this series of trials. This assumes that there are greater volumes of PTTs being collected from the post-consumer waste stream and that PTTs are being targeted at the MRF primary sorting stage, rather than being recovered from the MRF reject stream.

### 3.3.3 Financial assessment

**Modelling assumptions and scenarios**

Following delivery of the practical trials to demonstrate the recycling process stages for PET PTT, an assessment of the financial viability of the proposed process has been undertaken.

An Excel model was developed and used for the assessment, which has been carried out on using a 2 tph feed basis. This is a standard size for a washing and extrusion process for plastic packaging recycling.

The model used for the financial assessment is based on the overall recycling process presented in Section 3.3.1. Three scenarios have been included in the model based on discussions held with technology and equipment manufacturers and suppliers, as to whether the process would minimise the generation of fines through optimisation of the drying process stage or whether the production of fines is an unavoidable part of the recycling process and therefore the fines will need to be processed. The three scenarios considered are:

- **Scenario 1**: Fines generation has been minimised to 5% through optimisation of the drying process although fines must be removed before extrusion. The fines are rejected prior to flake sorting and are assumed to be sold at £300/tonne to reflect the fact the material is washed and PET rich. A sensitivity analysis has been carried out as part of the assessment to consider the effect of a greater level of fines production;
- **Scenario 2**: Fines are generated at 50% and an extruder designed to take a mixture of the <2 mm fines and the > 2 mm flakes; and
- **Scenario 3**: Fines are generated at 50% as seen during this series of trials, and a separate extruder is used to process the fines.

<table>
<thead>
<tr>
<th></th>
<th>Dry</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET PTT</td>
<td>67.5%</td>
<td>57.4%</td>
</tr>
<tr>
<td>PET bottle</td>
<td>27.5%</td>
<td>23.4%</td>
</tr>
<tr>
<td>Non target</td>
<td>5.0%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Moisture</td>
<td>5.0%</td>
<td></td>
</tr>
<tr>
<td>Fibre/FOG/dirt</td>
<td></td>
<td>10.0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
In addition to the three processing scenarios, the opportunity of selling the output material as a flake or as a pellet has been considered with an assumption that end market applications exist for both. As discussed above the end markets will need to utilise a non-clear PET and these applications and end uses are still to be determined and established.

It is likely that the IV modified pellet material would be used in non-food contact manufacturing applications. Trays of this kind currently use post-consumer PET bottle flake and post-industrial PTT flake. It is likely that the post-consumer PTT material would displace, or supplement, the PET bottle flake (assuming the IV of the PTT flake has been increased), allowing the bottle flake to be used back into bottles, ultimately displacing virgin PET.

Finding and establishing a market for the PET PTT flake would be more challenging. The IV of this material would not be modified in the overall process, and therefore it would be the same quality (from an IV point of view) as the post-industrial scrap material. This post-industrial scrap cannot be displaced as it is generated and recycled in-house, and therefore an alternative market would need to be found for the flake material.

Table 5 gives the key equipment required for the processing of the post-consumer PET PTT based on the process flow in Figure 29. Prices have been presented in euros as received by suppliers.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Budget purchase price (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIR sorter</td>
<td>€300,000</td>
</tr>
<tr>
<td>Granulator</td>
<td>€170,000</td>
</tr>
<tr>
<td>Hot wash</td>
<td>€540,000</td>
</tr>
<tr>
<td>Friction washers</td>
<td>€60,000</td>
</tr>
<tr>
<td>Hydrocyclone system</td>
<td>€180,000</td>
</tr>
<tr>
<td>Mechanical dryer</td>
<td>€50,000</td>
</tr>
<tr>
<td>Thermal dryer</td>
<td>€60,000</td>
</tr>
<tr>
<td>Water treatment plant</td>
<td>€100,000</td>
</tr>
<tr>
<td>Flake sorter</td>
<td>€350,000</td>
</tr>
<tr>
<td>Extruder</td>
<td>€1,300,000</td>
</tr>
<tr>
<td>IV booster</td>
<td>€700,000</td>
</tr>
</tbody>
</table>

In order to estimate the capital investment required for a PET PTT recycling facility, these purchase costs have been converted to pounds (£) and used together with the cost of necessary ancillary equipment (shredder, conveyors, bagging stations, etc.) and installation. In order to estimate the operating costs for such a facility, the power.

