SYNTHESIS REPORT
(FOR PUBLICATION)

Contract n^o: **BRPR-CT96-0247**

Project n^o: **BE96-3243**

ELECTROSTATIC RECOVERY OF PAPER AND PLASTIC PACKAGING WASTES (ELREC)

Project co-ordinator:	**ERA Technology Ltd**	**GB**
Partners:	**Hamos GmbH**	**DE**
	Komotini Paper Mill SA	**GR**
	HLC Henley Burrowes Ltd	**GB**
	University of Southampton	**GB**
	Fundación GAIKER	**ES**
	Ragn-Sells AB	**SE**
	KTH Polymerteknologi	**SE**

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1. Summary

1.1. Keywords

Recycling, electrostatic separation, plastics, paper, municipal solid waste

1.2. Results and benefits of the project

The ELREC project has developed a range of versatile new dry materials separation technology that is already finding a wide range of applications. The technologies find application in areas where manual sorting was previously the only option, and also have allowed separation of materials that were previously not previously possible, especially plastics separation.

The new electrostatic separation technology has been demonstrated at pilot plant scale. Separation of tetrabrik from mixed plastics, separation of PE and PP from a floating output fraction, and PVC and PET from a sinking fraction, has been demonstrated and evaluated by Gaiker in Spain. Separation of PE and PP has been evaluated at pre-production scale by Ragn-Sells in Sweden. Both these plant demonstrated potential viability of the plastics separation process.

KTH Polymerteknologi have worked closely with Ragn-Sells, particularly on output plastic quality analysis and plastics properties characterisation. They will promote development of recycling market through dissemination of material analysis techniques, and building market knowledge and confidence in recycled material quality and properties. They, and the University of Southampton, are applying the knowledge gained in the project in education and knowledge transfer to industry.

Gaiker and Hamos have tested a variety of samples and demonstrated electrostatic separation to many recyclers across Europe. Gaiker, Hamos and other partners are promoting transfer of electrostatic technology into mainstream practice, as well as looking for specific niche applications. Hamos have implemented the electrostatic separator units as production systems and have sold several to clients. A wide variety of applications have been demonstrated and new applications are arising.

ERA are promoting recycling, by organising Conferences on Waste from Electrical and Electronic Equipment (WEEE) and other recycling topics. Their subcontractor, Electrostatic Solutions Ltd, will continue to work with the ELREC partners developing electrostatic separation technology.

HLC Henley Burrowes are looking for opportunities to include the plastics separation technology in future municipal solid waste recycling plant developments.

Further Information on the Internet:

Web URL	language	description
www.era.co.uk/Recycle/index.htm	English	ELREC project web site hosted by ERA Technology Ltd. Links to all ELREC partner contact points.
www.hamos.com	German Spanish English French	Describes the Hamos range of electrostatic separator products, including those developed in the ELREC project. Very informative about the advantages of electrostatic separation.
www.rss-fukia.se/english.htm	English	Information on the Ragn-Sells plant progress
www.rss-fukia.se/svenska.htm	Swedish	
www.static-sol.com/recycling	English	Electrostatic Solutions pages on electrostatic separation in recycling and the ELREC project.

2. The Consortium

2.1. ERA Technology Ltd

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ERA is Project Co-ordinator of the ELREC project. Their technical role is in the development of electrostatic separator technology targeted at specific recycling industry user applications.

ERA has considerable expertise in research and development in materials and electrostatics applications and technology. ERA believes electrostatic separation technologies will find an important new area of application in separation and improvement of waste materials for recycling, ranging from removal of impurities (e.g. in composted materials) to separation and improvement of paper or plastic grades, and electronic waste materials recovery.

2.2. Electrostatic Solutions Ltd

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At the start of the ELREC project Dr Jeremy Smallwood was Electrostatic Section Leader at ERA, leading project technical development work. In March 1998 he left to set up Electrostatic Solutions Ltd, and subsequently continued working on the ELREC project for ERA as a subcontractor.

Electrostatic Solutions Ltd contributed significantly to ERA's electrostatics R&D programme and has a strong interest in further development of electrostatic separators and their applications.

2.3. Hamos GmbH

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Hamos GmbH is an EU market leader manufacturing, developing and selling electrostatic and electromagnetic separator systems for the recycling industry. Over 60% of its product is exported to a wide range of user clients across the EU and international markets.

The Hamos product range includes a wide range of magnetic and electromagnetic metal detector and separator systems, and electrostatic separator systems separating plastics, metals and other materials. Hamos is a small dynamic company of around 20 people, all of whom are highly qualified in their fields.

2.4. Fundación Gaiker

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Gaiker is a Technological Centre with 80 employees and 20 granted students founded in 1985 as a joint venture of several companies interested in R&TD in Material Science and Biotechnology. Gaiker's Foundation includes 57 associated companies (including paper mills, packaging industries, etc.), with interests in one or more of its four Knowledge Areas: Plastics and Composites, Environment, Recycling and Valorisation and Biotechnology.

Gaiker's fully equipped laboratories feature extensive materials identification, test and processing facilities. Gaiker has developed a hydrocyclone based waste separation system that is already finding application in the recycling of mixed plastic wastes. Gaiker is now implementing an extensive 5 year programme in technological development in the field of separation, compatibilisation and reprocessing of plastics. It has a strong relationship with several waste management and plastics recycling companies, which show keen interest in technology transfer in the recycling of plastic wastes.

Gaiker has participated in 3 Brite EuRam projects on mechanical recycling of plastics and is Project Co-ordinator of one of them. Gaiker is currently conducting 5 projects on valorisation of industrial wastes (including compatibilisation) for major Basque recycling companies, such as "PVC-Styrene Copolymers Blends for Automotive Industry" or "Compatibilisation of Thermoplastic Material Mixtures".

2.5. HLC Henley Burrowes Ltd

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HLC Henley Burrowes plc has considerable experience and an international capability in the construction and operation of MSW valorisation plant. Their core business is the processing and separation of Municipal Solid Wastes, making extensive use of recycling, energy from waste and other valorisation methods. In order to maintain a competitive edge in this market it is a commercial necessity to maximise revenues from the sale of these recycled material output streams. MSW comprises on average 28% paper, 5 % plastic film, and 4% dense plastic material. Their experience shows that the quality of separation of these materials is the key to efficient recycling.

In the ELREC project, HLC Henley Burrowes key role is the construction and installation of pre-production processing plant at Komotini and Ragn-Sells sites, and the construction and evaluation of an experimental MSW separation pilot line at their site in Worcester, UK.

2.6. KTH Polymerteknologi

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KTH Polymerteknologi is primarily interested in research and development of polymer manufacturing processes, engineering design, materials test, recycling of polymer materials, and polymer environmental issues. KTH is part of the Royal Institute of Technology, the largest Technical University in Sweden, which has developed an important industrial co-operation network. KTH has 70 employees, of which 64 are RTD personnel. KTH has strong links with Ragn-Sells and participates with Ragn-Sells in the foundation Ragner Sellberg for R&D waste management, and the recovery of raw materials from wastes.

KTH's role in the project is particularly linked to Tasks involving Ragn-Sells, where they provide R&D expertise and considerable EU project experience, to complement Ragn-Sells industrial capabilities.

2.7. Ragn-Sells AB

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Ragn-Sells is the largest of two large private enterprises within waste management in Sweden, with a yearly turnover of 1.8 MSEK and 1,500 employees. In fact, it is a fairly large group of specialised business areas, working together in Sweden, Norway, Denmark, and Estonia.

The activities of Ragn-Sells AB include management of industrial, municipal and special wastes from collection at site to design and running of landfills and deposits, recycling facilities, incinerators, water and sewerage treatment plants etc. plus environmental consultancy for third parties. Ragn-Sells is strongly developing from being a traditional waste transporter, to being a broad service and knowledge supplier, emphasising material recycling and energy utilisation as the "new" solution to waste problems.

Ragn-Sells brings significant industrial resources to this project, together with large opportunities for technology exploitation. Their key role is to host, build and evaluate a pre-production plant separating polyethylene and polypropylene from Swedish domestic packaging waste

With their wide materials recovery interests, Ragn-Sells see a wide range of opportunities for future spin-offs in applications of electrostatic separation technology. Strong and productive links have existed between Ragn-Sells and KTH for some years, exploring polymer recycling issues and opportunities.

2.8. Komotini Paper Mill

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Komotini's main activity is the production and trade of tissue paper products (toilet paper, kitchen towels, napkins) and cardboard. It employs 207 people and has a production capacity of 8,000 tonnes of tissue paper per year and 5,000 tonnes of kraft paper per year. As raw materials it uses 60% recycled paper and 40% pulp. Some products are made from 100% recycled paper and it is looking to expand this area.

