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Starting a Waste Plastics Recycling Business

Report Prepared For

Aberdeen Forward and Aberdeenshire Council

By

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Great credit must go to the staff of Scottish Recycling, in particular Malcolm Cunningham and Neil Cordiner. They not only had the courage to start a Plastics Recycling company but also the humility to allow their trials and tribulations to be aired in this publication. While their desire to create an environmentally sound, financially viable company failed, their experiences may help formulate future policies on plastics recycling and assist aspiring plastic recyclers to achieve profitability.

The visit to Plastic Polymer Processors Ltd was the highlight in our information gathering. Managing director Charles Forrest's practical approach was a real insight into successful waste plastics recycling.

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Bob Pringle and Mike Barker

Starting a Waste Plastics Recycling Business

Report Prepared for Aberdeen Forward and Aberdeenshire Council by
R T Pringle, SAC and Dr M B Barker, Napier University - March 2004

Executive Summary

Introduction

1. In October 1999, Scottish Recycling started recycling waste plastics into fenceposts and plastic lumber. SAC was brought in subsequently to help develop further plastic lumber products. Funding for SAC's input was supplied by Aberdeen Forward, Aberdeenshire Council, and from Landfill Tax Credits.
2. In December 2000 Scottish Recycling went into voluntary liquidation. Funding for SAC continued, but the objective changed to providing guidance for future waste plastics recycling businesses. "Starting a waste plastics recycling business", is the outcome.

Scottish Recycling

3. Scottish Recycling in its short life had more problems than the staff could cope with. In hindsight, its collapse was inevitable. Problems included:

- lack of suitable feedstock
- lack of expected support from local businesses
- inability to achieve the quoted throughputs from the extruder
- difficulty of manufacturing products from contaminated and variable feedstock
- poor price and lack of markets for manufactured plastic fence posts and boards
- product failure
- difficulties in quality control
- public expectation to satisfy a public good

4. Were Scottish Recycling to start producing again, a period of 12 months would be required after producing the business plan to install the manufacturing system, organise the sourcing of materials, develop and market test the products and establish a quality control system.

How we may use Plastics in Future

5. To determine the opportunities for recycling waste plastics, the likely way we use and reuse plastics in the UK should be reviewed.

6. At present 5% of all plastics, and 4% of plastic bottles manufactured in the UK are recycled, an increasing percentage of which is being sent to China for reprocessing.
7. To reduce wasting a valuable resource, bottles should be refillable and have a deposit, packaging should be reusable where practical, and non-refillable containers made from materials such as steel which is simple to retrieve in waste facilities. Plastic packaging containing food should be biodegradable, so that it can be discarded with food waste for composting.
8. PVC, which can produce dioxins when burnt, should be restricted to uses where it can be processed using closed-loop recycling, so that it can be kept out of the municipal waste stream. Residual, dirty plastics, with paper labels attached in the municipal waste can then be burnt with little impact on the environment.
9. Plastics waste recycling companies should be set up to recycle material which will still become available for recycling after the above recommendations come into play.

Types of Plastic Materials

10. There are six main types of plastics in the municipal waste stream. Most are incompatible with each other either when melted or when solid, so have to be separated for reprocessing and reuse. Separation is labour intensive, so adds cost to a relatively low value recycled product.
11. Thermoplastics, which soften on heating, are capable of being re-melted to produce new plastics products. Thermosets, as used in printed circuit boards, for example, cannot be symmetrically reshaped on heating. They can be recycled only if used in their original state for another purpose or if they are ground up and used as fillers to reduce cost in other plastic products.
12. Plastics, especially waste plastics, need to be designed differently from wood products, to overcome the materials limitations and take advantage of its advantages. Where possible, plastic recyclers should therefore leave the making of plastic products to manufacturers already in the field, especially as they have at present under-utilised extruding and moulding capacity. Recyclers can then specialise on producing substitute plastic feedstock from recycled waste.
13. Plastic lumber can be made from a mix of waste plastic types, with fillers used to reduce the cost of the feedstock. The low melting point plastics act as a glue to bind other incompatible plastics and fillers.

Plastics Likely to be Available for Reprocessing

14. The amount of waste plastics, which should become available in the municipal waste stream in any geographical area, can be estimated by multiplying the proportion of the UK population in the area with the UK plastics use per person. This allows the potential throughput of the business to be assessed.
15. Data on the use of plastic by the commercial sector is provided, so that an estimate can be made of the amount and type of commercial plastic waste becoming available annually.
16. In Germany recycling of waste plastics receives the highest subsidies of all materials recycled, to ensure plastic is recycled as part of the Green Dot packaging recycling scheme. The lower subsidies in the UK compared with Germany, together with the devaluation through unlawful practices of the

"Packaging Recovery Notes" scheme, makes waste plastic recycling in the UK currently marginal, or unviable.

Alternative Plastic Recycling Strategies

17. Entrepreneurs setting up a recycling company have a number of options. They can:-

- Recover and bale plastics for sale to recyclers at home or abroad
- Recover plastics and shred it for sale to plastic product manufacturers or recyclers as shredded single type plastic
- Melt and re-extrude shredded plastics into new pellets for use by plastics product manufacturers
- Shred mixed plastics and re-extrude with filler to produce plastic lumber
- Convert mixed plastics to their chemical constituents for use as feedstock for manufacturing new plastics

18. The most reliable sources of plastic waste are local authorities and the open market. Relying on a single company's waste for feedstock is risky. Their aim will be to minimise waste, reducing the feedstock available to the recycler. Should the waste producer fail, or change its products the supply of feedstock may disappear altogether.
19. Recycling of high quality pre-consumer and post-consumer waste plastic can be a profitable occupation as illustrated by the Grangemouth recycler, Plastic Polymer Processors Ltd.

Setting up a Plastics Recycling Business

20. The recommendations given by RECOUP for setting up a recycling business for recycling plastic bottles, including sourcing bottles, separation required and bale size are summarised.
21. Processes to identify, inspect, shred, wash, separate, and re-extrude plastic waste are described. The production of plastics lumber is described. The value of product is compared with the cost of the various processes and transport of material produced. Where possible a gate fee should be charged on all waste material sourced.

Physical and Structural Properties of Plastics Materials

22. Plastics are long chain molecules that are solid at room temperature. They have different properties compared with wood. Plastics can melt, twist, creep, sag or become brittle and snap. These characteristics can catch out the unwary plastic reprocessor, turning a splendid new product into a waste material, which has then to be disposed of at his expense.
23. The recycled plastics should be sold to an agreed specification. This requires the producer to test his product. This not only acts as a quality control within the business but the information can be passed on to the customer so that they can set their extruding machinery accordingly.

24. As a minimum, the recycler should be able to measure melt flow rate to assist with subsequent processing, impact strength of the reprocessed product and density. Other tests may include:

- Tensile strength
- Elongation at break
- Surface hardness
- Flexural strength
- Creep if product is to be under load
- Electrical resistance for electrical applications (eg electric fence posts).

25. Since recovered waste plastics from different sources will have a range of additives in them, the precise amount of additive in the final mix will be unknown. Additives may have to be added to the re-extruded plastic to produce a feedstock with the required characteristics. The addition of chemical compatabalisers allows normally incompatible plastics to be combined in a product, though this is likely to increase the cost of the final product.
26. Structural tests carried out on plastic lumber show how the addition of wood flour as a filler helps to produce a non-degradable plastic material that more closely resembles the beneficial properties of wood, such as reduced creep, ease of nailing and reduced weight.

Product Development

27. To illustrate the approach needed to develop a new product, the design of a plastic lumber farm fencing system was selected. The traditional fence system was analysed, the methods of erection discussed, and the designs for alternative fence systems selected. A market survey was undertaken to establish a potential selling price. Only by carrying out such a development exercise could an assessment on the profitability of the exercise be made.

Help in Starting a Business

28. 28. Starting a business is fraught with risks of initial over-investment, cash flow problems, inadequate marketing and failure to anticipate problems. Every potential entrepreneur will gain from visiting his local Small Business Gateway.

The SBG staff will give guidance, help develop business and marketing plans and possibly help access supplementary funding.

