General enquiries on this form should be made to:
Defra, Science Directorate, Management Support and Finance Team,
Telephone No. 020 7238 1612
E-mail: research.competitions@defra.gsi.gov.uk

SID 5 Research Project Final Report

- **Note**
  In line with the Freedom of Information Act 2000, Defra aims to place the results of its completed research projects in the public domain wherever possible. The SID 5 (Research Project Final Report) is designed to capture the information on the results and outputs of Defra-funded research in a format that is easily publishable through the Defra website. A SID 5 must be completed for all projects.
- This form is in Word format and the boxes may be expanded or reduced, as appropriate.
- **ACCESS TO INFORMATION**
  The information collected on this form will be stored electronically and may be sent to any part of Defra, or to individual researchers or organisations outside Defra for the purposes of reviewing the project. Defra may also disclose the information to any outside organisation acting as an agent authorised by Defra to process final research reports on its behalf. Defra intends to publish this form on its website, unless there are strong reasons not to, which fully comply with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.
  Defra may be required to release information, including personal data and commercial information, on request under the Environmental Information Regulations or the Freedom of Information Act 2000. However, Defra will not permit any unwarranted breach of confidentiality or act in contravention of its obligations under the Data Protection Act 1998. Defra or its appointed agents may use the name, address or other details on your form to contact you in connection with occasional customer research aimed at improving the processes through which Defra works with its contractors.

Project identification

1. Defra Project code: WRT 095
2. Project title: Developing bulk WEEE polymer separation and analysis techniques
3. Contractor organisation(s): Axion Recycling Ltd
4. Total Defra project costs (agreed fixed price): £ £209,000
5. Project: start date .... 01 June 2005
   end date .... 01 June 2007

6. It is Defra's intention to publish this form.
Please confirm your agreement to do so..**YES** ☒ **NO** ☐

(a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.
Defra recognises that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (not to be published) so that the SID 5 can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will Defra expect contractors to give a "No" answer.
In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

(b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

This is an Executive Summary of a two year DEFRA funded project carried out by Axion Recycling Ltd which investigated sorting and separation technologies for the processing of WEEE plastics waste streams. The work commenced in June 2005 and ended in June 2007. The main objectives of the project were to:-

a) Develop test methods to characterise real WEEE polymer streams and to measure the performance of WEEE separation processes

b) Conduct rigorous experiments to compare a range of alternative bulk separation techniques for WEEE polymers

c) Evaluate the separation processes tested in terms of their commercial and technical performance and their environmental impact when operated at full commercial scale

Main Outcomes
Objective 'a' was addressed in the first year of the project. This has resulted in the development and testing of a bespoke laboratory instrument for the rapid evaluation of polymers in an unknown mixture of particles. The exact design of the instrument embodies some unique IP and can not be released into the public domain. It does however enable a sample of mixed polymer types to be split into very accurate density fractions by means of increased-G separation forces, using liquid solutions with accurately defined specific gravity as the separating media. This accurate distribution of a sample across a range of densities can then be used to assess the performance of any commercial equipment which aims to separate groups of polymers based upon precise density sorting. The instrument has also proved to be valuable as a means to help identify and quantify the different types of polymer found in an unknown mixture, such as a sample of shredded mixed-WEEE plastic. When used in parallel with laboratory Infra-red spectrography and X-ray florescence devices, it is possible to build up an accurate picture of the mix of different polymer types in any sample, split across a range of densities and also to understand the distribution of additives found within the sample material.

Objectives 'b' and 'c' have been met by Axion conducting over twenty individual process trials using large samples of UK sourced WEEE plastic waste. These trials are described in detail in the Final Project report, completed in July 2007. The outcomes of which are summarised below:-

The plastics waste stream arising from the primary WEEE treatment processors in the UK and Europe is not a simple mixture of a few polymer types. Any process that attempts to extract a high-grade polymer product from this mixed stream of material must be able to handle a wide range of contaminants. This can include:-

- Metal – ferrous & non-ferrous – 2-7%
- Dust / fines – e.g. PU foam – up to 15%
- Rubber / elastomers
- Fibres / fluff
- Wood / Paper
- Cable / electrical components
- Dirt / grass
- Glass / stones
- AND some PLASTIC!

Axion's final report therefore includes assessment of pre-treatment and size reduction processes that are necessary to clean-up the plastic material before any polymer sorting can take place. Several different plastic sorting technologies were trialled using large scale samples of real-life WEEE plastic material. These technologies are grouped into liquid phase, density separation methods and dry sorting systems using spectrographic, electrostatic and X-ray techniques.