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15 These prices are quoted as an indication only and are not based on formal quotations from equipment suppliers. Prices are from discussions with equipment suppliers May 2016

16 Conversion rate of 1.2 used for modelling exercise
consumption of the units has been considered along with labour, maintenance and overheads (office costs, rent, etc.)

The capital expenditure (capex) and operational expenditure (OPEX) differ for the three scenarios and depending on if extruded pellet is made or if just PET flake is produced. Scenario 2 is assumed to have a slightly higher Capex than Scenario 1 due to the need for a more sophisticated extruder. The difference in Scenario 3 is that two extruders and IV jump reactors will be required to process the fines fraction separately from the flake material. A mass balance has also been calculated to determine the loss of material and yield.

The recycled PET pellet has been given a value of £800/tonne. In the current market (June 2016), this is likely to be on the high side as this is closer to the value of virgin polymer. A sensitivity analysis has been carried out as part of the assessment to consider the impact of lower sales values for the PET recyclate.

The recent fall in PET value has caused considerable upset and disruption in the UK recycling sector, with several high profile cases of PET bottle reprocessors going out of business. Figure 31 gives the price of virgin polymers during 2015.

**Figure 31 Virgin polymer prices 2015**

![Virgin polymer prices 2015](image)

The PET flake has been given a value of £400/tonne in the model. Post-industrial tray flake has a value in the region of £600/tonne, and so £400/tonne represents a lower value to reflect the coloured contamination and the fact it is post-consumer material. In Scenarios 2 and 3 where fines production is higher, a fines “flake” is also considered, which has been given a value of £300/tonne in the analysis due to potential processing issues.

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WRAP
The PET PTT rich bale infeed material, with a composition of that given in Table 4, has been assumed to have a positive value of £50 per tonne, meaning this is the price a PET recycler will pay the MRF/PRF for this material. There is no readily available data for the price of PET PTT bales, as this is not currently a common tradeable commodity. Table 6 gives the price of sorted, baled clear PET bottles and coloured PET bottles. It has been assumed that the PET PTT would have a value closer to the coloured PET bottles due to the additional IV increase required.

Table 6 Range of baled post-consumer PET prices

<table>
<thead>
<tr>
<th>Price (£/tonne)</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear and light blue PET</td>
<td>95 - 115</td>
<td>105 - 120</td>
<td>115 - 135</td>
<td>135 - 170</td>
<td>140 - 160</td>
</tr>
<tr>
<td>Coloured PET</td>
<td>40 - 50</td>
<td>50 - 60</td>
<td>65 - 75</td>
<td>55 - 60</td>
<td>50 - 55</td>
</tr>
</tbody>
</table>

Data from the WRAP Materials Pricing Report show as of March 2016, clear PET bottles having a value of £120 to £160 per tonne and coloured PET a value of £40 to £50 per tonne.

Results of financial assessment

Table 7 gives a summary of the results from the financial assessment modelling. The analysis has considered net revenue and payback period as simple indicators of commercial viability.

The analysis shows that selling the PET flake is unlikely to be economically viable for any of the scenarios. This is due to there not being an established end market for the PET PTT flake, as well as a reprocessor needing to increase the IV before using the material or utilise the flake in a lower grade application. The result of these factors is that the flake has a very low sales value, which negatively impacts the overall commercial viability of the recycling process.

With regards to the manufacture and sale of PET PTT pellet, Scenario 2 (extruding the fines and flakes together) gives the most favourable economics with a higher net revenue and lower payback period. This makes sense as it requires only one extruder in the process, which is a major aspect of the capital and operating costs and it maximises the yield. It does however rely on the development of an extruder to process the fines and flakes together.

18 WRAP’s Materials Pricing Report (August 2016)
Minimising the fines generated and extruding only the flake (Scenario 1) also gives a reasonable payback that is not much longer than the optimal scenario. This may be a more feasible method of processing, as extruders able to handle flake are readily available.

Processing the flake and fines on separate extruders appears to be the least economically viable method due to the additional Capex and Opex required.