Komotini collects and separates waste paper with a capacity of 20 tonnes/day. Separation is carried out manually. Automation of this process using electrostatic techniques will enable increased efficiency, lower costs and increased production. An increase in output of 80% is required to satisfy current demand. This work is in line with Komotini investment towards a cleaner and healthier work environment.

Komotini is involved in several other environmental initiatives including EEIG-EUROKENAF (concerning research in pulping the annual non-wood plant Kenny) of which it is a co-founder.

2.9. University of Southampton

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University of Southampton Department of Economics has an outstanding record of research in Econometrics and Economics, and has attracted the highest UFC rating (5) since 1989. The Department has particular research interests in Econometrics, Labour Economics, Inter-Regional Economics, Environmental and Resource Economics and Macroeconomics, and has ongoing international collaboration projects including current collaboration in EC funded research projects and networks.

Alan Ingham (BSc, MSc) has been lecturer in economics since 1973 and specialises in the economics of the environment and natural resources, the role of international agreements, and the use of incentives and financial instruments in environmental protection and resource conservation. He an invited member of the CEPR European Research Network on Economic Policy for the Environment, visiting Research Fellow at the University Catholic de Louver, Belgium, and visiting Professor at the University of Frankfurt.

Prof. Steve Thomas is an econometrician and Professor of Financial Markets in the Department of Management specialising in Financial Markets and Applied Economics, and has extensive experience in market modelling, economics of the environment. He applies this experience in consultancy, executive teaching, and managerial economics, and is economic strategy consultant to Charterhouse Tilney Securities. With the Financial Times, he is founding editor of two global business publications.

The University of Southampton's role in the ELREC project is to apply economics expertise to developing and understanding and modelling of the paper and plastics recycling markets, and to develop strategies for improving the viability of recycling processes, based on this knowledge.

3. Technical achievements

3.1. Development of new recycling technology

The ELREC project has developed new electrostatic separators, feeder and conditioning technology for recycling applications, and demonstrated the technology at pilot plant level. The importance of feeder and conditioning technology, particularly in the paper and MSW paper-plastic film separation, has been underlined by pilot plant trials. There is still scope for some improvement in these areas.

Types of separator developed include;

- Corona charged belt separator (CBS), suitable for separating papers, or papers and film plastics.
- Triboelectric charged belt separator (TBS) suitable for separating plastic pellets and flake materials
- Levitation belt separator (LBS), suitable for separating materials of two different conductivities such as tetrabrik and plastic

The new separators, developed by ERA Technology Ltd (UK) and Hamos GmbH (Germany), are based on the use of conveyor belts rather than the conventional drums used in previous designs. The

Corona charged Belt Separator (CBS) is a direct development of conventional drum separator technology, used in this project for separation of waste papers on the basis of their different electrical conductivities. The electrical properties of paper are highly dependent on their complex behaviour in absorbing moisture from the atmosphere. Much development by Gaiker (Spain) went into researching paper behaviour and developing moisture conditioning and feeder systems for the pilot plant.

In the CBS separator electrical charge is "sprayed" onto particles on the conveyor belt, causing them to stick to the belt and continue to travel along underneath the belt. Charge is gradually lost from the particles, which fall from the belt into bins after a time. More insulating particles retain charge and stick to the belt for longer, resulting in separation. Heavy particles do not stick and fall as rejects from the end of the belt.

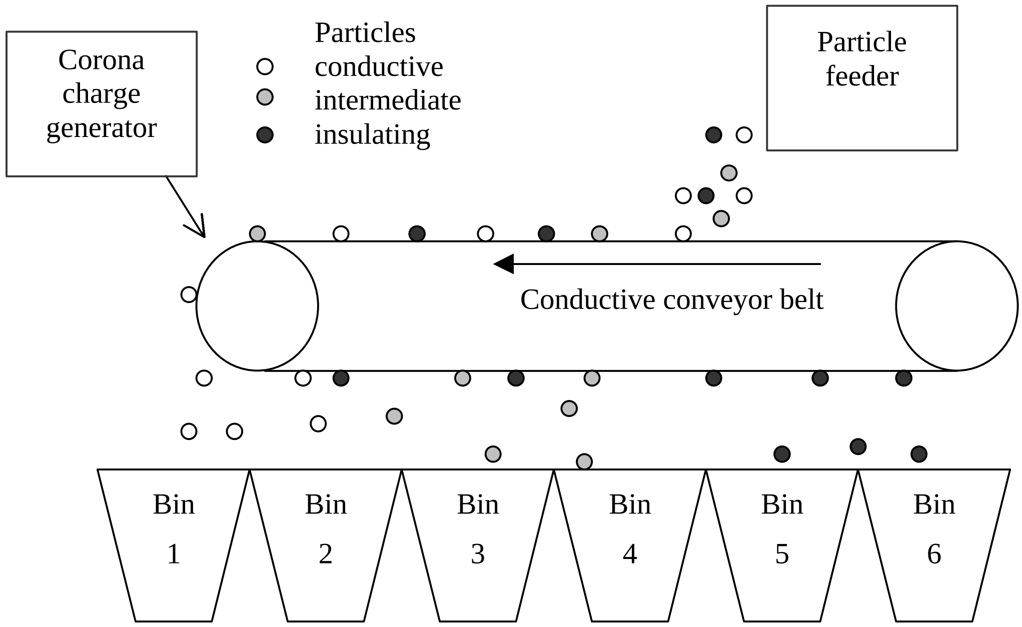

Figure 1. The Corona charged Belt (CBS) Separator

The CBS system was also used to separate paper and plastic film from UK "black bag" MSW, in a pilot plant built at HLC Henley Burrowes (UK) Malvern site. The material is an output stream from conventional MSW plants, and is highly contaminated.

The Levitating Belt Separator (LBS, Figure 2) works on a completely new principle, and was developed for separation of tetrabrik from mixed plastics. This separator uses and electric field to charge the conductive tetrabrik particles. The charged particles then levitated in the field and are entrained in an air stream that transports them from the separator as a tetrabrik rich output fraction.

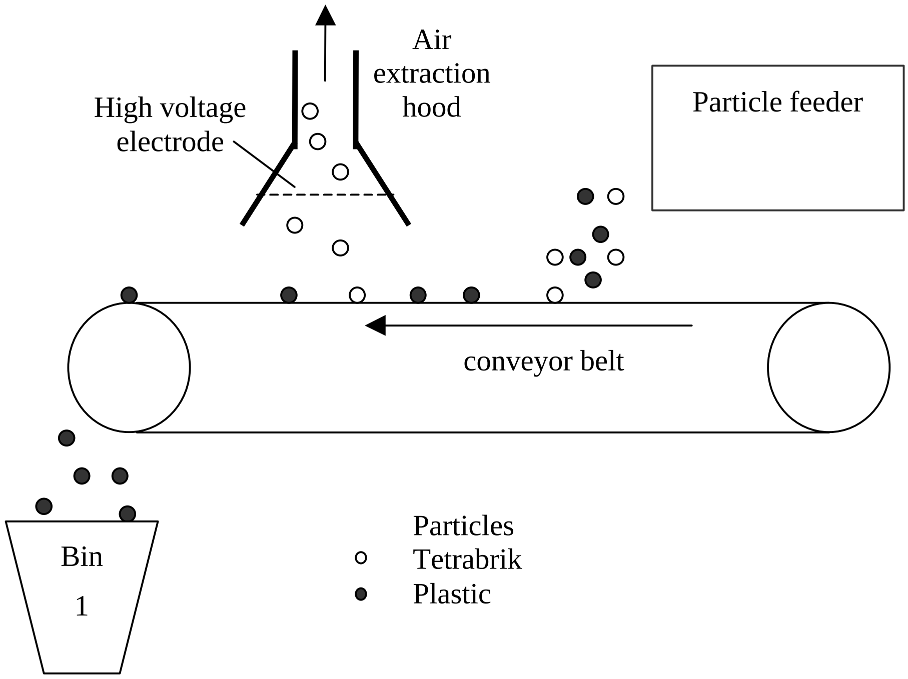

Figure 2. Levitating belt separator (LBS) system

The Tribocharged Belt Separator (TBS, Figure 3) unit is particularly suited to separating plastic particles. In this separator, plastic particles, which are conventional flakes 5-15mm in diameter, are charged by surface contacts (triboelectrification) in a specially designed feeder unit. The charged particles fall onto the conveyor belt, and are carried into the separation region. A high voltage electrode attracts particles of one polarity, while repelling particles of the opposite polarity, and achieves the separation.