The detailed conclusions from each of the trials on individual technologies are included in the body of the report, however the main conclusions are as follows:-

A complete process to treat the co-mingled materials found in WEEE plastics waste will be divided into two main stages:-

Firstly, the plant will require technologies that carry out the initial clean-up of the material, by removal of the non-plastic contaminants as follows:-

- Size Reduction – primary
- Metal removal – ferrous / non-ferrous / stainless steel
- Fines and dust extraction
- Wood and rubber removal
- Stone and glass removal
- Further Size Reduction - secondary

The above process steps should deliver a clean, accurately-sized mix of granules into the second polymer separation stage, at which point there is a choice of technologies to be used. Those investigated in this project included:-

- Increased-G Liquid Density Separation
- Infra-Red Light sorting
- X-Ray Transmission sorting
- Electrostatics Separations
- Colour Sorting

The benefits and limitations of these technologies are described in detail in the report, together with an assessment of their technical performance for each of the individual process steps.

All of the processes studied are essentially low-impact, mechanical recycling techniques which employ electrical power as the primary source of energy to deliver the sorting forces or changes in shape and size of the plastic waste stream. The environmental impact assessment was therefore based upon a complete process for the mechanical recycling of plastics. This was compared with the impact of typical processes for the production of virgin polymers used in E&E goods. Up to 95% savings in CO_2 emissions to atmosphere were estimated for the production of 1 tonne of recycled WEEE polymer in comparison to virgin material of a similar type..

A list of recommendations is given to assist process designers and potential plant operators with the selection of suitable equipment for the task of recycling this complex, but valuable, waste resource.

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

1 Project Objectives

The overall aim of this project was to research technologies for the recovery of high quality polymer materials from WEEE plastic waste, enabling their subsequent processing to realise maximum environmental and economic gain. With the UK implementation of the EU Directive for WEEE in 2007, the growth in arisings of this waste stream has the potential to yield over 200,000 tonnes/annum of waste plastic. In the absence of suitable technologies to recycle a significant proportion of this material, it will not be possible for the UK to meet the recycling targets set for WEEE items in the majority of the defined product categories.

The specific objectives of the Project were:

a) To develop test methods to characterise real WEEE polymer streams resulting from the bulk separation processes (by type, BFR content and density); to measure the performance of WEEE separation processes, and to report on the findings in an interim report within 14 months of the project start date.

b) To conduct rigorous separation trials to compare a range of alternative bulk separation techniques for WEEE polymers, using carefully characterised and statistically meaningful samples of real WEEE, and to report on the findings in an interim report within 18 months of the project start date.

c) To evaluate the separation processes tested in terms of their commercial and technical performance and their environmental impact when operated at full commercial scale and to report on the findings within 2 years of the project start date, as part of the final project report.

The work commenced in June 2005 and was completed in June 2007.

This report summarises the main findings of the research and describes how the above objectives have been met. A summary overview is given of the main technology trials conducted during the research project and readers who seek more detailed information should refer to Axion's final project report published in July 2007 in parallel to this document.

<u>Objective 'A' – Develop Polymer Analysis Techniques</u>

This objective has been met in two ways:-

1. Development of a novel laboratory technique for the rapid assessment of density for a mixture of plastic particles
2. Selection of suitable commercially available instruments for rapid analysis of polymer type and additive content.

1 Density Analysis

The design of this instrument was based upon the need to make a fast assessment of the distribution of plastic densities in any given sample taken from a mix of unknown polymer materials. This could either be to check the performance of a full scale separation device as an off-line quality measurement, or to investigate the composition of samples of feedstock mixed plastic wastes.

The analysis makes use of increased-G force to bring about a separation of the material in the batch to be tested (G = gravitational force). Plastic is introduced into a range of very accurately prepared liquid solutions (accurate to 2 decimal places on S.G.- 'specific gravity'). The increased-G is needed to create the required separation force at the set density, and the resultant split of material is then used for a series of iterative separations across the required density range. In this manner it is possible to build up a bar-chart of the distribution of mass across the chosen density fractions.

The statistical validity of this method has been checked during the design stage by mathematical evaluation of the required sample size and accuracy of liquid solutions needed to perform each test. The very high G-force used in the laboratory method shows good repeatability on known sample separation. A benchmark comparison has also been made of the results obtained using this technique with an independent density fraction analysis carried out by a third party.

Progress reports to DEFRA, made at three stages during the project, explained the design concept, development and commissioning tests with the instrument. The exact detail of the design is the basis of some unique intellectual property developed by Axion during the project and is therefore subject to confidentiality.