Glossary

Agglomerator	Machine for increasing the density of flakes of LDPE film.
Amorphous state	Polymer molecules are in random disordered array
Anisotropic	The molecules of an amorphous polymer put under tensile stress when heated will tend to align themselves in the general direction of the stress. On cooling the molecules will be frozen it this aligned state. The tensile strength of the resultant polymer in a direction parallel to the molecules will be greater than the original material, while at right angles to the molecules it will be less. The polymer is thus anisotropic.
Blow moulded	A short tube of melted plastic is extruded and trapped in a mould. Air is blown in to the centre of the plastic tube, so that the plastic takes up the shape of the mould cavity. Typically used to mould bottles, tanks and drums.
"Bring" system	System of Civic Amenity sites, where householders bring recyclable materials to deposit in separate containers for plastic, glass, paper, textiles, etc., so that the contents can be taken for recycling.
Char	Irreversible decomposition of plastics when heated above their melting points.
Chemical recycling	Plastic is converted back to its constituent chemicals.
Closed-loop recycling	Where plastic waste is recovered separately from other plastics and reprocessed to form new product, usually with some virgin polymer added. Useful, particularly for PVC, to keep it separate from general plastics recycling.
Compounded	Shredded plastics and additives mixed together prior to extruding.
Contraction	Shrinkage of plastic, usually as it cools.
Covalent	A chemical bond in which two or more atoms are held together by the interaction of their nuclei with one or more pairs of electrons.
Creep	Continuous deformation of a plastic material under an imposed load.
Crystalline state	Chains of the polymer are closely aligned in an orderly manner.
Devolatisation	Removal of entrained gasses and steam from molten plastics. Same as degassing.
Elongation at break	The percentage extension of a plastic test piece, at the point of test piece fracture.
EMAS	Eco-Management Accreditation Scheme.
Expansion	Percentage increase in one or more dimensions of a body, caused by a rise in its temperature (Units %/°C).
Extension	The amount a known length of plastic extends when a force is applied, divided by its original length (Units m/m = 1, i.e. dimensionless).
Extruder	Single or twin-screw auger, which heats and forces molten plastic through a profile or die
Extrusion moulding	Plastics are melted and extruded through a die in a continuous process. (e.g.. used for making plastic rod or plastic film).
Feedstock recycling	As chemical recycling.
Flexural modulus	The displacement under an imposed force of a plastic test piece, divided by its cross section, per unit length (Units N/m^2) or more usually GN/m^2 or GPa.

Force	Load applied to an object causing it to accelerate (Units N).
Formulation	Mix of polymer and chemicals, the latter added to alter the polymer's properties (e.g. hardness, UV stability, elasticity, strength, etc).
GFRP/CFRP	Glass/Carbon fibre reinforced polymer. The long strands of fibre reinforce polymer in the direction that strands are laid.
Glass transition temperature	Temperature range over which a heated polymer changes from a solid to a rubbery to a liquid state.
Granules	Extruded molten plastic chopped into short lengths to form free flowing granules. Same as pellets.
Ground plastic	As shredded plastic but usually to a smaller particle size.
Injection moulding	Molten plastic is injected into a mould via an injection screw, cooled, and then the object ejected. Used to make bottle crates, car bumpers, washing-up bowls.
Intrusion moulding	Like injection moulding but with a ventilated mould, which allows any steam or gasses generated to safely escape.
Isotactic	Type of polymer with a high degree of order within its molecular structure which results in a highly crystalline form.
ISO14001	An environmental management standard for an organisation, which states its environmental policy, assures internal compliance, demonstrates conformance, and is externally verified.
Load	As for force (Units N).
Matrix	Continuous polymer which surrounds particulates and glue's them into position in products made from mixed plastics such as plastic lumber.
Mechanical recycling	A recycling process where waste plastics are shredded, and possibly melted and extruded, to produce plastic suitable for making in new products.
Monomer	A compound from which a polymer may be formed by the linking together of its molecules.
MRF	Materials recovery facility where recyclable materials are recovered from the waste stream.
Particulate	Piece of material such as sand, silica flour, or ground glass.
Particulate composite	Combination of particulates mixed with a polymer to produce a homogenous material.
Pellet	As for granule.
Pigment	Insoluble powder material which imparts colour to a polymer.
Plastics	Polymer with additives which alter the basic character of the polymer to suit the application.
Polymer	Organic material composed of long chain molecules made up of many monomer units.
Polyolefin	Family of polymers with carbon and hydrogen molecules only. Consists of LDPE, MDPE, HDPE, PE, PIB (Oppanol) and PP.

PRN	Packaging Recovery Note. A reprocessor of plastic waste can sell PRNs to any company required, or funded, to recover packaging. The value of a PRN per tonne of product rises and falls with market demand.
Side group	An un-separable group of atoms sometimes called a radical.
Recovery of plastic	Process where plastics are recovered from the waste stream.
Recycling of plastic	Process which includes some or all of recovery, cleaning, and reprocessing processes.
Reprocessing of waste plastic	Process where plastics are re-extruded into new products.
Runways	Plastic residue left in runways between extruder and mould.
Shredded plastic	Plastic that has been mechanically shredded to produce small particles of plastic.
Source segregated	Where waste is separated into the plastics, paper, containers, compostable waste and residual waste, prior to putting out for collection.
Spurges	Material which spills out of a plastic extrusion process through leaks in machinery.
Stabiliser	A substance that is used to keep a material from degrading or changing its form.
Strain	The length a plastic extends when a force is applied, divided by its original length (Units are m/m = dimensionless).
Streamline	Line which shows both direction and velocity of a fluid.
Stress	The force applied to an elastic material divided by its cross-sectional area (Units are N/m^2).
Testpiece	Piece of plastic made from a batch of shredded plastic or pellets for use in testing the properties of the final material. Same as test specimen or test strip.
Thermoplastic	Plastics which can be moulded and remoulded repeatedly when heated.
Thermoset	Plastics, which cannot be reprocessed through reheating, although they do soften. The polymer undergoes a chemical reaction during its initial processing that locks the monomer chains together.
Wdf/Rdf	Waste/refuse derived fuel.

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1. INTRODUCTION

In September 1999 the company Scottish Recycling was set up to reprocess post-consumer plastic waste into fence posts and street furniture. Sixteen months later the company went into voluntary liquidation. “Starting a waste plastics recycling business”, briefly charts what happened over these 16 months, and, with the benefit of hindsight, considers the options for plastics recovery and recycling.

The first section, Chapters 1-6, provides an overview for the general reader, policy maker and aspirant recycler. For those not discouraged by what they learn in this section, the second section, Chapters 7-11 provides technical information we feel essential for developing a waste plastics recycling business.

Chapter 2 documents the lessons learnt during the brief life of Scottish Recycling. Chapter 3 discusses the various government approaches to controlling the production of plastics waste and speculates on how the type of plastics and their use may change over the next two decades to meet these controls. Reducing the generation of plastics waste, real producer responsibility, closed-loop recycling of specialist plastics and the use of biodegradable plastics for the packaging of food are discussed. Only by looking at the longer term can sustainable waste plastics recycling systems be put in place.

Chapters 4-6 provide an overview of the plastics likely to be available for reprocessing in the longer term, with alternative approaches for recycling different polymers entering the waste stream. At the end of Chapter 3 is a description of a successful plastics recycling company, to prove that plastic recycling in the UK can be viable.

Section II of the publication is primarily for those serious about starting a plastics recycling business. The details of setting up a plastic production facility are described together with the alternative strategies and the equipment required. In chapters 8 and 9 respectively, the physical and structural characteristics of plastics are discussed. Since product quality can only be monitored through routine testing, a series of appropriate tests are described for use during the production process. Chapter 10 describes an approach to developing a product, a fence post, which includes a market survey. Chapter 11 outlines the forms of financial and consultancy support that are available to businesses starting up or expanding into a new area.

As new information on waste plastics recycling is being published at a rapid rate, this publication represents a snap shot of the situation today. If it does nothing but provide a starting point for those interested in plastics recycling, its objective will have been achieved.

2. SCOTTISH RECYCLING – WHAT WENT WRONG?

2.1 Introduction

In 1999, local Aberdeen businessman Neil Cordiner, accountant Malcolm Cunningham and Ian Baxter formed the company Scottish Recycling. The plan was to recycle post-consumer, mixed plastics waste into new product. The company went into voluntary liquidation on 15 February 2001. As many lessons were learned over the two years spent setting up and running the company, the story of their experiences is related below.

2.2 Description of the Proposed Business

Statement of Purpose

In June 1999 the new business (Multi-Plastics Scottish Recycling Company Ltd, 1999) was described. "Scottish Recycling will have a facility, unique in the UK, and located in Aberdeen, that will allow both residents and industry of the North East to address the difficult problem of disposing of mixed plastics packaging waste in an environmentally responsible manner. In so doing, another area of waste will be reclassified as raw material and reduce dependence on finite natural resources. A range of plastics products will be produced for the construction and related industries. The facility will be available from the summer of 1999".

The Service

"Scottish Recycling, unlike many established plastics recycling facilities, are not (*sic*) dependent upon the segregation and cleanliness of the plastics waste entering the system. The robust nature of the technology that has been purchased allows the system to cope with completely mixed batches of plastics waste and still create an extremely versatile product range".