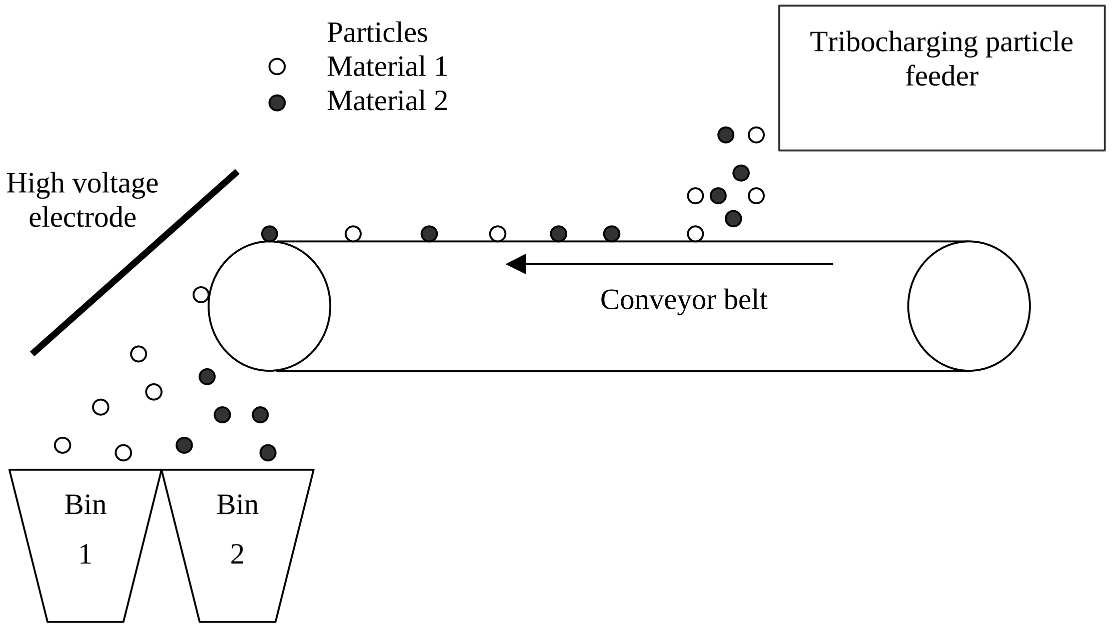

Figure 3. Tribocharged belt separator (CBS) system

The TBS separator was tested at small scale by Gaiker in Spain, separating PET and PVC from a sinking fraction, and PE and PP from a floating fraction from their MSW pilot plant. They also demonstrated separation of engineering plastics such as ABS and fire retardant ABS, from electronic equipment waste.

The user partners and technology developers have gained valuable experience in the preparation and conditioning of materials prior to separation. In paper separation, the dependence of paper properties on moisture content, and the hysteresis effect in the moisture - ambient humidity relationship, have been investigated. The difficulties caused by this behaviour have been overcome by development of drying and moisturisation conditioning techniques.

In plastics separation, drying techniques were required to optimise triboelectrification. The charging process was further improved by including equipment clean the material surface. Uncontrolled charging of the sample before the separator was countered by introduction of a purpose built ioniser equipment to discharge the material before the tribocharging stage.

Correct separation depends, especially in the recovery of papers, on the correct feeding of material onto the separator belt. The sample must be evenly spread as densely as possible, without overlapping or inter-particle interference. Gaiker developed feeder technology to optimise particle feed to the electrostatic separators, and conditioning systems to bring the material moisture content reliably within required limits prior to separation.

Other problems arose and were overcome, such as the generation of paper dust and flock, leading to health risks and dust explosion or fire risks. The dust generation is much reduced by careful selection of shredder technology, or by sieving of the material. The fire risk has been much reduced, in not eliminated, by development of a special electrode system that appears to have successfully eliminated incendive sparks.

3.2. Applications of the CBS separator

3.2.1. Separation of waste paper grades

Separation of a variety of papers were demonstrated in the laboratory, and on a pilot scale separator. UK and Spanish newspaper and office papers proved particularly easy to separate due to the large difference between resistivities of the newspaper and office papers. Separation of Greek wood-free and wood-containing papers proved more challenging, as the properties of these materials were less well differentiated. These materials were, however, of particular interest to Komotini Paper Mill. In pilot scale separation a 68% pure fraction of wood-free material, with 45% recovery, was achieved. It will be possible to improve on this with improvement of shredding and conditioning processes.

Control of moisture content and shredded particle characteristics are highly important factors in achieving separation. Conditioning and shredding stages introduce high capital cost and high running cost process stages.

The separation process is therefore more likely to be viable where suitable shredding already forms part of and existing process. Costs may be reduced where the material characteristics are sufficiently dissimilar such that moisture conditioning is not required, or where such conditioning already is part of an existing process.

Paper is a highly variable material. The electrical properties (and hence electrostatic separation) are not always well correlated with paper grade. Each waste stream must be evaluated according to it's own characteristics. In many cases, but not all, newspaper and magazine papers from different EU countries can be separated under suitable conditioning and operating conditions. Plastic contaminant can be separated from news and magazine papers under suitable conditioning and operating conditions.

It seems unlikely that electrostatic separation will, in the short to medium term, handle the high throughput volumes required of general production paper separation. The need for significant pre-conditioning of all the material and its likely associated costs tends to make this uneconomic.

Komotini expect that the technology will be best suited for more specialist separation of pre-sorted material. This is particularly attractive since a larger increase in value may be obtained by purification of an output fraction in this area. However, Komotini predict that separation of wood-free and wood-containing papers will be viable.

Electrostatic separation, of paper waste, may in the short term be best suited to;

- Removal of contaminants and improvement of high value output fractions.
- Separation of low to medium quantity high value products, where a simple, reproducible clean source is available.
- Separation of papers where the electrical properties are different by a large factor (at least 2 orders of magnitude). This will reduce the dependence on for complex and costly conditioning stages.
- Applications where previous plant processes provide the sample already in a suitably shredded, or conditioned, form. In general, the shredding and conditioning stages are the most costly parts of the process.

Improvement of the results by improved material shredding and conditioning is anticipated.

3.2.2. Plastics and paper recovery from conventional MSW

HLC Henley Burrows constructed a pilot plant in Malvern, UK to investigate separation of paper and plastic film from the output material from conventional UK "black bag" domestic waste recovery plants.

The trials carried out on the MSW sourced material over the test period have demonstrated the importance of sample moisture content, as influenced by ambient humidity. During the summer period, on test days with low relative humidity levels (of around 40%) it was found that a degree of separation was possible, which indicated that the use of an electrostatic system could be viable under controlled conditions. As the test year drew to an end the weather conditions in the area of the pilot plant site were the wettest since records began (over 200 years ago!). This has had the effect of rapidly affecting ‘dried’ samples, with the effect that moisture absorption caused results to deteriorate during the test run.

Contamination, coupled with high humidity resulted in mediocre performance, and the process is not viable for this waste stream at present. Nevertheless, a lot of useful experience was gained and these techniques will be open to exploitation with other cleaner waste streams in the future.

Pilot plant operation would be improved by including in-line facilities for drying and conditioning the material and the carrying air. Dust and flock in the "as received" waste, prepared using the shredding technology used in the conventional MSW plant, proved problematic and was removed by a pre-process screening operation.