2 Analysis of Polymer type and Additive Content

For the identification of polymer types, it was decided to investigate instruments which employ infra-red light spectrography as the main identification technique. During this exercise the main choice fell between Near-Infra Red and Mid Infra-Red methods. After a detailed testing programme, it was decided to select the MIR method for polymer analysis, mainly because of the greater tolerance to dark coloured plastics shown by this technique. A commercial MIR instrument was used to make a qualitative assessment of polymer types found in the density fractions described in the above method. This unit has also enabled Axion to check the performance of commercial scale separation methods during the project.

A hand-held X-Ray florescence device was chosen to identify individual additive elements that are present at parts per million level inside the polymer matrix. The unit has been used to detect materials such as chromium (Cr) or bromine (Br), which are important elements in plastics due to the RoHS legislation, as they have been given maximum allowable levels within Europe for the electronics sector. The instrument uses the principle of energy dispersive X-ray fluorescence as the basis for detection of a wide range of elements. This relies upon exposing the unknown material to a low level of X-Ray radiation, which penetrates the sample to a depth of a few millimetres and impacts upon the atoms within the structure. Individual elements then 'fluoresce' at specific wavelengths, which are detected and identified by the instrument, allowing a quantitative analysis of additive content.

During the selection process a set of known samples were prepared with set levels of bromine content. The accuracy of the calibrated instrument was then check against this reference set to confirm the performance of the unit. The performance of full-scale equipment trialled for removal of brominated flame retardants has been checked with this device during the project.

<u>Objective 'B' – Plastic Separation Trials</u>

The major part of the practical work programme has been devoted towards meeting this objective. In total over twenty different process trials have been organised on full-scale or demonstration items of equipment to investigate the suitability for a wide range of technologies to the WEEE plastics recycling task.

It was first necessary to define the range of feed-stock polymer waste streams under investigation and to set some limits to the scope of the processing requirement.

The flow of polymer waste from the primary treatment of WEEE material comes from four main sources in the UK marketplace:-

- Treatment of Fridges under ODS Regulations
- Treatment of CRTs under Hazardous Waste Regs.
- Plastic from commercial IT Recyclers – mainly B2B
- Mixed Small WEEE treatment – primarily ex household waste

Each of these streams has particular requirements for processing and contains a characteristic mix of polymer types related to the 'streaming' that has occurred due to the differing regulations that apply. Axion Recycling already had a clear knowledge of the type and mix of plastic found in each of the above streams form previous studies carried out for the Hampshire Natural Resources Trust in 2004/5 (1) and under the WRAP Brominated Flame Retaradant Extraction project reported in 2005/6 (2). (A brief explanation of the common polymer types found in WEEE is given in the appendix to this report, with a glossary of abbreviated polymer names used).

The main issue that arose with the initial inspection of large scale samples of material collected together for this trial programme was the high level of non-plastic contamination found in the bulk shredded material being produced by commercial WEEE treatment plants in the UK. It was clear that an evaluation of any process to bring about the recycling of a clean, high-purity plastic 'product' from this input waste material was going to have to deal with the wide range contaminants found in the samples. Typical content was as follows:-

- Metal – ferrous & non-ferrous – 2-7%
- Dust / fines – e.g. PU foam – up to 15%
- Rubber / elastomers
- Fibres / fluff
- Wood / Paper
- Cable / elec. components
- Dirt / grass
- Glass / stones

The technology trial programme was therefore designed to include the testing of different 'clean-up' processes as well as the core plastic/plastic separations needed to deliver the required output of sorted, clean plastic material. The different groupings of technologies tested are listed below:-

- Size Reduction
- Metal Removal
- Wood & Rubber Removal
- Centrifugal Separation
- Spectrographic Methods
- Colour Sorting
- Electrostatic Techniques

A brief summary of the main trials carried out is given here, to demonstrate the extent of the work programme and the degree to which the primary objectives have been met.

<u>1 Size Reduction Trials</u>

Size reduction is needed as part of the process for WEEE plastic waste:-

- To reduce large components to a manageable size for downstream processing
- To liberate metal and other parts from large pieces
- To achieve regular particle size, often important for efficient separation
- To reach the required size distribution for output product specifications

The input WEEE plastics can be delivered in several formats, ranging from whole dismantled casings, to large bales of rigid plastic or, more commonly, as rough shredded material. Each of these formats require a different approach to size reduction to make the material suitable for separation and recovery.