"The service is designed to reduce the requirement for the landfill disposal of plastics packaging waste, which until now, has been the option most frequently used in Britain. Landfill disposal is already overburdened in many areas of the UK and subject to increasingly tight environmental legislation. These increasing restrictions make landfill disposal less financially viable and less attractive to the waste generator. The aim is to encourage, initially at commercial locations, the segregation of the waste at source and deliver this to the facility with the minimum of inconvenience to all involved parties. The waste suitable for reprocessing at the facility includes all plastic packaging products manufactured from a wide range of secondary materials including:

- Polythene
- High Density Polyethylene
- Low Density Polyethylene
- Polystyrene
- PET
- Polyurethane
- Polypropylene

N.B. PVC is not suitable for reprocessing by Scottish Recycling.

"The waste itself goes through a series of processes prior to the final moulding stage at which point the products are recovered. The products take a wide variety of forms, ranging from timber and concrete alternatives to intricate designs, which in many cases can be created to meet with specific customer requirements. The goal at all times is to create an opportunity for the communities, both domestic and commercial, to make a significant contribution towards protecting the environment and creating a more sustainable future".

The description goes on to detail additional benefits to participating businesses, suggesting that Scottish Recycling will help companies reduce their waste going to landfill and assist them in achieving ISO14001 or Eco-management and Audit Scheme (EMAS) certification. "In the short term charges for receipt and reprocessing of waste are likely to match landfilling costs, but in the longer term, increased landfill gate fees and tax will make delivery to Scottish Recycling both financially and environmentally attractive". The directors also suggest that "companies delivering waste could get products they require made for them and so close the loop of sustainability".

Partnerships

The description further states that "Scottish Recycling is working with academic institutions, local authorities and major generators of waste to develop further opportunities for the recycling of plastics and additional products that optimise the use of waste material".

Material Wanted

The material wanted for reprocessing included:

- Coffee cups
- Soft drink bottles
- Toiletry containers, i.e. shampoo, shower gel, etc
- Thread protectors for oil drilling tubes
- Carrier bags
- Bread bags
- Car bumpers
- Chemical drums
- Chemical bags
- Shrink wrap
- Cling film
- Food packaging
- Cooking oil containers
- Yoghurt pots
- Milk bottles.

Below this list it was stated that "All the above can be packaged together into a receptacle without any segregation at all, although goods such as thread protectors and chemical containers, which are contaminated, will require washing via an approved contractor prior to reprocessing. Whilst it is not entirely essential for the process, it is beneficial if the food and toiletry packaging waste have the bulk of deposits removed (a quick rinse will suffice) to pre-empt the possibility of objections from organisations such as SEPA and Environmental Health".

2.3 Business Plan

A comprehensive business plan was prepared to cover the start up period 1999–2002. A third of the income would come from Packaging Recovery Notes (PRNs) and two thirds from sales of product. A gate fee, termed recycling fee by Scottish Recycling, of £10 per tonne would also be charged. Additional charges would be made for material that required dismantling prior to shredding.

The business plan showed that the facility would come into profit by November 2000.

2.4 Publicity and Company Profile

A number of press releases were put out between 3 September 1999 and 15 March 2000.

Jobs Boost for City Blackspot, 3 September 1999

"A unique recycling plant is set to bring jobs to an Aberdeen unemployment blackspot. City councillors have given Scottish Recycling the thumbs-up for Scotland's first factory to turn waste plastic and computer parts into new products. The base on St Machar Road, Tillydrone, will create up to 14 jobs. All waste storage will be indoors and strict control on smells and fumes have been agreed with the Scottish Environment Protection Agency and the Council's own watchdogs".

Plastic is Fantastic, 22December 1999

"Planning permission was granted by Aberdeen City Council in early September and from that time on, tonnes of various plastic waste has been arriving to be shredded and, more recently, processed into a range of "plastic wood" items. "The plastic is shredded and then heated up and moulded into items such as garden fence posts or planks," said Mr Cunningham. Last week, the first oil company contract for recycling waste was signed with Total Oil Marine and Scottish Recycling has established links with drinks firm Sangs of Banff to dispose of plastic bottles. "Rather than have to dispose of the waste elsewhere, companies pay us to take it and deliver their plastics waste".

Giving New Life to Old Plastic, 15 March 2000

"An Aberdeen recycling plant claims it could save the city council £250,000 a year - and create 50 jobs in the process. That's what it costs to dispose of the 10,000 tonnes of plastics waste generated by households. "We'd take it from the council for nothing," said Malcolm Cunningham, a director with Scottish Recycling based in Tillydrone. At the moment, just three oil companies also choose to recycle plastic rather than dump it". Scottish Recycling charges oil companies for taking their plastic - but considerably less than do waste disposal companies”.

The company’s publicity campaign was highly successful in raising awareness within the city of Aberdeen. It had enormous goodwill from the Aberdeen public and the backing in principle from Aberdeen’s Council for Economic Development and Aberdeenshire Council’s Department of Waste Management.

2.5 Support Funding

Aberdeen Forward and Aberdeenshire Council provided £25,000 support funding towards the project, of which 90% came from landfill tax credits. This money was routed to SAC, so that the primary author of this publication, Bob Pringle, could help develop five products, to be made out of the plastics waste. Scottish Recycling in turn promised to contribute an additional £10,460 for the moulds and management input time required developing the five products.

Aberdeen City Council helped Scottish Recycling by becoming the main tenant of the owner of the St Machar Road building and sub-letting the building to Scottish Recycling. Apart from this limited support, all other funding came from the managing director, Neil Cordiner.

2.6 Production Facility

The company Scottish Recycling started production in September 1999. The facility was located in St Machar Road, Aberdeen, rented and consisted of two adjoining portal frame buildings on one level, with two buildings on a second level one metre higher than the first (Figure 2.1). The length of each pair of buildings was 30 m, creating a 60 m long building in total with an overall width for the two spans of 42 m.

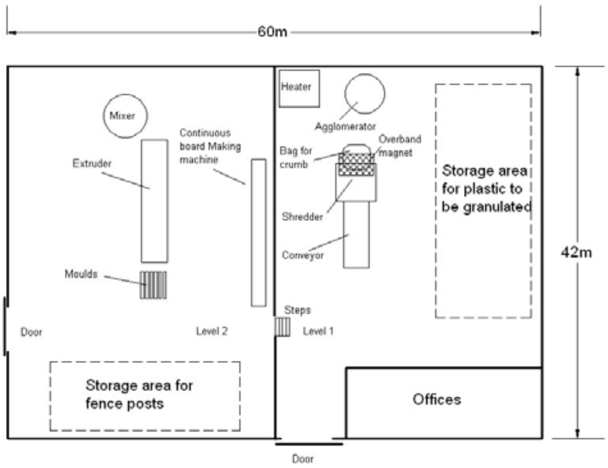


Figure 2.1 Layout of Scottish Recycling Manufacturing Facility

North Building

The North building housed:

- Reception
- Four offices
- Plastic/steel shredder
- Over-band magnetic steel extractor
- Light film shredder
- Intake plastic waste
- Shredded plastic crumb in 1.00 m^3 size plastic bags
- wood chipper to provide fuel for the space heater
- a wood burning space heater to heat the building

Later on a KweenB granule agglomerator was installed to densify light plastic.

The rest of the building area was used for shredding raw material and storage of delivered waste and shredded crumb storage in 1.0 m^3 bags.

South Building

The South building housed:

- a Scotmec Ltd vertical mixer to mix shredded plastic
- an oil fired steam generator to heat the shredded plastics as they were being extruded
- a plastic intrusion extruder to force the melted plastic into the moulds
- stainless steel moulds for fence posts and boards. (Eight moulds for posts).
- a second hand, continuous flow, board making machine, which was on trial
- pumps to cool the moulds with water so that the plastic components would rapidly solidify to enable rapid removal prior to filling with the next batch
- a chiller to cool the mould cooling water

Forklift trucks were used to transport material around the plant.

2.7 Technical Details of Plant

The process selected was based on studies carried out on post consumer mixed waste recycling in 1989 at the Centre for Plastics Recycling Research, Rutgers, the State University of New Jersey, USA (Renfree *et al*, 1989 and Nosker *et al*, 1989). The authors' idea was to avoid the processing and labour costs involved in cleaning and separating waste polymer types by processing mixed plastic waste as one material. The plastics in the mix with a low melting point would act as glue to bond the higher melting point, solid plastic granules in the mix.

Mike Seal and Nik Plevan of Scotland, who previously worked in the plastics industry, produced a confidential business plan in 1992, to raise interest in the concept. They recommended the A.R.T. adiabatic extruder.

The machines eventually purchased by Scottish Recycling were the:

- Untha RS 50 4S 960 Shredder for dense plastics, with a 44kW motor and a maximum rated plastic throughput of 450 kg/h. List price £83,000

- LRK 1000 shredder for lightweight plastics, with a 18.5 kW motor and a maximum rated plastic throughput of 350 kg/h. List price £ 43,000

- Starlinger Intrusion extruder rated at a plastic throughput of 500 kg/h and list price of £220,000.