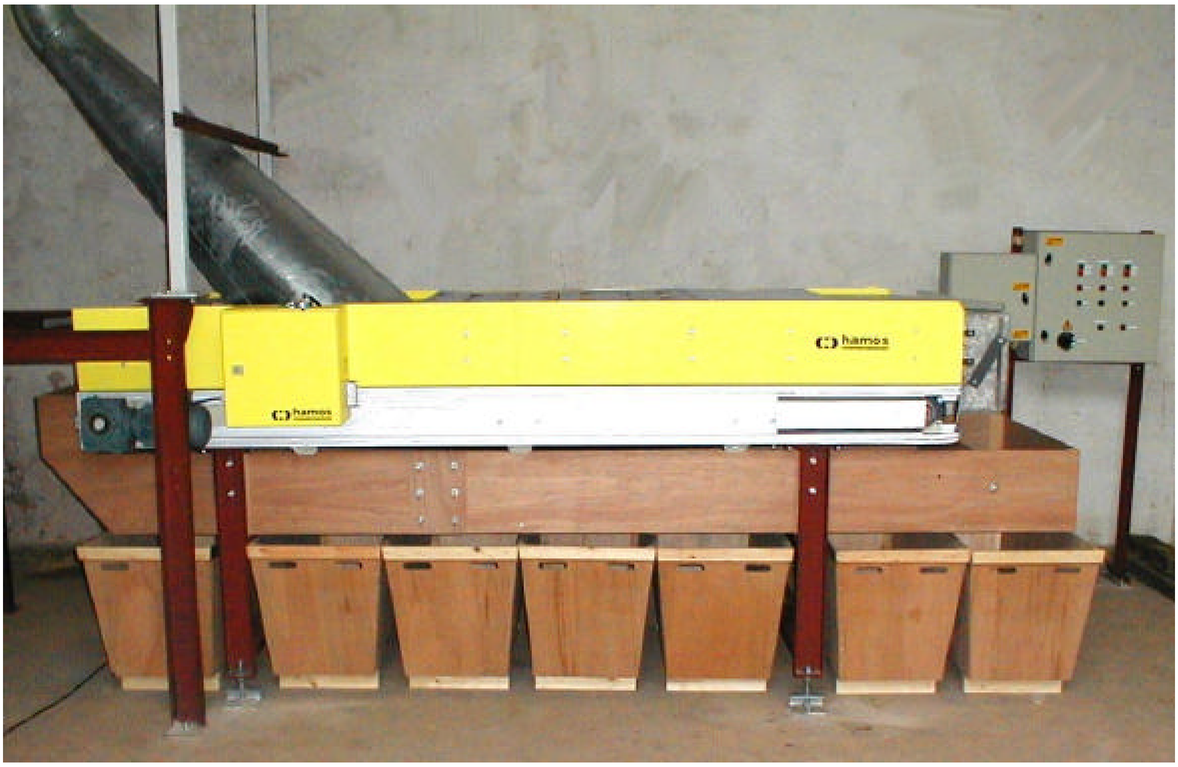

Figure 4. MSW separation plant at the HLC Henley Burrowes site in Malvern, UK

3.3. Applications of the TBS and LBS separators

3.3.1. Plastics recovery from the output of Gaiker's novel Spanish MSW plant

Gaiker have, in previous CEC projects, developed a novel MSW recovery system, which has as one output a mixed fraction of tetrabrik and mixed plastics, mainly HDPE, PP, PVC and PET. The first requirement is to separate tetrabrik from the plastics. A flotation separation is then performed, leaving a mixed HDPE & PP floating fraction, and a PVC & PET sinking fraction. These two mixed plastics fractions are recovered by electrostatic separation.

3.3.1.1. Separation of plastics from tetrabrik using the LBS separator

Automatic separation of milled tetrabrik and plastics (PP, HDPE, PVC and PET) was achieved using an LBS (Levitation Belt Separator) in a pilot scale plant at the Gaiker site. The LBS removed up to 85% of the tetrabrik fed in the initial mixture, in a single step. Using multiple stages, >95% pure tetrabrik, and a plastic fraction of purity and recovery both >98% were achieved. The plastics fraction was then fed into a flotation separator stage for density separation.

3.3.1.2. Separation of PE&PP or PVC&PET using the TBS separator

The automatic separation of PP/HDPE (floating packaging plastics) and PVC/PET (sinking packaging plastics) mixtures was demonstrated at pilot plant scale using a TBS (Triboelectric Belt Separator).

Working in a two step operation, 93% PP and 97% HDPE output purities were obtained. Separation of PE-PP in this way required further development because of its sensitivity to operational conditions, the similarity between the two materials (PP and HDPE are very similar materials including electrostatic behaviour).

In order to improve the PP/HDPE electrostatic separation a dry mechanical method of surface-cleaning of particles was included in the Ragn-Sells plant.

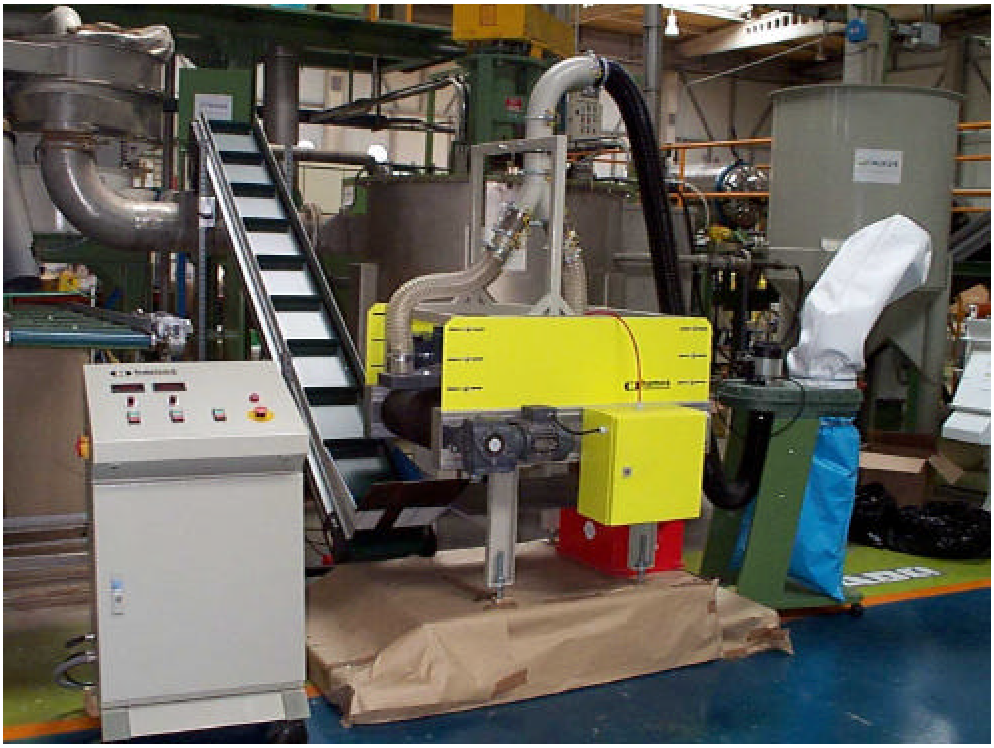

Figure 5 a) LBS separator for separating plastic from tetrabrik

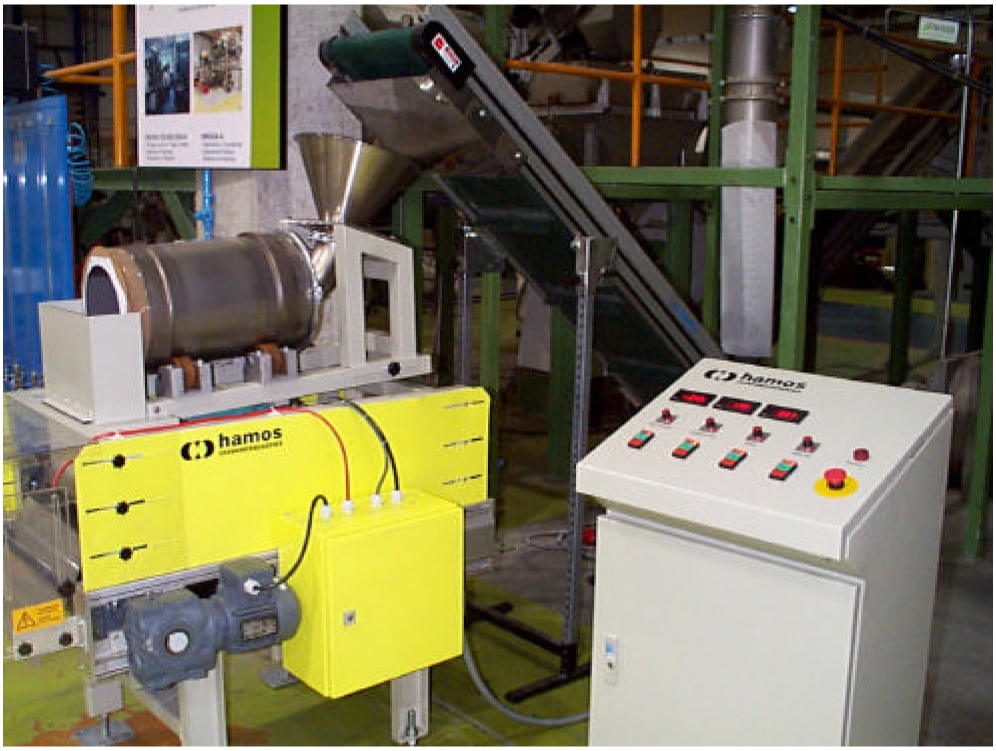

Figure 5 b) TBS separator for separating HDPE & PP or PVC & PET plastic

Figure 5. Electrostatic separators at Gaiker, Spain

The TBS plant, working in a two step operation, has obtained PVC 98% and PET 98% from the heavy fraction output from the Gaiker plant. The PET fraction obtained in the first step is run through a second stage in order to get a higher purity.