During this project, size reduction trials were carried out on the following types of machinery:-

- Single Shaft Shredder – Wagner

- Impact Mill – BHS Sonthofen
- Hammer Mill – Alpine Hosokawa
- Granulator – Herbold

A brief summary of the trials, main results and findings are given below.

Single Shaft Shredder - Wagner

This machine employs a single, slow-speed rotating shaft fitted with a large number of cutting teeth which turns against a row of stator knives to create the cutting action. A hydraulic pusher forces the material onto the shaft and pieces which are torn-off at the nip-point are then forced against a mesh screen, which only allows correctly sized particles to exit form the machine.

A large-scale trial was carried out to reduce whole TV casings down to sub-20mm particles in a single pass, at a throughput of 1.6 tonnes per hour.

Impact Mill – BHS Sonthofen

This design of milling equipment was selected for trial due to its novel approach to WEEE plastics treatment. The action of the rotating horse-shoe shaped impellers passing the stationary anvils produces a milling of the plastic / metal mixture. The metal is beneficially converted into rolled ball shapes enabling easier separation after this impact milling process.

Hammer Mill – Alpine Hosokawa

This type of machine was compared with the impact mill. A rotary shaft fitted with free swinging hammers spins inside a cage basket. Plastic and metal are fragmented in the unit, and again the balling-up of the metal allows for easier separation post his unit.

Granulation – Herbold

The design of this unit is a classic scissor-cut system employing guillotine-type blades mounted on a horizontal central shaft which pass very close to the stator blades. Pre-shredded plastic particles can be accurately cut down to a regular sized output granule under the control of the close-fitting screen under the blade section. Good quality size reduction of WEEE samples to a tight particle size distribution was achieved in this trial.

2 Metal Separation Trials

Metal separation is important as part of a WEEE plastics plant for several reasons:-

- To protect primary shredding machinery from ‘tramp scrap’ damage
- To recover value as copper / aluminium scrap
- To protect close-tolerance cutting blades from damage
- To ensure end product is essentially metal free

In the trial programme Axion carried out tests on the following types of metal removal equipment;-

High-Flux Magnetic Head Rollers – This equipment demonstrated the wide range of particles in the waste stream that are attracted by a strong magnetic field. This included some plastics and a lot of dust / fines. Metal parts which appeared to be stainless-steel were also removed by this unit, even though this metal is normally assumed to be non-magnetic.

Fine-Pole Eddy Current Separator – The residual copper, aluminium and other non-ferrous metal found in mixed WEEE plastic is often small in particle size, because upstream processing has removed the majority of larger metal parts. The unit used in the trial employed a fast rotating magnetic roller to create a rapidly changing flux in the eddy-current sorting region. This design of unit is able to remove smaller metal parts and successfully demonstrated this capability during the trial tests.

Induction Sorting Units – Two suppliers of induction separator equipment were used to demonstrate this technology. The material passes over an induction loop sensor head mounted below a fast moving conveyor belt. Any metal passing close to the loop creates a signal which is then used to trigger an air-pulse to eject the metal part. The machines both showed a high efficiency in removing the varied metal content from the plastic mixture during the trials on a single pass through the equipment.

Gravity Separators – The material that had been subjected to impact and hammer milling processes to generate metal 'balls' mixed with regular sized plastic pieces, was then sent for metal separation using the air-blown shaking tables known as gravity separators. In two trials the successful removal of the spherical metal parts from the plastic was clearly demonstrated. The gravity separator was not successful at removing flat and irregular shaped metal items from a shredded infeed of WEEE mixture, so it could only seriously be considered as a workable device if used in series with an upstream milling process to shape the metal content into 'balls'.

3 Wood and Rubber Removal

Trials were also carried out using gravity separation equipment in order to remove wood and rubber contamination from the plastic mixtures. In these tests it was demonstrated that dry wood splinters could be successfully separated from a mixture of WEEE polyolefin plastics. The removal of rubber was less successful.

4 Centrifugal Separators

Polymer type separations based upon differences in density were a key part of the project. Axion conducted large scale trials on three different designs of equipment that each employ high speed rotation of a liquid slurry of the plastic material as a means to bring about density-splits in a solution of known specific gravity (S.G.).

Mechanical Centrifuge Trials

Two different designs of externally driven mechanical centrifuges (or 'decanters') were used to compare separation efficiency of this type of device. Large scale samples of well-mixed plastic were prepared in advance and then exactly similar material could be sent to each of the density trials to allow a valid comparison.