Additional equipment included two conveyors, one auger, one overband magnet, one magnetic sensor, one hopper, two big-bag stands, a mixer, a dosing unit, and a pallet weigher, costing in total £54 k. A weigh bridge at £20k and a forklift at £12k were also purchased.

Starlinger set requirements on the operation of the intrusion machine. PVC should not be more than 1-2% of the mixed plastics feedstock, the proportion of polyolefins to ensure an undisrupted production should not be less than 40%, and the particle size from the grinder should not be more than 15 mm to ensure the structural integrity of the board and posts produced. A limitation set by A.R.T/Starlinger stipulates that if the proportion of polypropylene exceeds 30% of the polyolefins, the resultant posts or boards could be brittle at low temperature and shatter.

The moulds were stainless steel lined and cost £4,500 each for the 150 mm x 40 mm x 2.5 m boards and £5,000 for the 225 mm x 75 mm x 2.5 m boards. The moulds for the fence posts were over £2,000 each.

The agglomerator was purchased at a later date to densify the lightweight plastics. It cost £110,000 with a specified throughput of 500 kg/h.

2.8 Performance of Equipment in Practice

In practice, the intrusion process using the Starlinger machine never exceeded a spot rate of 290 kg/h, or 58 % of the 500 kg/h quoted for the machine.

The agglomerator had an average output of 58 kg/h, 12% of maximum quoted output. If previously shredded material was fed into the agglomerator, the dust produced was reported as “horrendous”.

The production goals proposed in the Business Plan were to achieve, by June 2000, sales of 200 tonnes of material per month, with an average price of £300/tonne, totalling £60,000 per month.

In November 2000, five months after this date, production was actually 22 tonne per month, a tenth of that estimated for June. Prices achieved were £220/tonne, rather than the £300 per tonne anticipated.

Since PRNs can only be issued on material recycled, the lack of production also meant that the tonnage for which PRNs could be issued was also a tenth of forecast. To make a bad situation worse, the value of PRNs per tonne of plastic had fallen to £ 30-45/tonne by November 2000 (Materials Recycling Week, November 2000), almost half the anticipated price range of £50-80/t.

2.9 Supply of Material

The aim of Scottish Recycling’s directors was to source plastics waste locally. However support from oil firms and other companies, which regularly disposed of plastics waste, never materialised.

Prior to setting up the company, managers of other companies assured the Scottish Recycling directors that they would send regular consignments of waste plastics to Scottish Recycling. The ability to recycle plastics rather than send it to landfill was seen as " a good thing". In practice, lorry loads of plastics waste promised to Scottish Recycling never arrived. On investigation by the Scottish Recycling directors, it was found that the waste plastics was going instead to landfill.

Some suitable waste was obtained locally but other waste had to be transported from as far away as Glasgow and beyond. This could cost as much as £200/tonne. Lack of material to process, was seen by the directors as a major problem once the output from the extruder started to increase. They had estimated the potential plastics waste production in Scotland alone to be 20-30,000 tonnes per year, so this should not have been a problem.

The wastes came in various forms. Loose plastic in large plastic bags suitable for forklift handling, large bags of plastic crumb, crates of lemonade bottles on pallets and pallets stacked with oil-drill-pipe, plastic, thread-protectors.

To assist Scottish Recycling obtain plastics waste feedstock, Aberdeenshire Council set up six collection points (Figure 2.2), in Aberdeenshire. These six sites together provided only one tonne of mixed plastics waste per month, a disappointing amount of feedstock considering the effort put in to collect the material. The value of the mixed plastics collected this way was estimated at £100–150 per tonne.

Figure 2.2 Plastics Waste Collection Skip at Inverurie Civic Amenity Site

To complement Aberdeenshire's efforts, Aberdeen City Council intended to open two civic amenity plastic recycling sites where people could dispose of plastic waste for recovery.

The publicity stimulated by press releases resulted in a raised public awareness of the plant. Cars would drive up to the gate with segregated plastic bottles and film in carrier bags and sacks. If the plant was shut, items would sometimes be thrown over the fence, resulting in untidy piles of waste plastics lying within the perimeter fence.

2.10 Production Problems

The first products made were fence posts, street furniture materials, spacers for transporting concrete on lorries, and other low quality end uses. Initially feedstock was largely plastic end-cap thread protectors for oil drilling pipes and mixed plastics waste.

The thread protectors were shredded into 10 mm granules, conveyed past a magnetic overband magnet to remove any steel and then conveyed into large plastic bags. The shredded product from the various large bags were then mixed with the other dry components, by feeding them into the Starlinger plastic intrusion machine (Figure 2.3), heated to 200°C. The now mixed and molten plastics was then extruded into closed ended moulds, to form posts or board (Figure 2.4). Cold water was pumped though the outer annulus of the moulds to cool the product prior to removal. The system was therefore a batch process.

Figure 2.3 Starlinger Vented Plastics Extruder in new home after Scottish Recycling ceased trading

The thread protectors were reinforced by 3.25 mm steel plate, so that the shredding process granulated the steel as well as the plastics. The steel created considerable wear on the shredder and contaminated the product with iron filings.

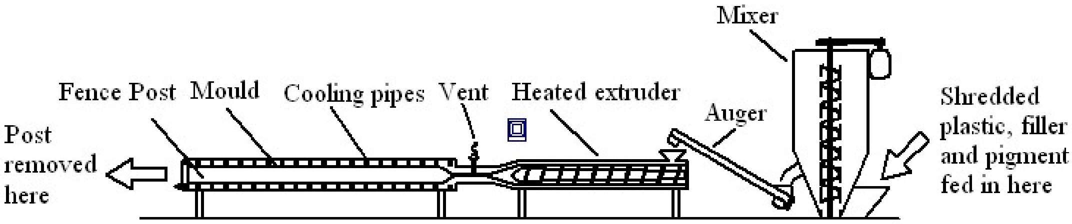


Figure 2.4 Diagram of Starlinger Extruder Plant

Mixed plastics waste was also used as a feedstock. The mix contained 60% by weight of low-density polyethylene (LDPE), 35% of mixed waste plastics, 2.5% sawdust flour, and 2.5% pigment. The cost of the pigment was £2.60/kg, which added £65/tonne to the cost of the product.

The company was urgently trying to increase the amount of posts and board produced. Due to the fluffy nature of some of the plastics after shredding, insufficient material was fed into the hopper throat of the Starlinger intrusion extruder to keep up with the potential output of the moulds.

A KweenB agglomerator was therefore purchased, to increase the density of the shredded product, and so allow a greater input through the mixer hopper throat. This helped to increase the feed rate into the Starlinger extruder, but placed another piece of vulnerable equipment into the production line. On one occasion a piece of polypropylene rope, hidden in a bag, wrapped round the agglomerator shaft, and caused the machine to jam while full of rapidly setting molten plastic. Production was halted until the solidified plastic was eventually removed.

The agglomerator, fitted primarily to increase the density of granules made from film materials, works by partially melting the plastics in what looks like a large "Moulinex" food processor. The resulting hot plastic is then sprayed with water, changing its phase from liquid to solid. This material is then shattered by rapidly rotating blades, into a dense crumb, which is then fed into the extruder closer to its designed throughput. The agglomerator was felt to be especially useful for future use, as more films were available than rigid plastics.

Problems over the required temperature settings for different plastics caused components to have poor surface finish and unusual shapes. It was latterly felt that this problem had been largely solved. However, the presence of certain chemicals or moisture in some of the recovered plastics resulted in some catastrophic plugging of the extruders which required extensive drilling out of plastic and sand blasting of the moulds. This caused production to be delayed for a week at a time.

The continuous flow, board-making machine, which was on trial, was seen as one way of speeding up the production of board. While the batch process with the moulds was effective, output was slow as moulds had to be heated, filled with plastic and cooled in sequence, with the posts and board being removed at the end of each cycle. Trials with the continuous machine ended in acrimony between supplier and user, with each blaming the other for failing to achieve a useful product. The problem involved setting valve openings to achieve a satisfactory plastic flow rate suitable to give a consistent product. However with a continually varying feedstock, achieving one valve setting to give a constant flow rate of molten plastics was unlikely to succeed.

Waste contamination with steel or stones and the variability of plastics processed was a constant problem. Even moisture on the product turned into steam within the screw mixer or moulds, sometimes with explosive results.

2.11 Sales of Product and Product Quality

Small quantities of plastics to make garden furniture were being sold to Garden Craft Products, Dyce, Aberdeen for making into garden and street furniture, but this was not satisfying their demand. Initially there was too much residual metal content in the plastics. This was reduced, but there was still some metal in the plastics made from oil pipe thread protectors.