The financial assessment and modelling assumes an extruded PET value of £800 per tonne. PET has dropped in value significantly since 2013 (price for virgin PET was £1,200 per tonne in September 2013), and the future value is likely to continue to be variable. A sensitivity analysis has therefore been carried out for Scenario 1 to determine how the change in value of the PET pellet recyclate effects the payback period. This sensitivity analysis is shown in Table 8.
The red cells show the point at which the investment does not pay back, and the orange cells show the point at which the payback period is greater than ten years. For an investment of this scale, the payback period would most likely need to be lower than ten years to be considered feasible.

The analysis shows that, for either scenario a value of more than £700/tonne is required to give a reasonable payback period for the investment when the feed cost is in the region of £50/tonne. With increasing feed cost and reducing product value there is a clear impact on the payback period, with Scenario 2 giving more favourable values.

Overall the financial assessment and modelling shows that Scenario 1 (fines minimisation) and Scenario 2 (providing an extruder to handle the fines and flake mix can be developed) are the most viable routes for a PET PTT recycling process, with the assumption that the sales price of the recycled PET output product must be greater than £700/tonne. Whether this is achievable in the current market conditions is questionable, and an increase in PET prices may be required before the investment can be considered attractive.
When considering Scenario 1 (fines generation minimised by optimisation of the drying process), the assessment and model uses a figure of 5% for the fines generation, where the PET fines are sold at £300/tonne. A value of £300/tonne has been assumed in this case for the fines as they are generated during the drying stage, and are therefore clean with low levels of PVC and other contamination. The disadvantage is the material is not in a desirable format for extrusion, and therefore has been given a lower value than the washed PET flake.

This level of fines generation may be optimistic considering the trials delivered during this project demonstrated a 50% level of fines generation. For this reason, a sensitivity analysis has been carried out on Scenario 1 to evaluate the impact of higher levels of fines being generated (10%, 15% and 20%). The results of this analysis are shown in Table 10. As the level of fines generated in the recycling process increases so does the payback period on the investment.

<table>
<thead>
<tr>
<th>Fines generation</th>
<th>5%</th>
<th>10%</th>
<th>15%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payback period (years) (scenario 1)</td>
<td>5.7</td>
<td>6.7</td>
<td>8.1</td>
<td>10.3</td>
</tr>
</tbody>
</table>

At the higher levels of fines generation, it would be more beneficial to process the two materials together if possible, however even at 10% fines generation and rejection the economic model still gives a feasible payback period.

3.3.4 Product specifications
As per the financial assessment presented in Section 3.3.3, there are two different product options from the PET PTT recycling process. It has been assumed that Scenario 1 would be pursued as this gives the stronger commercial case for investment. The two options are:
- Extruded, IV modified PET pellet; and
- Sorted, washed PET flake.

Example product specification data tables have been produced for these two products, and it should be noted that these are presented as provisional data sheets as these recycled materials do not currently exist as a commercial traded commodity, and as a result the test methods and data have not been subjected to accreditation.

Since the minimisation of fines will be most likely required to enable the PET PTT recycling process to be economical, results from analysis of the fines and the >2 mm flake have been combined to give data for materials that would have been created if fines were minimised.
### Table 11 Data table for washed PET flake material

<table>
<thead>
<tr>
<th>Description</th>
<th>Washed PET flake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Post-consumer PET pots, tubs and trays (PTTs) and PET bottles separated from kerbside collected dry mixed recyclables</td>
</tr>
<tr>
<td>Format</td>
<td>15 mm – 20 mm hot washed PET flake</td>
</tr>
<tr>
<td>Bottle:PTT ratio</td>
<td>40:60</td>
</tr>
<tr>
<td>Colour</td>
<td>94% clear/light blue and 6% coloured</td>
</tr>
<tr>
<td>Crystalline/amorphous</td>
<td>Amorphous</td>
</tr>
<tr>
<td>Residual moisture</td>
<td>1%</td>
</tr>
<tr>
<td>PVC content</td>
<td>&lt;0.04%</td>
</tr>
<tr>
<td>Other contamination (polyolefin, metal, paper)</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Intrinsic viscosity (IV) (dL/g)</td>
<td>≈ 0.7 dL/g (estimated)</td>
</tr>
<tr>
<td>Food contact approved</td>
<td>TBC – derived from post-consumer food and non-food packaging</td>
</tr>
</tbody>
</table>