The quality of the PET and the PVC is not yet good enough for the market, which requires 99.9 % purity. In the case of PE, PP and tetrabrik, a first comparison of cost and benefit estimates a cost of 74 Euro/ton and the possible revenue of 68 Euro. With Spanish packaging green dot payment, currently fixed at 0.22 EURO/kg it can be considered viable. Electrostatic separation (which features very low operation costs) increases the quality of the sorted materials. The acceptance of the market is predicted to be improve and a better price may be achieved.

Figure 6. PE-PP separation plant built at Ragn-Sells (Sweden)

3.3.2. PE & PP plastics recovery from Swedish MSW at Ragn-Sells, Sweden

The TBS separator technology was tested at larger scale in a 250kg /hr PE-PP separation pilot plant, built at the Ragn-Sells site in Sweden. This allowed Ragn-Sells to evaluate process reliability and future requirements e.g. volumes and types of polymers to be separated. PE and PP were selected as they are the most common packaging materials in pre-separated plastics from Swedish households. Experience with the pilot plant is very encouraging, yielding 97-99% pure PE and PP product for some samples. Separation quality can vary with changes in temperature and humidity, so the input material is conditioned in a controlled dry air stream before separation.

Further exploitation of the technology is not just a technical problem. Market perception of the quality of the recycled material is important, and techniques must be developed for measuring output product quality with easy tests. The properties of product mixtures, which are typically less than 100% pure, must be demonstrated to be suitable for real market applications. KTH Polymerteknologi (Sweden) have addressed these issues in the project. KTH developed a method of analysis of output plastic material for monitoring and quality assurance of the recycling plant product.

Trials have been made using waste materials from several Swedish and German sources. Typical results are given in Figure 7 & 8. The sources of material in these cases were well known German recycling companies.

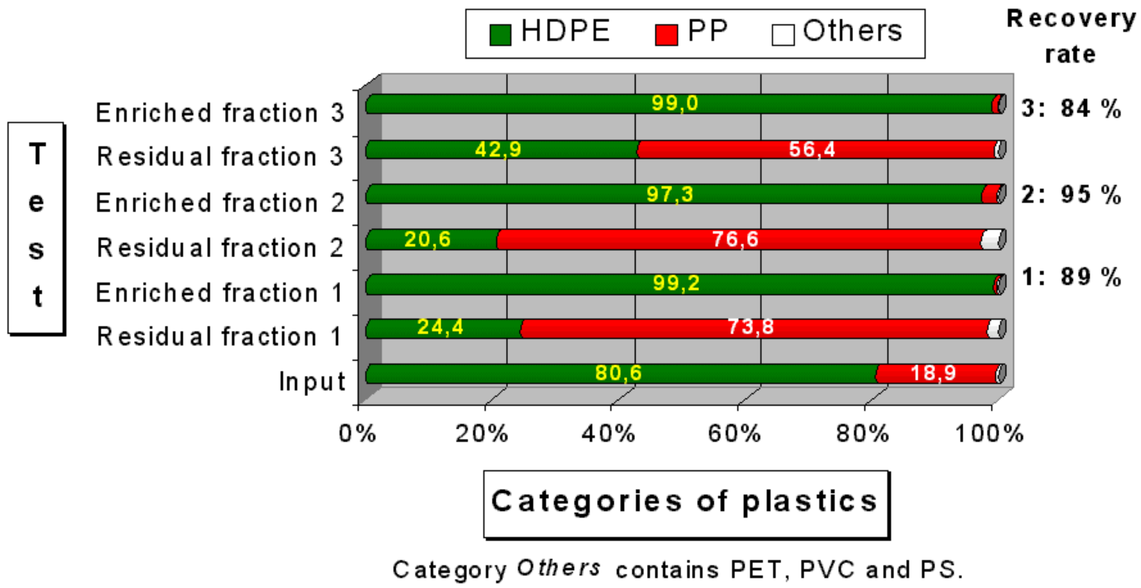

Figure 7 Results from separation of German recycled material Source 1

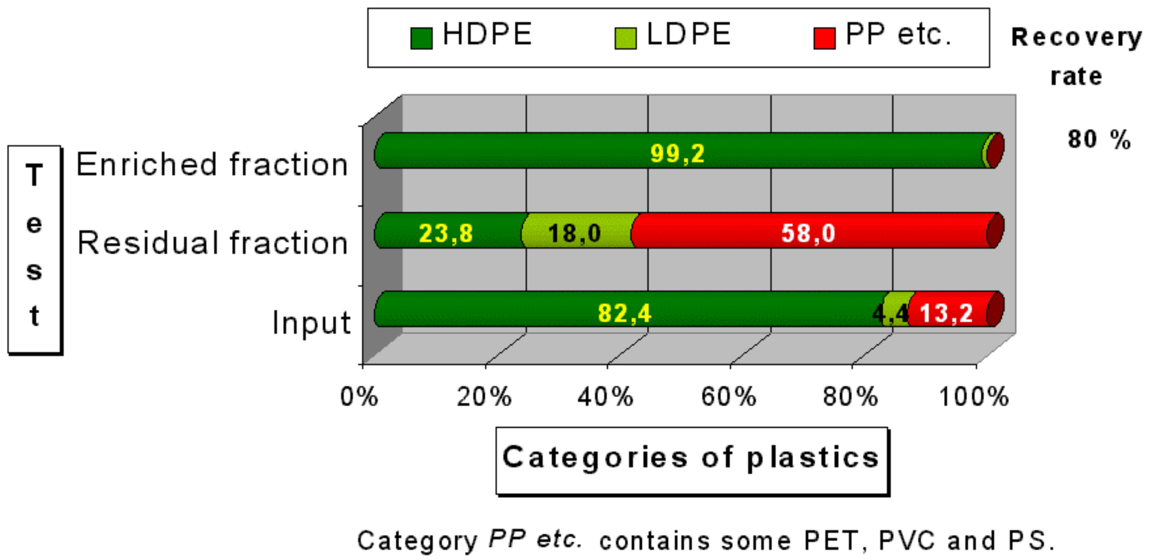

Figure 8. Results from separation of German recycled material Source 2

Tests separating rubber and PVC from scrap cable gave the following results;

Cable scrap sample	Rubber (% wt)	PVC or Cl (% wt)	Recovery
Initial content, separation 1	49	51	
PVC fraction, separation 1	11.6	88.4	87.3 %
Rubber fraction, separation 1		4.1 Cl	
Initial content, separation 2	48	52	
PVC fraction, separation 2	7.4	92.6	85.4 %
Rubber fraction, separation 2		4.5 Cl	

Clearly, useful separation has been achieved with a wide variety of materials at pre-production scale.

3.4. Marketing the new electrostatic separator technology

Hamos now offer production triboelectric charged (TDS) separator systems, based on ELREC designs, for professional applications (See www.hamos.com) . This is marketed as the EKS system family. One version of this was tested as part of the Ragn-Sells PE & PP separation plant.

The EKS triboelectric separator is supplied in single or double-stage units for low, medium and high throughputs of 1.500 kg/hr and more. Two-stage machines can either be used these in parallel mode for maximum production throughput, or in serial mode for second stage separation of one fraction. This adaptability enables the separator to meet practically all customers' requirements.

Model	Stages	Throughput (approx.)
EKS 0521-0	1	Laboratory and small production 200...350 kg/h
EKS 1021-0	1	400 - 750 kg/h
EKS 1022-1	1	Two machines in parallel for 1000 - 1500 kg/h
EKS 1022-3	2	500 - 1000 kg/h with subsequent separation of one fraction

The electrostatic separation system offers the following benefits compared to other systems;

- Separates plastic without separation liquids (dry separation process, no chemicals or auxiliaries necessary)
- Simple operation
- Low energy consumption
- High product purities
- Quick amortisation
- Low personnel costs

All production equipment is supplied as a standard with integrated material handling and automatic control. By integrating these into the device with big-bag filling stations for the finished products, Hamos offer a turnkey solution. Special designs are also built on request according to the customer's needs.

3.5. Industrial applications of TDS separators

During 2000 Hamos have separated many different materials for customers. Typically the customer sends a material sample of approx. 20 kg for separation tests in the Hamos laboratory. Hamos then demonstrate the purities and throughputs that can be obtained with the material. Based on the test results they submit a detailed quotation to the client.

Most of the inquiries received deal with the following products:

- Plastic-plastic mixtures
- Cable scrap
- Plastic production waste
- Plastic window frames
- Bottle caps
- PET beverage bottles
- Other plastic mixtures
- Post consumer household packing material (“DSD”)
- Plastics from automotive production scrap

Figure 9. The Hamos EKS used for recycling of PVC windows. This unit has been supplied with complete material logistics

3.5.1. Current applications using the Hamos EKS production separator for plastics sorting

3.5.1.1. Separation of PVC window profiles

The new EKS electrostatic separator is able to separate the rubber sealing from shredded PVC window profiles. During 2000 Hamos sold four machines for this application. A clean PVC fraction with a purity of more than 99,9% can be reached from a typical input PVC fraction containing approx. 5- 7% rubber. The few rubber particles remaining after this electrostatic separation can be separated with an opto-electronic colour sorter, to reach a practically 100 % clean PVC.