Scottish Recycling's main sales effort went into the sale of large volumes of low value products. Boulevant Concrete Products had a need for spacers to transport their concrete products. Scottish Recycling was therefore supplying these, but not at a price that benefited Scottish Recycling. There was also potential to supply kerbing materials for roads.

The fence posts had a step between the inverted pyramid point, which made them more difficult to drive into the ground compared to conventional timber posts (Figure 2.5). The plastic was also very dense, so when staples were being hammered in, these could fly off in any direction, with potential risk to the fence erector. Posts therefore had to be predrilled to take staples, an extra operation taking time and adding to fence erection cost. The price of the posts was reduced to £2.20 each in an effort to increase sales.

Figure 2.5 Timber Post, Round Post (BPI-Dumfries) and Scottish Recycling Square Post

There were problems with the structural strength of posts and the plastic spacers for transporting concrete products, as the plastic products sometimes fractured. One post sent by courier on a cold night broke in two when dropped. Analysis by Napier University students (Charrel, Lonchamp, 2001) found that: -

- a large unmelted piece of plastic had created a line of weakness across the post (Figure 2.6)
- there was a concentration of low-density plastic on the perimeter of the post
- the un-melted lumps had a melting point of 270°C, while the core and perimeter melting points were 180°C and 140°C respectively
- rapid cooling in the mould had caused delamination between plastic streamlines
- bubbles were present in the plastic indicating insufficient cooling time and/or too high an extrusion speed
- had process temperature been sufficiently high to melt the un-melted lumps, the lower melting plastics would have become charred

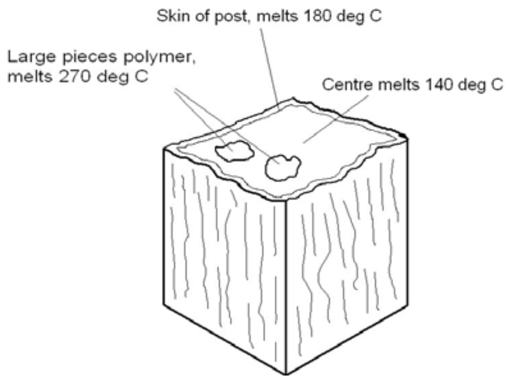


Figure 2.6 Broken Scottish Recycling Post

The above assessment would be expected of the "Rutgers" University mixed plastics approach. However, the size of the high melting-point pieces of plastic was excessive and the cooling rate may have been too rapid. There were therefore major problems with product quality.

2.12 Changes in Direction

Prior to the company going into voluntary liquidation, management identified a number of issues needing to be addressed: -

- Inadequate space to separate material prior to shredding
- A requirement for a facility to remove contaminants from feed-stocks
- Greater control of material type, form and level of contamination coming into the factory
- A change from the manufacture of low value, high structural performance items such as fence posts to higher value, lower specification products such as compost bins
- Greater emphasis on marketing

2.13 Summary of Problems

Scottish Recycling went into voluntary liquidation for a number of reasons: -

- There was no established supply of unshredded single type plastics or mixed waste plastics.
- Promises of plastics waste failed to materialise.
- What little available plastics there was came in shredded granules from a distance at a considerable cost.
- Aberdeenshire Council's provision of plastics collection facilities produced too little too late.
- The lack of an inspection table to pre-check plastics being processed led to jams in the agglomerator.
- As PVC had to be kept below 2% of the final mix, inspection to remove PVC prior to shredding was vital.
- Lack of input material quality control led to plugging of the moulds and extruder.
- The metal reinforcement in the plastic oil-drilling-pipe end caps led to excessive wear on the shredder and excessive metal contamination of some of the plastic lumber sold.
- The maximum throughput achieved from the intrusion line was 58% the quoted maximum.
- The maximum throughput achieved by the agglomerator was a tenth of that quoted.
- The fence post product was unsuitable for nailing, was heavy, and failed structurally due to large, un-melted pieces of plastics in the mix.
- Delamination parallel to the direction of molten plastics flow into the mould also resulted in structural failures.
- Initially production problems prevented sufficient product output to supply demand.
- When adequate production was achieved, markets could not be found.
- Cost appeared to be a factor, resulting in Scottish Recycling dropping the price to an unsustainable cost of production.
- The initial publicity, so successfully achieved, came to haunt them. Householders keen to recycle their waste ended up dumping carrier-bag quantities of waste plastics within the factory grounds.

3. HOW WE MAY USE PLASTICS IN FUTURE

3.1 Introduction

There is little sense in setting up plastics recovery and recycling facilities for today's needs only to find that the pattern of plastics usage changes. This chapter therefore looks at how plastics may be used in the longer term.

Plastic bottles should increasingly be reused and refilled, rather than recycled after one trip. Food packaging should be biodegradable, so that it can be put out with compostable material. Closed-loop recycling should become the norm for waste PVC and, where suitable, for recovered plastic components from scrapped cars, washing machines and other manufactured goods. Mixed plastic films should be kept out of the household waste stream. The days of trying to recover and recycle polythene contaminated with food and sticky labels are numbered. What is not predictable is how long this transformation will take.

3.2 Producer Responsibility

3.2.1 UK Legislation

The Producer Responsibility Obligations (Packaging Waste) Regulations (1997) was brought into UK law to help meet the requirements of the then approaching EC landfill Directive of 1999, to reduce waste sent to landfill.

Companies affected have a turnover in excess of £2 m and produce 50 tonne or more of packaging. Small companies are unaffected. The target set for 2001 was for 52% of packaging entering the UK waste stream to be recovered. This recovery target specified a minimum of 25% recycling over all the packaging materials, namely paper, plastics, steel, aluminium, glass, wood and "others", with a minimum of 15% recycling per material.

In 2002 these targets were increased to 59% recovery, with a minimum of 19% recycling per material.

The responsibility for recovering the packaging is shared between the packaging raw material producer, the company converting the material into packaging, the filler of the packaging, and the seller of the packaged produce, in proportions 6 : 9 : 37 : 48% respectively. For a product like yoghurt, the manufacturer of plastic granules for the container is responsible for recovering 6% of the packaging, the plastic container manufacturer 9%, the yoghurt producer 37% and the supermarket selling the yoghurt 48%.

Actual recovery in 2001 in the UK, quoted by Michael Meacher, Secretary for the Environment, in the press in 2002, was 50% recovery with 25% recycling, and 15% recycling for each material.

3.2.2 Producer Irresponsibility

The flip side of the producer responsibility legislation is that 41% of all packaging can be dumped, either to landfill, or illegally discarded along road verges (Figure 3.1) by users of the packaged produce. For plastics, the most expensive of all packaging materials to recover and recycle, the legislation allows 81% to be dumped or discarded.

The situation is even worse in practice, since efforts to recover packaging are easiest in areas of high populations. Remote rural areas are therefore most likely to have the poorest recovery infrastructure; so that dumping and discard rates in these areas will be considerably higher than 81%. The solution is not to try and gather and recycle what has been produced, but to tackle the generation of plastics waste at source (Figure 3.2).

Figure 3.1 Plastic Bottles Littering Roadside

Figure 3.2 Use of One trip Bottles is creating the waste problem

3.3 Bottles and Liquid Containers

3.3.1 Refillable Containers

Plastic bottles can be reused for refilling or recovered for recycling using a deposit scheme. Supermarkets or shops selling drinks and liquids can have reverse vending machines (Figure 3.3), allowing bottles to be returned singly or in crates. Plastic bottles can be refilled up to 20 times (Carlsberg, 2000) before they have to be disposed of or recycled. If reusable glass milk bottles are rarely found in the municipal waste stream, there is no reason why refillable PET drinks bottles and HDPE liquid containers should end up in the waste stream either. A deposit scheme for beer and fizzy drink bottles has been practised in Seattle, USA since 1973 (Warmer, 2002). The improvement in recovery rate changed from 25% in 1972 to 94% in 1973 when the deposit scheme was introduced (Figure 3.4), falling back slightly to 87% by 1998.

A deposit scheme for single-use bottles was introduced in Germany on 1 January 2003.