The **Flottweg Sorticanter** uses a horizontal screw rotating inside a cone-shaped outer shell, which also rotates but at a different speed. The liquid – plastic mixture is pumped into the machine where the spinning action creates the high-G separation needed to accurately split the plastic particles. Some drying also occurs inside the machine. Several tonnage scale trials indicated a very accurate density-cut for this unit which is seen to justify its high capital cost and mechanical complexity in comparison to other systems.

Trials on the **Foma Centrec** unit, which employs a spinning open-topped bowl to create a liquid vortex of high-G separation, was used on the same test material. Separation did occur but not to the same accuracy of density-cut as seen on the Flotweg unit. This machine is however a lower cost unit.

Hydrocyclone Separation Trials

A pilot-scale rig at the University of Berlin was used to conduct a full set of separation trials on several different plastic samples. Hydrocyclones have no moving internal parts and rely upon the pumped velocity of the fluid entering the unit to create a standing-vortex of spinning liquid where high-G separation takes place. Particles suspended in a liquid medium of fixed density, are forced to report to either the 'floating' fraction in the overflow, or to the 'sinking' fraction, termed the underflow. The results of this work indicated that the hydrocyclone is a flexible piece of equipment where the physical configuration of the parts has a great impact upon the degree of separation achieved. Particle shape and size also have significant effect upon the separation efficiency. It was clear from the many trials carried out, that hydrocyclones can only be used to create a 100% pure fraction to one side of the required density cut-point. Operators of this design of separator must accept that if the overflow material is to be collected as a pure density fraction then the underflow fraction will have a mixture of the different infeed densities. In full scale plants this means that multiple hydrocyclone units will be needed to generate high-purity output of all plastic density streams.
While the individual hydrocyclone units are cheap in comparison to mechanically driven centrifuges, they cannot make such accurate separations and a lot of additional equipment is needed to operate them commercially; tanks, pumps, sieves and drying equipment will be needed as part of a complete installation.

5 Spectrographic Methods

The use of spectrographic methods as the basis for identification and sorting equipment is a rapidly growing area that has been enabled by development of high speed digital cameras and very rapid processing computer power as the combined main elements of each machine. Other forms of electromagnetic radiation have also been used as the detection method for polymer identification, such as X-ray radiation energy. Trials were carried out on two large scale units:-

- Titech Near-Infra Red Light Polysort machine
- Scan & Sort – X-Tract – X-ray Transmission sorter

NIR Sorting trials

Samples of VDU monitor cases and mixed WEEE plastic scrap were used for the trial of the Titech unit. Over several passes through the machine it was possible to conduct a positive pick of individual polymer types based upon the NIR reflectance from each chip as it passed under the detection cameras. The chips are ejected from the end of the belt using a bank of air-pulse jets fired in precise timing with the transport of the material from the end of the conveyor belt. Over the course of 4 passes through the machine plastic types ABS, PS, PP/PE and PC were set as the 'target' polymer to eject. The accuracy of each sorting run was assessed off-line using laboratory MIR instrument to check the Titech identification was correct.

The results showed that, for the light coloured mixture of VDU monitor cases, the sorting efficiency was quite good, with 15 out of 20 sample chips being identified correctly as ABS on the off-line tests. For the remaining 5 chips in the sample the identified polymer type was always similar to the styrenic family of polymers and often the second-best fit was identified as ABS plastic. Similar results were obtained for the PS and polyolefin sort.

With the mixed WEEE sample the results were not very good, with only a small percentage of plastic being picked out as ABS and PS polymer types. This was attributed to the high level of black / grey material in the sample which makes the level of reflected IR light very low.

X-Ray Transmission trial

The sorting trial using this technology was designed to test the detection and removal of brominated flame retardant additives from samples of mixed WEEE plastic. In advance of the trial a sample was prepared where whole CRT casings were sorted into with- and without-BFR additive using a sliding-spark detector unit. The light coloured plastic was all VDU monitor with BFR additive and the black TV casings were all non-BFR materials.

The sorting takes place based upon the X-ray transmission through each particle as it passes along a conveyor belt. High speed mathematical processing of the detected X-ray image enables the effects of thickness to be removed, such that the level of transmitted energy is entirely dependent upon the atomic density of the sample. Bromine gives an increased atomic density over non-brominated plastic materials, so this forms the basis for the detect-eject decision. Once more, a bank of air-jets is used to sort the material based upon the detection data.

The results of the trial showed that it is possible to remove an essentially bromine-free fraction from the plastic mixture, although this was at the expense of a loss of non-bromine material to the reject stream.