3.5.1.2. Separation of plastic from bottle caps

A leading recycler in Southern Germany recently installed an EKS electrostatic separation system for sorting of plastics from recycling of bottle caps. In the first separation step, a PE fraction with more than 99,5% purity is dry separated from a mixture of expanded PVC and PE. In a second separation step, a clean PVC product with a purity of more than 99 % is produced. The customer achieved high-quality plastic materials from poorly usable waste.

3.5.1.3. Hamos sold separation system for car plastics

One of the leading manufacturers of automotive plastics has an EKS separator for separation of mixed ABS and PMMA production wastes. Car tail lights are recycled using this system (Figure 11).

An ABS fraction with a purity of 99,8% can be achieved after shredding of the complete tail lights or parts of it. In a second separation step a clean PMMA fraction with a purity of 99,7% is achieved. Using electrostatic separation technologies, production wastes that have been incinerated can now be reused as valuable plastics.

3.5.1.4. Butler-MacDonald (USA) buys EKS

Butler-MacDonald (Indianapolis/ Indiana), one of the leading American plastic recyclers, has purchased an EKS system for the dry separation of plastic mixtures, to add to its range of separation facilities. Plastic mixtures from computer recycling, such as ABS and HIPS, can be separated into clean fractions.

3.5.2. Successful Separation of HDPE/PP-bottle fractions

The EKS system can separate HDPE/PP plastic mixtures from post-consumer bottle recycling (Figure 10). After a floatation separation the remaining floating fraction has a PP content of typically 5-20%. After drying a clean HDPE fraction with a purity of more than 99% can be achieved by triboelectric separation.

Figure 10 Separated HDPE-PP bottle fraction mixtures

Figure 11 Separated plastics from various mixtures

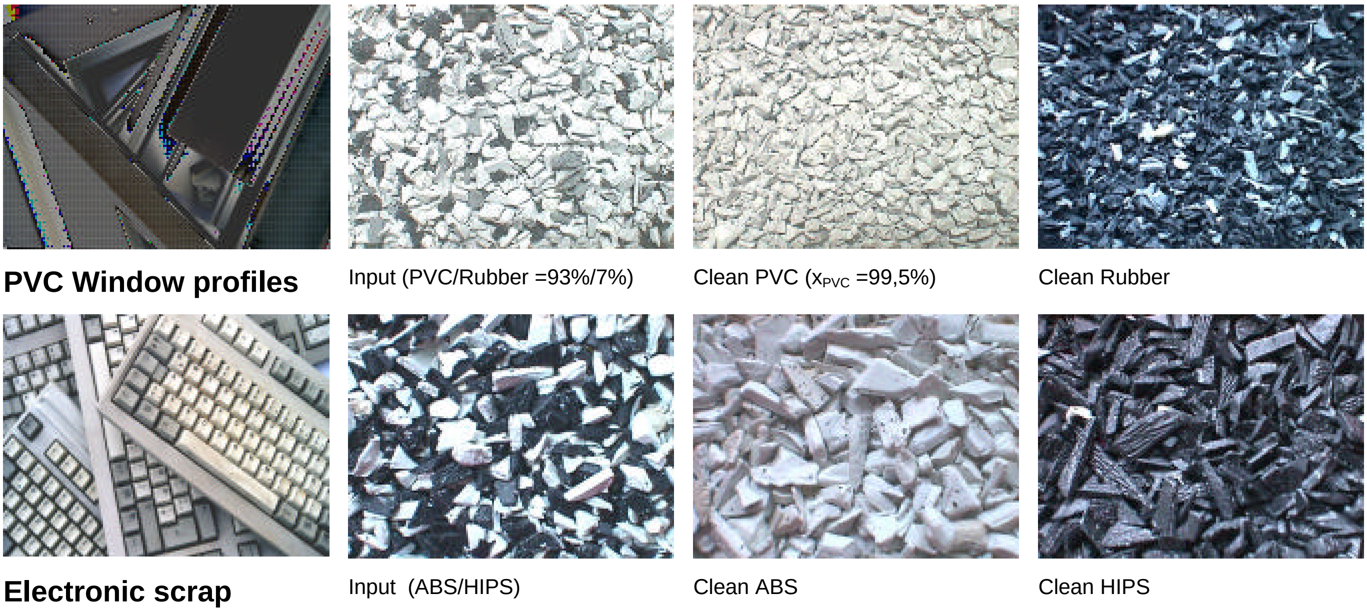

Figure 12 Separated plastic from various mixtures

3.5.3. Industrial applications of the CBS separator technology

3.5.3.1. Separation of X-ray films

X-ray films become obsolete after a certain time. They are recycled to recover the silver content and the polyester. As all X-ray films are packed in a paper envelope, a mixture of paper and plastic is produced as waste. At the moment, all X-ray films are extracted manually, making it expensive to achieve clean plastic output. Cost may be reduced by avoiding the manual separation step by shredding the X-ray films with the envelope. After shredding, the paper-plastic-mixture is processed in a wet system for further treatment of the polyester. The paper contaminant causes problems in this process, as wet separation of the paper from the liquid is not possible.

With electrostatic separation it is possible to achieve a clean plastic and paper fractions. A relatively good paper fraction is achieved (which goes to incineration) and an acceptable plastic fraction, which goes directly into the wet process. Figure 13 shows the results of the plastic-paper-separation.

Input Clean polyester film Clean Paper

Figure 13 Separated X ray film - a suitable application for the CBS separator

3.6. Research and development of economic strategies

A considerable amount of data, covering the supply and demand of virgin and recycled papers and plastics in Europe, has been collected together for the first time. As the markets are world-wide, data from US, Canada and the rest of the world was also included. A comprehensive bibliography was compiled covering these markets, and recycling policies and legislation and represents a unique and valuable resource for future work in this area.

Econometric models of supply and demand for virgin and recycled papers and plastics in the EU were developed and calibration, powerful statistical methodologies. This is the first time such modern techniques have been used in this field, where the available data is often poor.

Some of the barriers identified to establishment of recycled products in the market include;

- established suppliers of virgin materials do not like it (reduces use and price)
- new suppliers, immature markets, fixed costs of entry
- need to jump start demand, no suppliers-no demand

The main market forces for recycled products include;

- rising prices for virgin materials used as production inputs making recycled products price-competitive
- rising disposal costs for solid waste
- transportation costs are significant
- processing costs highly dependent of material

Consumers do not bear the full marginal social cost of disposing of their recyclable waste. The marginal cost of throwing away a bag of garbage is zero, while the social marginal cost is greater than zero. Programs to provide incentives to consider externalities include;

- develop better pricing structures for waste collection
- refundable deposits, easily accessible consumer information

Some conclusions are that current policy is to increase collections of waste material for recycling whilst not promoting demand (market price low and unstable). Future policy may need to be more material specific.

3.7. Paper recycling market

Mixed waste paper often ends up in landfill. There are limited users of this material due to extra capital costs required to use mixed waste paper feedstock. Prices can be depressed from supply fluctuations and availability of competing materials. Market development would follow from encouragement of capital investment in paper mills using mixed waste, and the promotion of secondary products made from mixed waste paper.

Paper price is strongly influenced by global considerations. The crisis in Asia, especially in Indonesia, is leading to a flood of low priced fibre in an attempt to boost revenues. Lower virgin wood chip prices drive down the price of recycled paper. Future developments will also depend on world factors such as exports from Russia, and consolidation in the paper and pulp industry in Europe and in Asia.

3.8. Plastics recycling market

3.8.1. Overall plastics market conditions

There is substantial interest in plastic container recycling, but processing structure and end markets are not well developed. Reprocessing prices are usually low relative to costs. Virgin plastic supply is growing quite rapidly, whilst recycling is growing at a lower rate. Market drivers for many types of plastics are new uses as plastic replaces glass, paper and metal. The supply of PET bottles is growing fastest. New developments appear imminent such as the use of composite materials such as PET with an impermeable core, PEN (Polyethylene naphthalate) and HDPE bottles with PVC sleeves (labelling). The separation of these materials will be important.

Plastic film also forms an important part of the waste stream. Markets for recycled film could have strong impacts on overall effective recycling rates.

Prices have fallen for both PET and HDPE. Recent events in Asia have led to substantial exports of low cost resin, with the consequent knock on effects for recycled resin. However recent increases in the price of crude oil will have some effect on nullifying part of this.