Image
### Table 12 Data table for extruded recycled PET

<table>
<thead>
<tr>
<th>Description</th>
<th>Recycled PET pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
<td>Post-consumer PET pots, tubs and trays (PTTs) and PET bottles separated from kerbside collected dry mixed recyclables</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td>3 mm extruded PET pellet</td>
</tr>
<tr>
<td><strong>Bottle:PTT ratio</strong></td>
<td>40:60</td>
</tr>
<tr>
<td><strong>Colour</strong></td>
<td>Non-clear, suitable for dark coloured or black applications</td>
</tr>
<tr>
<td><strong>Crystalline/amorphous</strong></td>
<td>Amorphous</td>
</tr>
<tr>
<td><strong>Moisture</strong></td>
<td>&lt;1%</td>
</tr>
<tr>
<td><strong>PVC content</strong></td>
<td>&lt;0.04%</td>
</tr>
<tr>
<td><strong>Other contamination</strong></td>
<td>&lt;1%</td>
</tr>
<tr>
<td><strong>(polyolefin, metal, paper)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Intrinsic viscosity (IV) (dL/g)</strong></td>
<td>0.8 dL/g (measured)</td>
</tr>
<tr>
<td><strong>Food contact approved</strong></td>
<td>Not yet approved – extrusion process demonstrated for PET bottle flake</td>
</tr>
</tbody>
</table>

#### 3.3.5 Fines minimisation and recovery

The processing trials demonstrated that there were a considerable generation of <2 mm fines during the centrifugal drying process. There are two options to consider for the fines; minimising the level of fines generated during the process through further optimisation work, or recovering the fines generated as part of the overall recycling process. Both options are considered following desk based research and discussions with technology and equipment manufacturers and suppliers.
Recovering the fines generated by the granulation and washing trial was straightforward, as the fines material was retained within the dry product stream and the PET PTT flake could be screened at 2 mm to separate the fines fraction. However, if an existing PET bottle reprocessor plans on using existing processing equipment to recycle PET PTT, fines may be lost elsewhere in the process and will need to be recovered from other contamination.

Minimising fines appears to be the most economical approach (see Section 3.3.3) when considering a new process which can be designed specifically for recycling PET PTT.

**Fines minimisation**

In order to determine how best to minimise the generation of fines, four of the major European PET wash line providers were contacted to give their opinion on how to potentially minimise fines production when recycling PET PTT. *Table 13* gives the feedback provided by the wash line suppliers. The feedback has been anonymised for the purpose of this report.

**Table 13** Summary of feedback from wash line suppliers

<table>
<thead>
<tr>
<th>Company</th>
<th>Suggestion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Company A</strong></td>
<td>Since the generation of fines appears to be as a result of excessive mechanical energy, Company A suggested that a gentle mechanical dryer, at a lower rotor speed, is used which is then followed by a thermal dryer. The thermal dryer will be able to remove the residual moisture with no further mechanical force on the material. The downside of this suggestion is that two separate dryers are needed and thermal drying is more costly to operate than mechanical drying. However, it has a high probability of working and minimising the production of fines.</td>
</tr>
<tr>
<td><strong>Company B</strong></td>
<td>Company B proposes that a horizontal centrifugal dryer could be used to mechanically dry the PET PTT material. This does not use a central high speed rotor which impacts the flake like a conventional centrifugal dryer, and instead the material is spun in baskets using only the centrifugal force. This type of dryer has been designed for brittle material and there is minimal friction force acting on the material. This drying unit is available on the market. Company B suggest that a thermal dryer should be used after this horizontal centrifugal drying unit as a final drying stage, which concurs with Company A.</td>
</tr>
</tbody>
</table>
Company C also suggests a mechanical dryer for the complete drying of the material (to <1% moisture as required by the extrusion process). Company C proposed a unit which is a horizontal dryer, similar to the dryer used in the trial in this project, with two modifications:

1. Instead of a conventional polygonal screen, which is designed to create high friction (to aid cleaning), a round screen could be used to remove the moisture without creating excessive friction.