Figure 3.3 Reverse Vending Machine for Bottles (Courtesy of Tomra)`

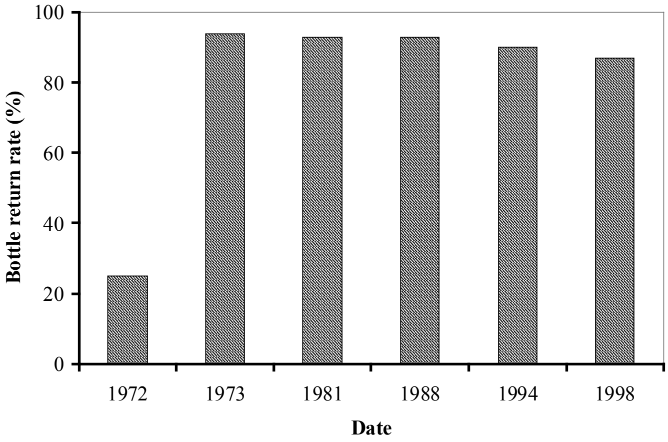


Figure 3.4 Return Rates for Beer and Carbonated Drinks Containers in Seattle, USA

3.3.2 Charge for Drinks Containers in the Waste

There is overwhelming evidence to indicate that incentives, or "carrots", to return bottles or recycle them work only in part (McKenzie Mohr, Smith W, 1999). A much better approach is to combine the "carrot" with the "stick". The carrot is the deposit. The stick could be provided by government requiring local authorities to estimate by sampling the quantity of plastic bottles in the municipal waste. The authorities would then charge drinks companies, milk producers and hair gel product suppliers, etc, for the proportion of their bottles in the waste stream. For this to work, bottles would have to be clearly marked with the company name. Alternatively, plastic bottle producers could agree across the industry to pay for this waste regardless of make.

An alternative approach is for the government to pass legislation allowing local authorities to charge householders by volume or by weight for putting out their waste. The second approach has to be carefully introduced to limit any increase in fly tipping.

3.3.3 Organisation to Encourage Drinks Container Recycling

Recycling of Used Plastics Ltd, RECOUP, (RECOUP, 2003a) is a UK wide marketing organisation, set up to promote and facilitate post consumer plastic container recycling and to overcome technical and economic barriers to growth in recycling. It is a registered charity set up in 1989, with members made up from local authorities, the packaging and drinks industry, supermarkets, recyclers and waste management companies.

RECOUP estimates that bottle recycling has increased from 600 tonne per annum in 1994 to 14,770 tonne per annum in 2001. While this appears a fine achievement, the actual recycling rate for plastic bottles in 1999, when the recycling rate was 10,045 tonne per annum, was 3.6% of the plastic bottles manufactured annually (RECOUP News, Issue 10). More recent data suggests that the recycling rate has increased slightly to about 4% (RECOUP, 2003b).

To focus on increasing plastic bottle recycling, while of merit, tends to distract attention away from the real solution, which is to change over to reusable plastic bottles. If one trip, disposable drink containers are to be allowed, they should be made of a material such as steel, which is easily recoverable using magnetic extractors, present in almost every materials recovery facility in the UK.

3.3.4 Non-recyclable Plastics

Most plastic bottles marked with the respective plastic type symbol, can be recycled. RECOUP's guidance is that some bottles, such as the black PET Tango bottles produced by Britvic Soft Drinks Ltd, Chelmsford (Figure 3.5), are not suitable for inclusion in most bottle recovery and recycling schemes (RECOUP, 2003b). Britvic put a recycling label on their bottles, knowing, it must be assumed, that while their bottles could be recycled, in practice they will be separated out and put to landfill or burnt. This infringes at a minimum the spirit of the Trades Description Act (1968). Many other companies similarly claim their containers or packaging are recyclable, knowing that they are unlikely to be recycled in practice.

Figure 3.5 Will this Bottle be Recycled in Practice?

3.4 Food Packaging

3.4.1 Range of Polymers Used

At a casual glance, fruit, vegetables, meat, bakery produce and ready meals appear to be sold covered in either polythene (LDPE) or cling film (PVC). Further inspection reveals that trays of PET, PVC, PS, EPS, and PP are used to hold the produce prior to covering it with film. Sometimes an absorbent square of porous material is placed at the base of the tray to absorb any moisture or blood. A paper label is then stuck on the film to describe the produce and give a "display till" date. The package now consists of a range of incompatible plastics, paper and glue, largely unsuitable for recycling.

To complicate the situation further, modified atmosphere packaging or MAP, is used particularly for chopped up, ready-to-eat salads and other produce with a short shelf life (Fellows, 1997). Such packaging is designed to allow the living fruit or vegetable to respire (breathe), but at a lower than normal rate. This enhances the food's shelf life and slows mould development. Special films are often laminates of two or more films, formed to create the ideal porosity for oxygen intake and carbon dioxide release. These laminates can include unusual polymers, which are virtually impossible to segregate and recycle.

To complicate a difficult situation still further, nylon bags are used to allow "boil-in–the–bag", ready-to-serve meals. Nylon when reprocessed can produce toxic fumes.

The range of polymers used for all these different applications is shown in Table 3.1.

Table 3.1 Laminate Film Layers used for Food Packaging

Layer One	**Layer Two**	**Layer Three**	**Typical Food Application**
Polyvinylidene, chloride-coated polypropylene	Polyvinylidene, chloride-coated polypropylene		Crisps, snack foods, biscuits, chocolate
Polypropylene	Ethylene vinyl acetate		Modified Atmosphere Packaging (MAP), bacon, cheese, cooked meats
Cellulose	Polyethylene	Cellulose	Pies, crusty bread, bacon, coffee, cooked meats, cheese
Metallised polyester	Polyethylene		Coffee, frozen foods, MAP
Polyethylene	Nylon		Vacuum packs for bulk fresh meat
Nylon	Medium-density ethylene	Butane copolymer	Boil-in-the bag packaging

For the plastics waste reprocessor, this vast range of plastic makes plastics' recycling extremely difficult; particularly as the bulk of the plastics do not bond with each other when melted.

3.4.2 Disposal of Food and Biodegradable Wrapping Together

A proportion of the fresh sandwiches, meat, vegetables, and fruit is discarded each day by supermarkets and shops when the "display till" or "use by" date lapses or the food deteriorates for some reason. While a small proportion of such food goes to hostels to feed the poor, much goes to landfill.

Since food in the home will also often be disposed of while still wrapped, there is logic in requiring that all food packaging be biodegradable. If both packaging and food are biodegradable, both contents and packaging can be put in the home or office "compost" collection bin, removing at a stroke the problem of trying to collect and recycle contaminated waste films, food trays and sandwich packs.

Biodegradable plastics and trays are now available on the market, albeit at a price about 4-5 times that of conventional, oil-based, plastic. Sainsbury's supermarket organic produce is part way there with its biodegradable trays (Figure 3.6), though their covering film is not yet biodegradable. While initially the change to biodegradable packing will mean a large increase in packaging cost, economies of scale and increased competition are likely to reduce this price differential considerably within a few years.

Figure 3.6 Sainsbury's Organic Date Packet, with a non Bio-degradable Film Cover

Food manufacturers may cite the complex structure of plastic films and laminates used to create modified atmosphere packaging (MAP), as a reason for retaining oil-based plastics. However, the laser based plastic perforation systems developed to perforate oil-based plastic films could possibly be used for biodegradable plastics too. Development work may be required to find out whether or not this can be done.

A parallel development to the permeable MAP film is the permeable label. The idea is to perforate the label instead of the film. This would allow any film to be used, with the permeability of the label altered to suit the fruit or vegetable inside the pack. The label would cover a fixed size hole in the film, allowing the optimum amount of oxygen into the pack to maximise shelf life. While permeable labels have been talked about for years, they have not to our knowledge made their appearance on to the market shelves.

What is not disputed is that plastics play a very significant part in keeping produce fresh and hygienic, preventing waste by stopping food from drying out or going mouldy. What is needed is to develop a biodegradable plastic that is cheap enough to use for food packaging. It should be translucent if possible, so food is shown off to its best effect. MAP versions of degradable film or porous labels should be made available.

3.4.3 Biodegradable Plastics

Only a limited number of biodegradable plastic substitutes are presently available. One is based on maize starch, another on potato starch. These degrade on contact with micro-organisms found in the soil.

The Ecover plastic is made from potato starch, and is strong enough for waste bags. It has a slightly strange, sweet odour, which is suitable for waste bags but in its present form would prevent its use for food packaging. It is also slightly sticky to the touch and tends to crease when scrunched up.

Mater-Bi, sold in the UK under the trade name “BioBags”, is made from cornstarch and is soft, relatively strong, odour free and takes printing well. It is smooth and slippery, just like LDPE plastic bags. It is used for supermarket carrier bags and plastic utensils. As it is relatively unmodified starch, its natural colour is cloudy in appearance. The plastic has undergone four years of research and full-scale tests. It meets the German standard DIN 54900 for biodegradable packaging. Its present cost is about 4-5 times that of oil-based plastics.

A translucent version of the Mater-Bi product, suitable for displaying fruit and vegetables for sale, but made from vegetable oil, is said to be under development.

To test the biodegradability of potato and cornstarch based bags, sample bags were put thorough Aberdeenshire Council’s Banff in-vessel composter. They completely disappeared in less than 14 days.