6 Colour Sorting trials

Colour sorting was investigated as a means to beneficially improve the quality of the finished polymer material post sorting and granulation. Trials were conducted on two commercially available colour sorting machines using mixed WEEE plastics at the 3-8mm particle size range. In both sets of trials it was proved possible to sort dark particles from light particles to generate a clean, light-coloured fraction. This adds value by allowing the recyclate to be coloured with masterbatch to suit end-user requirements. Colour sorting technology is well established as a means to improve particulate materials and it worked well on the WEEE plastic samples tested in these trials.

7 Electrostatic Separation

The use of electrostatics was investigated using two different methods to remove contaminants from the plastic material and also to investigate separation of polymer types, such as HIPS from ABS.

The machines trialled employed two methods of static charging to create the sorting forces:-
Tribo-electric sorting technology based upon the different tendency of materials to take-on static charges when brought into contact with each other and the walls of a charging chamber, or
Corona Discharge Ion-bombardment charging using a very high voltage electrode to transfer high density static charges onto the surface of particles.

The first method proved to be partially successful at removing wooden contamination from a mixed polyolefin stream. During trials to separate HIPS from ABS there was an enrichment of the two fractions to a 75:25 mixture of ABS/HIPS, but this will probably not be of sufficient purity to yield high grade polymer outputs. Earlier separation of rubber from PVC using this technology had proven very successful, demonstrating that the degree of separation achievable is fully dependent upon the static charging behaviour of the individual plastics within the infeed mixture.

A corona discharge machine was used in an attempt to remove wood particles from a mixed, polyolefin rich sample. The method did bring about a reasonable separation of the wood material but with some loss of plastic, although this did take two passes through the machine. It is fair to state that the primary application for the corona discharge sorting method is the removal of conducting metals from non-conductive plastics (i.e. copper filaments from PVC / PP cable insulation).

Objective 'C' – Technical, Commercial and Environmental Impact
Axion Recycling have carried out an assessment of the technical performance of each different technology trialled as part of the above work programme. This has been presented as an analysis of the separation efficiency achieved with the various types of samples used in the trials. In most cases it has been possible to give data about the capital cost of each technology and to quote estimated throughput rates based upon the large scale trials conducted. However in some cases it was not possible to run full-scale trials on equipment, because the technology providers were not able to handle tonnage quantities of the plastic waste. In these instances an assessment of the throughput performance was not possible.

The environmental impact has been assessed by looking at a total plastic recycling process, because the impact of individual machines has little meaning for comparison with an equivalent process to produce virgin polymers. The main impacts of a mechanical recycling process made up of a series of machines of the type investigated in these trials is the combined consumption of electricity used in motor drives. In particular the powerful motors needed on size reduction equipment and for thermal extrusion to make finished pellets of polymer product are the main power users in any plant.

Axion have utilised data from earlier research conducted by external consultants as part of the WRAP funded BFR Extraction Project. In this work the total CO_2 emissions associated with recycling one tonne of WEEE plastic has been compared with the amount of CO_2 produced to manufacture one tonne of virgin material (e.g. ABS, PS, PP). This study indicated that:-

Recycling of 1 tonne of clean plastic chip by mechanical methods produces 90 kilos of CO_2. The same recycling process plus conversion to extruded pellet, produces 115 kilos of CO_2 .The equivalent production of virgin styrenic polymers creates an emission of 2,600 kilos CO_2 per tonne. (Ref – APME website – Eco-profile data for polymers 2005)

It can therefore be stated that every tonne of mechanically recycled plastic give a 95% saving in CO_2 emissions by way of substituting the need for new virgin plastic to be manufactured.

Conclusions

This report gives a brief summary of a series of trials carried out on individual items of process equipment as part of the overall task of recycling WEEE plastic waste. In terms of configuring a total process to deliver high grade polymers as a product from the input waste material, there is no single answer to the question, "*What is the optimum plant layout?*".

The designer of a process for the task of separating plastics from WEEE must first clearly define the limits of the range of raw materials that are going to be handled and their delivery formats. The degree of pre-processing that has taken place at the upstream treatment plant will affect the amount of processing needed at the plastics recycler. For example, finely shredded plastic from fridge treatment sites needs minimal size reduction in comparison to baled CRT casings.

The exact choice of polymer processing technologies will also depend upon the required output material quality in terms of polymer purity.

In general it can be stated that most WEEE plastics plant will require technologies that carry out the initial clean-up of the material, by removing the non-plastic contaminants as follows:-

- Size Reduction – primary
- Metal removal – ferrous / non-ferrous / stainless steel
- Fines and dust extraction
- Wood and rubber removal
- Stone and glass removal
- Further Size Reduction - secondary

The above process steps should deliver a clean, accurately sized mix of granules into the polymer separation stages, at which point there is a choice of technologies to be used:-

- Increased-G Density Separation
- Infra-Red Light sorting
- X-Ray Transmission sorting
- Electrostatics

- Colour Sorting

The benefits and limitations of these technologies have been described in the trial reports.