2. A step change in speed is proposed where the material is gradually brought up to speed. The material would be fed into the centre of the machine (centre with regards to x axis orientation) and then the speed of rotation would increase along the length of the unit gradually. This gradual increase in speed should prevent the material from immediate introduction to high mechanical forces and should be gentler on the flake.

There is already a unit on the market as described above. Company C do not suggest that a thermal dryer is required after this stage. Using only a mechanical dryer would be beneficial in terms of investment and operating cost.

In contrast to the other wash line providers, Company D suggests that the generation of fines during drying is inevitable, and rather than minimising the generation, one should actively produce the fines and then process this fraction.

This may be a suitable option if 100% of the feed material was PET PTT, where all the material is brittle and could be easily broken up. The extrusion trial delivered in this project demonstrated that extrusion of the fines fraction is feasible, however it may be challenging to design a system that could handle a mixture of fines and >2 mm flake.

Therefore, if the infeed material is a mixture of PET bottle and PTT, actively generating fines would not be a recommended approach.

All of the above suggestions may be valid, however without empirical data and demonstration of the technology it is difficult to conclude at this stage which would be the most effective method for minimisation of fines production.
Recovery of fines
It was originally thought that the fines would be mainly generated during the granulation and high-intensity washing stages of the PET recycling process although through this series of trials it has been shown that the fines were generated as a result of the drying process. Both WRAP’s previous work and this project have shown that an excessive amount of fines are produced when recycling PET PTT.

As well as reducing the yield from the recycling process, excess levels of fines can potentially cause problems with blockages during processing. Normally fines are captured in sieve filter screens following a granulation process which allow particles smaller than target (usually <2 mm) to pass through and are collected to be discarded. Fines produced following the washing process will be collected by filtering the waste water and are usually compressed into a compacted filter cake which will contain a significant quantity of paper and glue from labels, dirt, grit, non-target plastics as well as finely ground PET to be collected before disposal.

For PET fines to be recovered the fraction needs to be efficiently captured and separated from the production stream in order to facilitate reprocessing. A series of filters could be put in place to capture fines most likely to contain easily accessible target polymer. Trials on fines material capture would need to be carried out at a commercial production facility in order to determine the exact method of capture that would not restrict the efficient running of the production line.

Fines sorting and contamination removal
The trials carried out as part of this project were done using test equipment, where special consideration was taken with regards to the type of material. For this reason fines generation was minimised significantly, up until the point of drying. The fines generated from these trials were clean and had low levels of PVC. However, if an existing bottle recycling line that had not been designed for PET PTT were to be used to process PTTs, where the granulation and washing were not suitable for PTTs then the fines generation could be entirely different. For this reason, methods of recovering fines from sources other than drying have been considered.

Separation of the fines during the processing trials required only the use of a screen. If the fines were generated elsewhere, for example after dry granulation or in the waste from the friction washer, the fines could be significantly more contaminated and would require further processing before extrusion. Generation of these types of fines was not observed in the processing trials at a significant level due to the prior careful consideration to the type of material.

It is possible that fines produced in areas of the process other than drying are likely to contain a significant proportion of contamination in the form of non-target plastics (PE, PP, PVC) as well as paper, glue, metals, dirt and grit. It may be possible to eliminate a significant proportion of these impurities during a careful pre-sort of the feed materials entering the granulation process and judicious selection of the fines material produced.

Four decontamination and separation techniques have been considered through this desk based research. Some techniques such as optical sorting have been discounted
due to difficulty in detecting the particles <2 mm and the higher moisture content of the fines. The moisture causes the material to stick to the conveyor belt, preventing it from being sorted and the maximum resolution of the flake sorter is 2 mm. Processing the fines using a specialist centrifugal recycling decanter designed by Flottweg (Sorticanter) for the processing of plastics has also been disregarded following consultation with a specialist recycler due to difficulty the technology would have in separating out the PET from contaminants such as paper, glue and grit.