Greenhouse gas emissions are required to be reduced in line with the Kyoto protocol. The reduction falls to the domestic sector with consequent very high energy prices and political unpopularity. One solution is to achieve reductions by increasing storage in carbon sinks. Energy companies in North America anticipate being able to use carbon sequestration as a way of avoiding reductions elsewhere, probably through use of Tradable Permits.

An important conclusion is that recycling of plastics will reduce GHG emissions and can therefore act as a method of carbon sequestration. If a method of trading and paying for carbon sequestration were to be introduced then this would become an additional source of revenue for recyclers to be added to that obtained from the sale of material.

On this basis it seems that it could be profitable to recycle plastics even at zero or negative output material prices, as long as the output material did not give rise to GHG emissions.

3.8.2. Supply of plastics, market demand and confidence

Whilst it is preferable if the market rewards sound resource use within its own profit margins, since the market never considers external costs, political intervention becomes necessary. Examples are economic incentives for the development of material recycling by taxes on landfilling and incineration, subsidies paid by authorities, or fees paid by consumers to finance recycling of products after use. As regards plastic packaging, Swedish consumers pay a weight-based fee. Such a system seems to be less well supported within the EU.

A current barrier to further recycling of plastics is the problem of establishing user confidence needed for sales. Ragn-Sells have found a very widespread conservative bias against recycled plastics. The form of the material may be important - the market prefers extruded and granulated recycled plastics to flaked recycled plastics.

Part of the suspicion is that supplies and quality cannot be guaranteed. This uncertainty either demands compensation by a risk premium in the form of a much lower buying price than for virgin plastics, or hinders business. Useful standards for recycled plastics are still missing. Many in the business believe that such standards will be necessary to really expand the use of recycled plastics in other than low-tech products like plastic bags etc. Standards must be formulated in a way that fits producers and consumers and does not create unnecessary bureaucracy. They have to become widely accepted and therefore rely on some kind of official status, imposing their break-through.

Evaluating today's situation, attitudes need to mature, and economic measures must put pressure on other plastics-containing products than packaging. The European co-ordination work must ensure that the industry meets the same pressures in all member states. An alternative viewpoint is that the waste definition must be changed to exclude recyclables. Product designs must be better adapted to recycling, including easy demounting, a reduction of the number of used materials, and common standards for the choice of materials in the same type of products.

3.8.3. Cost model: Example of the financial benefit of Separating Plastics by Polymer

The following example shows a simple cost model of the potential benefit of plastic separation in a recycling plant. A mixed input material is priced at £10 per tonne and separated with a throughput of 5000 tonnes per annum (TPA). The value of the output materials is significantly increased, even though only a total of 33% of the input mixture is recovered.

	Material	Quantity (tonnes)	Price per tonne (GB£)	Total Value (GB£)
Input material	**Total mixed plastics**	**5000**	10	**50000**
Output material	Mixed plastics	3362	10	33620
	PET	438	90	39420
	HDPE	750	80	60000
	PVC	450	25	11250
	Total	**5000**	**N/a**	**114290**
Prices for both mixed plastics and Separate polymers are from Materials Weekly				

4. Exploitation plans and follow-up actions

4.1. Ragn-Sells

RS and the associated Ragnar Sellberg Foundation are members of the non-profit organisation KretsloppsCentrum (in English: the Recycling Centre) (see www.kretsloppscentrum.org) with several university colleges, research institutes, local municipalities, and other companies. The Ragnar Sellberg Foundation has an ELREC Project web site See www.rss-fukia.se). Ragn-Sells and KTH are also developing market links with European plastic recyclers, the Network for Plastics and the Environment, Plastkretsen AB and the Swedish Environmental Protection Agency. RS plans to promote market development by introducing Plastkretsen to the possibilities now offered by electrostatic separation in separation of plastic packaging in Sweden.

Ragn-Sells is developing 14 collection sites with basic pre-sorting of domestic packaging plastics in Sweden. This creates a fundamental need for an advanced treatment method. Cost calculations indicate that there is a clear economic benefit in using the ELREC system. Markets, rather than costs, appear to be the main obstacle and Ragn-Sells is actively working to eliminate this barrier.

Ragn-Sells is strongly considering electrostatics for sorting WEEE material, including plastics from TV sets, computers and other sources, in the near future.

4.2. KTH Polymerteknologi

Exploitation by KTH lies in three areas;

Education for industry of Masters of science and PhD. with a deep knowledge about recycling of polymers in particular, but also in handling of material waste,

Transfer of scientific knowledge to industry to enable them to further develop automatic and economical sound recycling business and

Transfer of information to the scientific community about the latest knowledge. These three parts contribute to the development of a globally sound sustainable society.

Studies of different methods for quality assessment and assurance of recycled plastics have already lead to the publication of three scientific papers, with a manuscript in preparation.

Development of analytical techniques, which allow rapid and non-destructive analysis of samples, will tremendously reduce the personnel and laboratory costs and consequently the production cost of the recyclate. In addition, the possibility of on-line monitoring and constant control of the recycling process is attractive. Specification of physical and chemical properties of recyclates should be provided and guaranteed between narrow tolerances by manufactures, if the recycled material is intended to compete with virgin material in high performance applications.

KTH is working with Ragn-Sells to further strengthen co-operation within the Recycling Enterprises via Seminars and discussion meetings arranged for SME's and large industries

4.3. Hamos

Construction and sales of industrial separator systems to the materials recycling markets is central to Hamos core business (see their web site www.hamos.com). The ELREC project has resulted in new designs of electrostatic separator that Hamos have now brought to market, as separator modules or as complete turnkey materials recycling solutions. Several EKS systems are already sold, and a wide variety of separation applications have been demonstrated. Hamos actively market their products at recycling Workshops, Seminars, and Exhibitions and through articles written for trade journals.

Hamos is specifically seeking new applications for the ELREC electrostatic separator technology, in particular;

Separation of plastic mixtures, plastic - rubber, and other insulating solid materials using the TBS technology, and marketed as their EKS separator range

Separation of shredded plastic-paper, packaging and other similar materials (such as X ray film) using the CBS separator technology

Electrostatic separators for electronics waste recovery, based on the ELREC separators

Complete plant based around electrostatic separators

Development of new variants of electrostatic separator s to meet specific user needs.

4.4. ERA Technology Ltd.

ERA is acting as the main contact point with two EC Thematic networks. The TRA on Polymer Materials is particularly relevant in the context of markets for recycled polymers and their properties. The Thematic Research Action on Waste Minimisation and Recycling (TRAWMAR) is relevant from the wider technological applications of the ELREC technology.

ERA Technology has recently undergone management and structure changes that have led to recycling technology work no longer being seen as strongly aligned with ERA's planned business directions. Amongst the current activities to be developed are Services in electronic system Failure Analysis and lead free solder technology. ERA has an active Conference department who will continue to organise Conferences and Seminars on recycling issues such as WEEE.

4.5. Electrostatic Solutions Ltd

Dr Jeremy Smallwood worked with ERA over the duration of the project, most recently as a subcontractor with his consultancy company Electrostatic Solutions Ltd (ESL). ESL will work with the ELREC partners in exploiting the technology and future electrostatic separation technical development, and will maintain strong links with ERA Technology, Hamos and Gaiker in particular. The results of the ELREC project are also finding application in ESL's consultancy work and specialist electrostatics training. ESL, developing ELREC exploitation activities.

4.6. Komotini

Komotini intends to further study the electrostatic separation of wood-free and wood-containing paper. They plan to construct paper separation plant to demonstrate viable paper separation on a pre-production scale.

4.7. Gaiker

Gaiker gives demonstrations at its facilities to national recycling companies, covering not only packaging waste recyclers but also the electric and electronic or automotive recyclers and any other industries interested in these separations. Gaiker has also included the electrostatic separation equipment within its "tour for visitors".

Gaiker has tested the electrostatic separation of many different samples: PS and metalled film mixture, PET and paper mixture, saffron and straws mixture, electrical and electronic plastic wastes, films and mixed plastics fractions from selective collection of packaging waste, cellulose and plastics from sterilised incontinence residues.

Future publications are planned in technical magazines, including the more relevant results of electrostatic separations that have derived from the project completion. Presentations at technical meetings will also be used for dissemination of electrostatic technology awareness.

Gaiker will collaborate with partners to offer electrostatic separation within its services. Gaiker will promote the transference of electrostatic technology to industrial practice by in-plant demonstration of mixed materials separation. Gaiker will actively develop custom solutions for the separation of specific streams and the integration of electrostatic separators in production and/or recycling lines.