3.4.4 Time and Temperature Dependent Degradable Plastics

A time and temperature degradable plastic is made from oil-based polythene. It has a chemical added during manufacture, which breaks down the strong, long-chain plastic molecules of 300,000 molecular weight (MW) into short-chain, low strength particles, with insufficient strength to resist degradation into small particles. Once this material is broken down to a MW of about 40,000, it can be consumed by soil micro-flora.

With the trade name Symphony Plastic's d_2W^{TM}, the plastic is similar in appearance to conventional plastic film. It can be made as a full clarity material, for displaying food inside packaging and has been passed for direct food contact. Its rate of decay is dependent on both time and temperature; the higher the temperature the faster it degrades. Degradation will therefore be more rapid in a large, commercial, high temperature composter than in a cool garden compost heap. With the normal degrading chemicals present, the plastic can be made to last anything between 6-18 months.

The problem with Symphony Plastic's d_2W^{TM} is that its rate of decay is time and temperature dependent, rather than being triggered by burying the material in compost or soil. The material did not degrade in the 14 days in the composter as the other biodegradable plastics did. It did however degrade in my office into a million tiny pieces after a year and a half, much to the distress of our office cleaner. While the concept of the material, made up of hydrogen, carbon and oxygen molecules, with a minute amount of degrading chemical added, appears excellent, the question as to how to ensure the material breaks down when required, has yet to be solved.

3.5 Closed-loop Recycling for PVC and Plastic Components

In the manufacture of PVC, common salt is added to the oil-based feedstock to provide the chlorine element in the long chain polymer. It is this chlorine element that may cause toxic dioxins and furans to be produced, when PVC is burnt. Without the chlorine there would be no dioxins or furans emissions. As far as possible PVC plastics should therefore not be burnt.

When recycling PET, PVC should be kept out of the recycling process as not only can it stain the plastic, but it can also produce fumes of hydrochloric acid, which could harm staff involved in the recycling process.

An initial evaluation of PVC could lead to the conclusion that this type of plastic should be banned from use altogether. Not only can PVC produce dioxins when burnt, but also all sorts of additives such as lead, calcium, zinc, tin, barium and cadmium (ARGUS 2000) are included to improve its characteristics as a plastic. However, the material is so useful for the manufacture of window frames, guttering, down pipes, plastic weatherboarding and electrical PVC cable insulation, that to ban the material would mean losing a very versatile product. The solution is therefore to ensure the material is recycled in a closed-loop.

The majority of the really valuable items made from PVC are long life materials. Cable insulation, weatherboarding, window frames, and pipes are all likely to last 40 years or more. The major increases in the requirement for closed-loop recycling of PVC is therefore still some way in the future. The PVC items with a short-term use, like plastic bottles, are rapidly disappearing off the shelves. Kitchen cling film is the only short life PVC in regular use.

3.6 Plastics which can never be Recycled

It is highly unlikely that the twin layer films used for modified atmosphere food packaging, nylon boil-in-the-bag packets and the miscellaneous other films and trays will be recycled. This is partly because of their non-compatible nature, partly due to the adhering food residues and partly because of contamination by paper labels and glue. Increasingly this material is being separated out of municipal waste and turned into a waste, or residue derived fuel (WDF or RDF). If our predictions that biodegradable films for food packaging will replace conventional oil-based plastics, much of this material will disappear, while the biodegradable films will go into the compost waste stream.

3.7 Sustainable Plastics Recycling

If plastic bottles increasingly become refillable, the amount of bottles available for recovery and recycling will fall dramatically. Potential plastics recyclers should be aware of this so that the recycling industry is not over-subscribed. The most likely single-trip bottles will be the HDPE shampoo type bottles, as there is such a range of bottles and designs on the market. Recyclers should therefore target PET and HDPE and leave the miscellaneous food films to the temporary expedient of burning for energy, or possibly for use as feedstock for mixed plastic recycling into plastic lumber.

Waste plastic from agriculture and commerce will always be available for recycling. This may be in the form of agricultural films for storing silage, fleece for agricultural crops, polytunnel film, expanded polystyrene packaging, film used to protect electronic equipment, etc. So long as it is clean, of sufficient volume and single type polymer, this material can be re-shredded and used directly in extrusion moulding or extruded into new pellets.

3.8 What is Wrong with Burning Plastics?

There is a view that burning plastics along with mixed municipal waste enhances the calorific value of the waste, so that the entire municipal waste stream can be used for energy production. With modern flue gas filtration systems for energy from waste plant, the dioxins and furans from the PVC and the salt in the food waste, can largely be captured in the filter material and sent to hazardous waste landfill sites. This saves on the cost of the manual labour involved in the separating out of recyclables, while producing electricity for the grid and possibly hot water for nearby residents. With such a system, there is little need to reduce plastics production, as it then becomes a useful fuel.

This approach is not part of the National Waste Plan 2003 for Scotland (SEPA 2003). The report recommends removing material suitable for composting or recycling prior to burning the residue. As plastic consumes about 90 MJ/kg to make and releases 43 MJ/kg when burnt (Bourstead, 1996 and APME, 1995), in energy terms it is more valuable as a recycled plastic than as a fuel.

The preferred approach is therefore an integrated waste management strategy as recommended by Williams (Williams, 1998). Municipal waste is split into a number of streams. High moisture content, biodegradable material (food and garden waste) should go for composting or anaerobic digestion, clean recyclable material should be recovered for recycling, while un-recyclable plastics can be burnt. Soiled paper can be composted or burnt.

Only inert ashes, stones and residue material should be landfilled. Taking the moist biodegradable material out of the waste raises the calorific value of the non-recyclable paper and plastic, allowing the energy from waste plant to be smaller and more efficient.

3.9 Chemical Feedstock Recycling of Plastics

The chemical feedstock recycling process is the breaking down of waste plastics into their component chemicals, so that they can be remade into plastics again. This tends to be carried out in large chemical plants, a number of which have been constructed on the continent. A pilot facility is located in Grangemouth, Scotland. If plastics can be shredded and re-extruded directly, avoiding chemical feedstock recycling, this probably represents a less complex approach to plastic recycling. It is certainly more appropriate for small-scale recyclers for whom this publication is targeted.

3.10 Summary

Changes in how we use plastics will determine the long-term future for plastics reprocessors. While no one knows what the future holds for certain, the following changes are recommended.

- Refillable plastic bottles should predominate.
- Disposable, single-trip bottles should be made from one polymer only.
- Disposable containers should preferably be made from steel for ease of material recovery.
- If a mix of polymers is essential for a container, these must be designed for easy separation or should be chemically compatible for re-extrusion.
- Producers must become ultimately responsible for the plastic they produce and any waste plastic that ends up in landfill or on roadsides.
- Plastic food packaging should degrade within 14 days within a municipal compost plant
- Non-biodegradable plastic food films should be phased out.
- PVC should be kept out of waste being burnt and should be reprocessed back to PVC products.
- Commercial packaging films and containers should be collected and reprocessed.
- Damaged or spoiled virgin plastics can be re-shredded for reuse.
- Plastic components of manufactured products should be designed for recovery and reprocessing.
- Plastic consumables such as CDs, CD cases, biros, pens, toner cartridges, should all have a returnable deposit on them at the point of sale.
- Environmental campaigners should target manufacturers of single-trip containers, non-biodegradable food packaging and government legislators, not their local authority trying its best to deal with increasing volumes of plastic waste.

4. TYPES OF PLASTIC MATERIALS

4.1 Introduction

Plastics are chemicals that bond together to produce a solid material at room temperature. Unlike wood, which changes little if warmed, cooled, exposed to sunlight or put under load, plastics can melt, twist, creep, sag or become brittle and snap. These characteristics can catch out the unwary plastics reprocessor, turning his splendid new product into a waste material, which has to be disposed of at his expense. Waste plastics reprocessing needs a level of knowledge of plastic materials well beyond that required by workers in wood.

This section reviews the characteristics of the different types of plastics in common use, to assist in developing a recycling strategy. More detailed information can be found in the second section of the report, Chapter 8, Physical Properties of Plastic Materials.

4.2 Types of Plastics

Plastics can be divided into four basic categories: -

- ***Thermoplastics*** such as polyethylene, which soften on heating and harden again on cooling (e.g. Milk bottles).

- ***Thermosets*** or *resins* are plastics which cannot be melted and re-moulded when heated (e.g. printed circuit boards and fibre glass resin)

- ***Elastomers*** or *rubbers (e.g. Car tyres, rubber-bands, tennis balls)*

- ***Natural polymers*** such as cellulose, lignin and protein, which provide the mechanical basis for most plant and animal life (e.g. wood, straw and silk). These now include the recently developed biodegradable plastics.

In plastics recycling, thermoplastics dominate, but thermosets, wood, paper and straw can all be used as fillers and reinforcers.