Gravity separation table
It may be possible to utilise gravity separation to separate fines arising from a dry granulation process. Gravity separation is an industrial method of separating components where separating the constituents with gravity is sufficiently practical: i.e. the components of the mixture have different specific weights. It works using a fluidised bed principle; air is forced through the deck causing the light fraction to preferentially float above the heavy fraction to a degree that enables a very subtle and sensitive separation to occur. The deck is reciprocated causing the heavy fraction to move uphill while the light fraction floats downhill. Variations in deck speed, air quantity, deck type, deck angle, depth of product and take-off points allow for efficient separation. Figure 32 shows an example of a gravity separation table.

Figure 32 Commercial gravity separation table

Gravity separation is used in a wide variety of industries including agriculture to separate grains and in recycling to separate metal or rubber from plastic and to separate different grades of plastic. Gravity separation is an attractive option as it generally has low capital and operating costs and uses few, if any, chemicals that might cause environmental concerns and increase treatment costs. More recent developments in table separator technology allow separation of materials with the same gravity but with different bouncing effect.

There are many manufacturers of gravity separation equipment which may be suitable for separation of fines materials generated from PET PTT. These include Crown\textsuperscript{20}, Holman-Wilfley\textsuperscript{21}, Oliver\textsuperscript{22} and Skiold Damas\textsuperscript{23}. The installed cost of such technology is likely to be in the region of £100,000 – 200,000 per industrial unit.

Further investigation is necessary to determine whether this technology could achieve separation of the fines material generated to a high enough purity for recovery.

**Hydrocyclones**

Hydrocyclone technology could be used to sort either wet or dry fines. The technology uses the float/sink separation principle which separates particles according to their density. The hydrocyclone is vertically oriented and the medium (usually water or saline) is loaded with the plastic particles and forced into the hydrocyclone, as can be seen in Figure 33. The configuration of the centrifuge forces the load into a circular motion and causes centrifugal acceleration to form a vortex. The acceleration forces the heavier particles to the outside and those with lower density than the medium used to the centre of the cyclone. A pipe introduced from above into the centre of the cyclone removes the floating material. Changing the density of the fluid medium controls the separation parameters however, a narrow particle size range and good control of solid: liquid ratio is needed in order to deliver acceptable separation results.

[Figure 33 Hydrocyclone separation principle\textsuperscript{24}]

\textsuperscript{20} http://www.gravityseparator.co.uk/
\textsuperscript{21} http://www.holmanwilfley.co.uk/
\textsuperscript{22} http://www.olivermanufacturing.com/products/gravity-separators.php
\textsuperscript{23} http://damas.com/products/grain-seed-cleaning-machines
A number of companies including Herbold\textsuperscript{25}, and Salter\textsuperscript{26} specialise in cyclone technology. The installed cost of specialised hydrocyclone equipment is estimated to be in the region of £250,000-500,000 for a single density split, depending upon throughput.

**Electrostatic separation**

It is possible to separate out dry mixtures of plastics using the difference in their electrostatic properties as a separation parameter. The particles to be sorted are electrostatically charged and are drawn to either the positive or negative electrode then collected, as shown in Figure 34.

**Figure 34** Electrostatic separation of plastic using frictional charge method\textsuperscript{27}

Drawbacks to this method are that the material needs to be relatively clean and dry and only two components can be separated at a time which means that it would need to be combined in a series of steps or with another method such as density separation. Depending upon the parameters of the PET PTT fines the technology may also have difficulty in dealing with especially small particles.

Companies including Hamos\textsuperscript{28} sell technology such as the hamos EKS which is specifically designed for plastics separation. Hitachi Zosen\textsuperscript{29} also sells a high-purity plastics separation unit, as does Prodecologia\textsuperscript{30}.

\textsuperscript{25} http://www.herbold.com/en/pet_recycling.html
\textsuperscript{26} http://www.saltercyclones.com/
\textsuperscript{28} http://www.hamos.com/products/electrostatic-separators/plastic-plastic-separators,35,eng,39
\textsuperscript{29} http://www.hitachizosen.co.jp/english/technology/hitz-ttech/material.html
\textsuperscript{30} http://www.prodecolog.com.ua/en/about/Laboratory/laboratoriyequipment_dry_sepration/
Froth flotation
Froth flotation\textsuperscript{31} is a process for selectively separating hydrophobic materials from hydrophilic and is widely used in many industries such as mining, waste water treatment and paper recycling. The plastic mixture is subjected to a combination of alkaline treatment and surfactant adsorption followed by froth flotation using mechanical flotation cells.