4.8. HLC Henley Burrowes

4.8.1. MSW Separation

More development is required before separation of papers and plastics from conventional MSW waste, will be an attractive option. The main application would be removal of plastic from waste intended for fuel. This gives the benefit of pollution reduction, with output of recovered plastics which can be sold on to generate an additional income stream. The market will require a capacity of the order 25-50t/hr, and an estimated target 75% recovery of plastic (for sale). For the moment, MSW separation would require stimulus such as legislation, greater economic benefit or penalties to stimulate viability.

4.8.2. Plastics separation

The situation for plastics separation is promising. HLC Henley Burrowes regularly tenders for new recycling plant construction, installation and operation contracts across Europe. Future tenders will include plastic separation in future plants, where inclusion of plastics separation will add value and income from purer output products. HLC HB estimates the plastics separation technology could be in full scale plant use within 5 years.

4.9. University of Southampton

The University of Southampton continues to educate and disseminate through publications and presentations. This year's work on the econometric analysis of recovered paper prices has been followed up with completion of a research paper comparing recycled and virgin material prices in terms of cyclicality, volatility and trends using recent econometric advances.

Two research papers on the econometric behaviour of recovered paper prices and virgin material prices together with Value-at-Risk calculations are currently near completion. Exploitation will be via the dissemination of these findings to the business community via journals and further seminars.

5. References

5.1. Publications

Title/Authors	Publication details
Sorting of recovered polymer materials in relation to their long term properties. Frida Stangenberg.	M.Sc. Thesis. KTH Polymerteknologi. Materials samples supplied by Gaiker to KTH, and work arising, were reported. Supervisors: S. Karlsson, KTH and S. Ågren, Ragn-Sells.
Recycyling of mixed plastic fractions: mechanical properties of multicomponent extruded polyolefin blends using response surface methodology. S. Tall, A-C. Albertsson and S. Karlsson	Journal of Applied Polymer Science, 1998.
Improvements in the properties of mechanically recycled thermoplastics. S. Tall, S. Karlsson and A-C. Albertsson.	Polymers & Polymer Composites, 6(5), 261 (1998).
Mutual compatability at low contamination levels for recycled ABS, talc-filled PP and high-impact PS. S. Karlsson, S. Tall, M. Colgnaghi, L. Maffioli and A-C. Albertsson,	Submitted for publication
Quantification of antioxidants in polyethylene by Near Infrared (NIR) analysis and partial least squares (PLS) regression. W. Camacho and S. Karlsson	International Journal of Polymer Analysis and Characterisation In press.
Quality determination of recycled plastic packaging waste by identification of contaminants by GC-MS after microwave assisted extraction (MAE). W. Camacho and S. Karlsson	Polymer Degradation and Stability 71 (2001) 123-134
Pulp and paper price cycles Isabel Andrade	Submitted for publication
Quantitative methods for compositional analysis of blends based on recycled polymers. W. Camacho and S. Karlsson	Polymer engineering and science Accepted.
Simultaneous determination of molecular weight and crystallinity of recycled HDPE by infrared spectroscopy and multivariate calibration W. Camacho and S. Karlsson	Journal of Applied Polymer Science. Submitted for publication
"Separación por medios electrostáticos" R. Miguel, E. Larrauri, S. Arnaiz, I. Cacho, C. Robertson, J. Smallwood, J. Coit, R. Ufer and R. Köhnlechner,	Residuos, 54 (2000) 62-67
An econometric analysis of recovered waste paper prices. I Andrade, S Thomas	Proc. Int. Symp. Recovery and Recycling of paper. Dundee, 19th March 2001. Ed. Ravindra K Dhir, Mukesh C Limbachiya, Moray D Newlands. Thomas Telford. ISBN 0 7277 2993 4. Pp 43-56
Recovery and improvement of waste papers using electrostatic separation techniques. J Smallwood , C J Robertson	Proc. Int. Symp. Recovery and Recycling of paper. Dundee, 19th March 2001. Ed. Ravindra K Dhir, Mukesh C Limbachiya, Moray D Newlands. Thomas Telford. ISBN 0 7277 2993 4. Pp 115-126

5.2. Meetings & Conferences

Date	Meeting/Conference	Notes
10th September 1997.	Seminar on Electrostatics and Environmental cleanliness. Institute of Physics, London	ERA Technology presentation “Electrostatic separation of papers and plastic in waste paper recycling”
27-28th October 1997	IDENTIPLAST,International Conference and Exhibition, in Brussels, Belgium.	KTH presented paper "EPDM Elastomers as Impact Modifiers for High-Density Polyethylene Contaminated with Polypropylene, Polystyrene or Poly(ethylene terapthalate)"
September 1998	TRAWMAR (targeted action on waste minimisation and recycling) The TRAWMAR meeting was held in Greece	Gaiker presented on behalf of ERA and the Consortium a paper concerning the achievements to date of reached in the ELREC project.
30th September 1998	Triboelektrische Kunststoffseparation 3. Rudolstädter Recyclingtag in Rudolstadt.	Hamos presented paper
23rd Feb. 99	Recycling Electrical and Electronic Equipment 1. , London	Proceedings published as ERA Report. 99-0025
February 1999	PROMA 1999, Bilbao	Gaiker presented a paper in the environmental technical exhibition and conference.
February 1999	VI Congreso de Ingeniería Ambiental - Residuos, Cartel R2, Bilbao (Spain), 1999.	Separación por medios electrostáticos de papel, cartón y plástico en diferentes calidades. Larrauri, E., Miguel, R., Arnaiz, S., Robertson, C., Smallwood, J. and Coit, J.
24th-26th April 1999	Identiplast II Conference, Brussels	Gaiker and Ragn-Sells attended.
April 15th 1999	Seminar “The fate of our used resources”, Stockholm.	Seminar arranged by Kretsloppscentrum and Ragn-Sells. KTH attended.
May 31st to June 2nd 1999	Nordic Polymer Days, Copenhagen, Denmark.	Prospects and Obstacles in Recycling of Mixed Plastic Waste S. Karlsson and A-C. Albertsson.
14th-17th June 1999	“Analysdagarna”, Uppsala, Sweden.	Microwave assisted (MAE) extraction of antioxidants in polyethylenes W. Camacho and S. Karlsson.
September 1999	Global Symposium on Recycling, Waste Treatment and Clean Technology (REWAS '99), San Sebastian, Spain,	ERA presented paper
13-15 October 1999	2nd International Conference on Solid Materials, Lisbon	ERA presented paper

Date	Meeting/Conference	Notes
24th November 1999	Recycling Electrical and Electronic Equipment 2. , London	Proceedings published as ERA Report 99-0867
26th April 2000	Meeting with the Network for Plastics and Environment, hosted by RS	Presentations on plastics research made by KTH
1st September 2000	OKR-Workshop, Bad Neuenahr	Hamos presented practical results of PE/PP separation system
8-9th September 2000	Society of Plastic Engineers Annual Recycling Conference, Dearborn (USA)	Hamos presented 3 Papers about electrostatic plastic separation
14th -15th September 2000	Kunststoff-Recycling-Kolloquium 2000 (FKUR-Meeting), Krefeld Germany	Hamos presented on Electrostatic Separation
11th October, 2000	IEEE Annual Meeting, Rome (Italy)	Hamos presentation to Presentation at the Electrostatic Processes (EPC) Committee Meeting
24th October 2000	Conference of European cable recyclers, Brussels	Hamos demonstrated TBS separator
1st November 2000	Meeting with the Network for Plastics and Environment	RS presented separation results
4th December 2000	A seminar on possibilities and incentives for using recycled plastics in new products	60 representatives from industries and authorities present. Arranged by Plastkretsen, Association of Swedish Recycling Industries, KTH and KretsloppsCentrum.
21-22rd February 2001	Workshop on the importance of sorting for the recycling of plastics	In liaison with Dr Eva Ahlner, Swedish EPA. TRA CL IV
20th March, 2001.	Symposium on Recovered Paper in Dundee, Scotland	An econometric analysis of recovered waste paper prices. I Andrade, S Thomas
20th March, 2001.	Symposium on Recovery and Recycling of Paper in Dundee, Scotland	Recovery and improvement of waste papers using electrostatic separation techniques" J Smallwood (Electrostatic Solutions Ltd) and C J Robertson (ERA Technology Ltd)

5.2.1. Presentations of production electrostatic separator equipment at trade fairs

Date	Meeting/Conference
26– 29 June 2000	ENTSORGA , Köln
12– 14 September 2000	RECYCLE, Birmingham (GB)
17– 20 October 2000	Pollutec, Lyon (FR)
17– 21 October 2000	Fakuma, Friedrichshafen
08– 09 November 2000	ARC-Meeting, Dearborn (USA)
08– 11November 2000	Ricicla 2000, Rimini (IT)