The following conclusions are highlighted as important findings from the project to be considered in overall process selection:-

- Size Reduction is important, it is needed to:-
    - liberate different materials joined together as one component
    - standardise the size of particles for the clean-up stages
    - granulate to a close size-distribution for polymer type separation
    - present a free-flowing granular product to customers
- Metal Removal is likely to be needed at more than one step in the process. All shredding and granulation equipment requires upstream metal removal to protect the machinery from damage. Final products will need to be metal-free to meet customer quality standards.
- Induction Sorting is seen to be a novel approach to removal of all metal types in one piece of machinery in comparison to traditional magnetic and eddy-current systems.
- Polymer Type separation using increased-G density separation in the liquid phase works well, provided that the correct choice of centrifuge is made for the defined job. In these trials the Flottweg Sorticanter gave very accurate density cuts and did some partial drying of the plastic granules.
- Sorting for polymer type on the basis of accurate liquid-phase density separations only works if the infeed material contains a simple mixture of plastics across the target density range. Complex materials with high additive and filler content will move individual polymers outside of their normal '100% pure' density range and make the separation task impossible under this method.
- NIR sorting technology can handle polymer type separation of the main plastic groups (e.g. styrenics sorted from polyolefins). In these trials the exact sorting of a specified type of polymer, such as 'ABS-only', from a plastics mixture proved less efficient. This sorting works best at larger particle size (30 – 50mm) and with a tight size distribution, this was not the case in these trials.
- X-Ray Transmission sorting showed good performance for removal of brominated additives from a plastics mixture.
- Electrostatic separation works best for simple mixes of plastic and is dependent upon the charging properties of each individual polymer in the mixture. Fine metal removal using a Corona discharge unit works well.
- Colour Separation of small granules was seen to work well in these trials as a way to add value to finished products
- Some success was seen on wood and rubber removal using air-blown Gravity Separators in this work programme.
- The combination of Impact or Hammer Milling of plastic streams with a high residual metal content (>15% metal) with a Gravity Separator as the metal removal stage, was seen to deliver a high grade of clean metal spheroids from the waste stream. The effect on the plastic in this process was less beneficial. This approach would be best applied at a primary WEEE treatment plant as part of the metal recovery operation.

Recommendations

The following recommendations are directed to process designers or plant operators who are considering investment in WEEE polymer separation plant:-

- Select the minimum number of different input plastic streams, in order to minimize the complexity of the separation task.
- Check and define the format of the delivered-in plastic material from different suppliers, to make sure the plant can handle any variations.
- Ensure adequate metal removal steps are included throughout the process. Failure to provide good protection to size reduction machinery will cost dearly in terms of high wear and increase the likely occurrence of a catastrophic failure caused by metal ingress.
- Make careful analysis of the mixture of plastic types found in all different input streams and use this information as the basis for the selection of polymer sorting technology. This analysis to include an evaluation of additive content, in particular flame retardants.

- Choice of the most suitable polymer separation technology should be based upon the above analysis. Density separations are unlikely to be successful with complex mixtures that include polymers with high filler and additive content. In those cases, a combination of the dry sorting technologies described in this report will be needed.
- Conduct full-scale trials of all main process steps before committing to purchase.

Main Implications of the Findings

One of the main findings from this work that has clear implications in the treatment of E&E waste equipment, is the fact that the polymer streams arising from primary WEEE plants are highly co-mingled and contaminated mixtures of different materials. Even with the well defined streams of plastic arising form the treatment of CRT screens and refrigeration goods, there is still a lot of pre-processing to be carried out before the task of polymer separation can take place. When dealing with the mixed plastic from bulk treatment of small WEEE, the degree of variation in the plastic mix is even greater, as are the number and type of contaminants. This makes the processing task of recycling high-grade polymers from WEEE plastic waste even more difficult.

The main result of this problem of highly mixed input waste material, is that the extraction of a useable fraction of high-grade single polymer type can only be achieved at low yield based upon the total input tonnage. There is then a large proportion of mixed plastic which cannot be easily recycled back into saleable product due to the incompatibility of the polymer types and the high incidence of fillers and additives (such as BFRs) found in the material.