Argonne National Laboratory\textsuperscript{32} uses a froth-flotation system to recover plastics from automotive shredder waste. The polymer concentrate runs through a series of tanks where the chemistry of the solutions in each tank allows recovery of a specific plastic. This technology may be applicable to PET PTT fines but clearly further research and development would be required to assess its feasibility in this context.

\textsuperscript{31} http://www.ncbi.nlm.nih.gov/pubmed/20576423  
\textsuperscript{32} http://www.anl.gov/about-argonne/discoveries
4.0 Conclusions

The project designed and delivered a series of trials to further develop and optimise a PET PTT recycling process, by demonstrating the key processing stages. ‘PTT rich’ material was sourced from a UK PRF, which was a mixture of PTTs and bottles. The material was produced from a residual stream following primary sorting at a MRF, which was processed at a PRF to sort HDPE, PP and PET bottles among other materials which were missed during the original sort.

Compositional analysis was conducted on 147.8 kg, involving hand sorting into 17 material categories. The analysis found the PTT rich material was 58.3% bottles, 32.4% PTTs and 9.3% other material. The material had a lower level of PTTs than expected, which reflects variation in the infeed material to the MRF and PRF. The analysis showed the material was 94% PET, with mainly clear and light blue bottles (42.9%), coloured PET bottles (15.4%), PET PTT with lidding film attached (16.6%) and clear PET PTT (12.5%).

It is important to recognise that the current composition of the PTT rich stream is a result of the material being produced from a non-target stream. MRFs and PRFs focus on recovering higher value streams such as HDPE and PET bottles and therefore remove the PTT material. This means the material used for the processing trials can be considered to be the worst case scenario. If PTT was targeted at the collection and primary sorting stages then the composition would change, which would have an impact on the processing efficiency and yields achieved when recycling PET PTT.

A series of trials were delivered at test centres of technology suppliers. The trials were designed to replicate the overall recycling process, with the material being produced at each trial being moved on to the next trial for processing.

The first trial evaluated NIR sorting technology to separate PET PTTs and PET bottles. Initial optimisation tests were carried out to achieve the best balance between recovery and purity. The PTT rich material processed without any problems and a suitable purity and recovery was achieved. The trial demonstrated it is technically feasible to sort PET PTTs from PET bottles. It is a technically difficult separation as there is only a subtle difference in infrared spectra between PTTs and bottles. The consequence is that a lower separation efficiency is achieved than expected when two different polymers are separated.

The second trial granulated and washed the NIR sorted material. This was a key trial in the project as previous work delivered for WRAP had shown the PET PTT recycling process to have a low yield and an excessive level of fines generation. The aim of this trial was to optimise these processing stages and minimise the production of fines. Both wet and dry granulation techniques were trialled and it was found that a wet granulation process with a 15 mm screen was the optimum process.

After granulation the material was passed through a friction washer, a hot wash process and then a second friction washer; there were no processing problems with these stages. Issues were encountered with the hydrocyclone separator as the equipment became blocked due to differences in the particle geometry of the PTT flake compared to bottle flake. The overall yield of the granulation and washing trial process was 70%.
Material was lost at the friction washer after the granulation stage and at the separation stage to remove polyolefin material and was found to be fairly contaminated, which impacted on the yield achieved. This is a consequence of the material being produced from a MRF residual stream as a result of sorting other recyclable streams.

The trial mass balance showed the granulation and washing processes were not producing an excessive level of fines as originally thought. The trial showed it was the drying stage that was responsible for the high level of fines, with more than 50% of the material being classed as fines (<2 mm) after this process. A mechanical centrifugal dryer was used, which was designed for PET bottles but has been shown to be too aggressive for PET PTT material and resulted in a very significant level of fines.

The next stage in the trials was a flake sorting trial to remove non-PET material such as PVC and PS. The flake sorter can only sort material over 2 mm, so the material was screened at 2 mm. This screening process removed 42% of the material as fines, which is a significant loss of material. Overall the flake sorter achieved a 72% yield; this is lower than would be expected when sorting PET bottle flake. This is due to the presence of black plastics and non-target plastics. It was a straightforward sort but the yield was fairly low, again due to the material being generated from a MRF residual stream.