It is apparent that the majority of WEEE treatment plants in the UK will be operating on a mixed-bulk basis, with shredding or fragmentising of the whole electrical items as the leading technology approach. This means that the majority of the WEEE plastic arisings being created over the coming months will have the problems of contamination and mixing described above.

Further work is therefore needed to understand how best to tackle the processing challenge represented by the residual fraction of plastic that is left-over after separation by the methods described in this report have taken place. In particular it has been found that the incidence of brominated flame retardants in some waste streams is very high (e.g. IT and computer VDU plastic scrap). In plastic waste from small household and large white goods, it has been found that there is a high level of heavily filled plastic and these material tend to broaden the range of densities associated with each common polymer type. It is not possible to separate these materials by density methods.

If the recycling targets set in the WEEE Directive are to be achieved for the small household WEEE material, then some additional methods of processing this residual plastic mixture need to be found. This requires further work looking at the areas of:-

- Extraction of Brominated Flame Retardants from the plastic matrix
- Development of compatibliser additives for thermoplastic mixtures to produce viable polymer blends with acceptable physical properties to suit market applications
- Recovery of extracted fines, wood, rubber and minority plastic types by environmentally sound methods

It is important that the primary WEEE treatment processes being implemented across the UK are properly controlled and audited to make sure that the principles of 'Best Available Treatment and Recycling & Recovery Technology' (BATRRT) are being put in place. This can only occur with proper enforcement of the legislative requirements, without which the WEEE plastics stream may well become the best method of waste disposal for the primary processor.

Finally it is essential to level the playing field for European WEEE polymer processors by ensuring that exports of mixed WEEE polymers and streams such as CRT polymer that contain high levels of legacy additives such as BFRs are strictly controlled to ensure that they are subject to the same controls and processing requirements as material processed within the EU. If this does not happen then European recyclers will continue to be disadvantaged and both innovation and investment will be restricted.

Axion Recycling gratefully acknowledge DEFRA funding support for this research project. The use of brand names for some of the commercial equipment tested during the work programme does not represent any endorsement of particular brands by either Axion or DEFRA.

Appendix 1 – Polymer Types in WEEE Plastic & Glossary

The mix of the primary polymer types found in WEEE plastic waste has been widely reported, however in summary the main groups of plastic types are as follows:-

Polyolefins – this term is used to described the thermoplastic polymer materials which are manufactured from oil-derived monomers, mainly ethylene and propylene. The polymerisation of these monomer compounds into long chain structures produces a range of plastics, which are dominated by the two materials:-

Polyethylene - abbreviated to PE
Polypropylene – abbreviated to PP

In a typical sample of mixed WEEE plastic one would expect to find between 5 – 20% of these polymers. They are usually identified by their ability to 'float' in water as the pure plastics have densities less than 1.0 gram/cc.

Styrenics – The styrene monomer is the basic building block of this group of plastics. It includes a benzene ring grafted onto the base ethylene monomer molecule. Polymerisation of this produces polystyrene plastic (PS) , often associated with its expanded form as packaging foam – expanded polystyrene (EPS). There are many developments of engineering plastics based around the styrene building-block, these include more complex blends or alloys of different polymer types which can also include 'rubber-like' elements to increase flexibility and toughness of the final material. Some of the polymers mentioned in this report include:-

ABS - Acrylonitrile-Butadiene-Styrene

PC/ABS - a blend of polycarbonate with ABS

HIPS - high impact polystyrene (contains some butadiene)

Typically the styrenic fraction of any WEEE plastic sample will account for 30 – 70% of the mixture.

Other plastics in WEEE
Some of the other polymers mentioned in this report and found as minority fractions of the mix are :-

PVC – polyvinylchloride
PU – polyurethane – mostly from foamed insulation in fridges
PA – polyamide – commonly called 'nylon'
PMMA – polymethyl methacrylate – acrylic or Perspex
POM - acetal
PET - polyethylene terephthalate

More detail can be found at websites of the APME http://www.plasticseurope.org/Content or BPF http://www.bpf.co.uk/bpfindustry/plastics_materials.cfm Useful information on the properties of commercial grades can be found at www.matweb.com

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

At the time of writing the project Axion Recycling has held one major dissemination event. This was a mini-exhibition of the main technologies tested during the project and 17 suppliers of equipment attended the event at Newark Showground on 11th July. Axion Recycling gave an overview of the main project research and findings, as well as a presentation by Dr Roger Morton on the WRAP funded BFR Extraction project which was related to this DEFRA work. Over 120 people attended the event from within the UK recycling and WEEE treatment industry, with positive responses being obtained form most visitors and exhibitors on the format and style of the day's programme.