The extrusion trial demonstrated that post-industrial PET PTT material can be modified to give an IV of 0.8 dL/g, from an inlet IV of 0.64 dL/g allowing it to be used in place of bottle flake in PET tray manufacture. Due to extrusion issues experienced with the PET PTT <2 mm fines it was not possible to increase the IV to the target of 0.8 dL/g. The >2 mm PET PTT flake was extruded with an IV of 0.77 dL/g, which is very close to the target. There was also an upwards trend in the IV increase and with further optimisation it is likely the PET PTT flake could have reached the target. The extrusion trial proved the technical feasibility of increasing the IV of the PET PTT, and shows the importance of using an optimised extruder design to allow for processing of <2 mm fines.

Based on the results and learning from the practical processing trials a process for PET PTT recycling has been developed. The process includes all the stages demonstrated in this project, with an additional shred and pre-sort at the beginning of the process. All stages of the recycling process have been optimised apart from drying, with further work being needed to minimise levels of fines production.

The processing trials have shown that improving the infeed material to a PET PTT recycling process is key. A process for changes to primary sorting at MRFs has been proposed, to enable a targeted PET PTT stream to be generated, which would have a positive impact on the whole process and yield.

A financial assessment was undertaken to evaluate the commercial viability of the PET PTT recycling process. Three scenarios have been modelled considering different levels of fines generation and the possibility of extruding fines together with flake or separately. The assessment has also evaluated the viability of producing both flake and pellet for sale.
The assessment has shown the production and sale of PET flake is unlikely to be commercially viable. A lack of end market applications for flake is a key reason for this result. Production and sales of PET pellet is more positive. The evaluation has shown that it could be feasible to either minimise fines generation or to process fines and flake together.

A key issue is the generation of fines in the PET PTT recycling process. Desk research has been conducted to investigate other drying techniques that could be used to minimise fines production, as well as techniques to recover the fines fraction. Several suggestions have been made for alternative drying technologies that could be investigated, including use of a gentler mechanical dryer. These options will need to be demonstrated and evaluated to determine if fines generation can be reduced to a more acceptable and commercially viable level. Research has also been conducted on methods to recover fines from the process including hydrocyclones and electrostatic separation.

The key conclusion is that a PET PTT recycling process can be established on a technically feasible basis. The problem processing stage is drying, which produces an excessive level of fines. The process yield could be improved by enhancing the quality of the infeed material and reducing contamination levels. It appears to be economically viable to produce a PET pellet, either through minimising fines generation or producing fines and processing the fraction.
5.0 **Recommendations**

The following are recommendations to make from this demonstration project.

The PET PTT recycling process has been fully demonstrated from NIR sorting to separate PTTs and bottles, granulation, washing, flake sorting, extrusion and IV modification. The drying process trialled was problematic and resulted in an excessive level of fines generation, which had a detrimental effect on overall yield. Further work is needed to improve and optimise the drying process stage. Several suggestions have been made in this report for alternative drying techniques that could be trialled and evaluated. The key is to use a very gentle drying process that will not generate a high level of fines from the brittle PTT material. These techniques should be trialled so that a comparison can be made and a suitable process identified.

It was concluded from the series of processing trials that the low yield achieved was due to the infeed material being generated from a MRF residual stream, rather than a targeted product stream. If more local authorities collected PET PTTs at the kerbside and provided householders with clear communication on what can and cannot be included in collections there would be a greater volume of material for MRFs to process. This would encourage MRFs to sort and process a targeted stream of PTT rich material. This improved quality will positively affect the whole process yield. This in turn should improve the commercial viability of the recycling process. This change would obviously have an impact on MRFs in the UK, as facilities would need greater capacity to process a greater volume of material. This in turn would require additional separation equipment, baler and storage capacity.

Further work is needed to establish secure end markets for both PET PTT flake and pellet. Suitable end uses for a coloured flake and pellet should be demonstrated through practical trials, to help build confidence in both the recycling sector and end users, as well as overcoming any technical challenges.