4.3 Thermoplastics

The different types of thermoplastics are labelled with numbers 1-7, created by the American Society of Plastics Industry (SPI). The EU system, which is still under discussion, uses 01, 02, 03, 04, 05, 06 and 07, but is basically similar.

Polyethylene Terephthalate (PET or PETE)

PET or PETE is the plastic used for blow-moulding clear, colourless bottles (Figure 4.1). These mostly contain lemonade, diluting juices, Coca-Cola, vegetable oil or washing-up liquid. These bottles can be one trip or returnable. They usually have polypropylene tops with security rings; the latter remaining with the bottle once the top is removed. They may also have a cylindrical PVC label wrapped round the bottle. Significant quantities of PET bottles are being sent to China for processing into clothing and textiles.

Figure 4.1 Packaging made from Polyethylene Terephthalate (PET)

High-density poly-ethylene (HDPE)

HDPE is used for blow-moulding opaque bottles containing detergents, oil, shampoos and face creams (Figure 4.2). It is also used for children's toys. It is naturally semi-transparent, so is used for the cloudy-white plastic milk bottles.

The lids of these are injection moulded, using predominantly polypropylene (PP). While the bottles therefore contain two distinct polymers, being polyolefins, they can be recycled as one. As there is not the same contamination risk with creams and shampoos as with drinks and foods, seals tend not to be used.

Figure 4.2 Packaging made from HDPE

Recycled HDPE is used to make bottles for non-food application, plastic pipes, plastic wood, flowerpots and waste bins.

Poly vinyl chloride (PVC)

PVC can be clear like PET and is used for cake trays, fruit trays and Coca/Pepsi-Cola bottle labels, Easter-egg containers, blister (bubble wrap) packaging and the cling-film used to cover food (Figure 4.3). Some clear soft-drink bottles and vegetable oil bottles are PVC, but they are becoming less common.

Figure 4.3 Packaging made from PVC

Not only can PVC produce dioxins and furans when burnt in energy-from-waste plants; it produces fumes of harmful hydrochloric acid (see Section 3.5) when heated above its narrow moulding temperature range. If collecting plastics for recycling, PVC is normally separated out for fear of affecting workers, corroding extrusion machinery and causing brown marks in clear PET.

Low-density polyethylene (LDPE)

LDPE is used for polythene bags for food and garments, supermarket carrier bags and shrink-wrap (Figure 4.4). It is also used for trays for cold meats and microwave meals. The film used for silage bags or to suppress weed growth in strawberries is LDPE. It is chemically similar to HDPE, but is less dense and more flexible. It can be clear and colourless, or dyed any colour. It tends to be hand sorted and baled at recycling plants. LDPE is commonly baled for shipment to China for reprocessing.

Figure 4.4 Packaging made from LDPE

Polypropylene (PP)

Polypropylene is used for the majority of bottle caps. It is also used for refrigerated containers, cake trays and ice cream tub lids (Figure 4.5). It can also be used for carpet making. It's colour can be clear or dyed to any colour.

Figure 4.5 Packaging made from Polypropylene

Polystyrene (PS)

Polystyrene is the thin, hard plastic used in plastic water cups, supermarket food trays, margarine and yoghurt containers, and disposable plastic cutlery (Figure 4.6). When extruded with a blowing agent, it becomes lightweight foam, used for coffee cups, egg cartons, foam trays for meat, foam protection for electronic equipment during transit, or an insulation material.

Figure 4.6 Packaging made from Polystyrene

When granulated and melted the blowing agent is released, returning the material to its basic, non-expanded, form.

7 Other miscellaneous plastics

No 7 is a catchall number, rarely used in practice, for the remainder of plastics in use. They have no recycling potential and should preferably be burnt to produce energy.

4.4 Commercial Plastics

Plastics from cars, vacuum cleaners, children's toys, include the plastics listed above. In addition there are many engineering plastics, such as ABS, Nylon, Polycarbonate, Kevlar, etc. which are valuable, and are very suitable for closed-loop recycling. These engineering plastics tend to be much easier to recover and recycle than those from the mixed plastic municipal stream, as they tend to be single type materials, such as ABS dashboards from cars. The exceptions are very contaminated plastics from agriculture or films and containers from dirty industrial processes.

4.5 Which Plastics can be Mixed Together?

Most combinations of plastics will be incompatible during processing; they do not physically blend together. However, some do. Different grades of PE can usually be processed together into new products. These are part of the polyolefins group which have only carbon and hydrogen in their make up.

In general, it is best to separate polymers into their separate categories prior to shredding and reprocessing.

4.6 Contaminants, which must be Removed

Where possible, recovered plastics should be reprocessed into the highest quality material that can be produced. This will achieve the highest price. The cost of collecting waste, shredding it, removing contaminants and possibly re-extruding it is similar whether the final product is low or high value. British Polythene Industries (BPI), Dumfries started converting recovered agricultural film into low value fence posts. They are now concentrating on producing high value film.

Materials that need to be removed from high value plastics waste, such as PET, PE or LDPE are non-target plastic films, PVC in any form, nylon, paper, and metals, soil and any moisture. If the material has to be washed, the wash water has to be treated prior to disposal. Water treatment systems are expensive. The cost of the treatment system for BPI, Dumfries was into the millions of pounds.

4.7 Risks from Using Recovered Plastics in Products

There are obvious risks in using recovered plastics in products. Recycled plastics is unacceptable for packaging, which is to be in direct contact with food, unless the recycling process is specifically approved for this purpose. It can be used however, as a laminate, with virgin film next to the food. Any contaminants in the recycled material can lead to complete rejection of blow-moulded products and films. Extrusion moulding is therefore usually preferred if some contamination cannot be avoided.

Small quantities of PVC in PET can cause brown spots in the clear recycled plastic. In single plastic reprocessing, hand inspection and sorting of all plastic where PVC can be present is therefore essential.

As Scottish Recycling found to their cost, the presence of even a small length of polypropylene rope in with film can jam up rotating machinery, with dire consequences.

4.8 Mixed Wastes

Mixed plastics can be processed together. This is the basis of the "Rutgers University" process pioneered in Aberdeen by Scottish Recycling. In this case, at the specified processing temperature, some plastics will melt, forming the glue, or matrix, and some will remain solid. This gives rise to a composite plastics material, the properties of which are a combination of the matrix material and the characteristics of the un-melted material it surrounds. This is why mixed waste processing is used only for thick walled products, where the size of the un-melted plastics materials is small relative to the thickness of the product. Even with this proviso, the Scottish Recycling fence post sheared at the boundary between a large solid particle and adjacent matrix.

4.9 Summary

Before deciding on a plastics recycling strategy, the nature of plastics has to be well understood.

- Plastics are formed when monomers join together to produce long chain polymers which are solid at room temperature but can have very different properties.
- Plastics can deform, crack, melt and degrade, often within months of being sold.
- Failed products can be costly and incur replacement under guarantees.
- Thermoplastics are of most interest to recyclers, though thermosets can be used as fillers and for reinforcement.
- Plastics for domestic use are usually labelled with numbers 1-7 within a triangle to denote type of polymer.
- It is easier to mix and reprocess thermoplastics of the same family e.g. PE's.
- Plastics collected from domestic waste need to be manually inspected and sorted to check for contaminants.
- PVC and nylon contaminants have to be excluded from polyolefin, PET and PS recycling for both operator safety and contamination reasons.
- Some mixed plastics can be reprocessed using the "Rutgers" approach. This is suitable for thick walled applications such as plastics lumber.
- PVC and nylons should be recycled in closed-loop systems, where the materials are manufactured with recycling in mind.

5. PLASTICS LIKELY TO BE AVAILABLE FOR REPROCESSING

5.1 Introduction

Before setting up a plastics recycling company, the type and tonnage of waste plastics being disposed of locally must be quantified. This will indicate which plastics to source and reprocess. Some plastics, typically packaging, appear in the waste stream soon after manufacture. Other plastics can be locked up in cars, buildings or reusable containers for decades before they become available. Data quantifying the amount of plastics manufactured may therefore differ considerably from the quantity of plastics waste becoming available for recycling. The former can only be used as a rough estimate of potential plastic waste arisings.

Food films and trays are likely to be biodegradable in future, for disposal via the compost bin. The plastics recycler should therefore either ignore food packaging waste, or ensure that the recovery process selected can pay off the investment before biodegradable food packaging starts to dominate.

5.2 Range and Quantities of Plastics in Use

5.2.1 Plastics Use by Sector

Total UK consumption of thermoplastics for the year 2000 was 3.94 million tonnes per annum (WasteWatch, 2003). The proportions of plastics (Figure 5.1) shows that LDPE film dominates at 1.00 M tonne per annum, followed by PVC at 0.78 M tonne, and Polypropylene at 0.76 M tonne. While PET and HDPE represent only 0.24 and 0.54 M tonne per annum of consumption, they are the main plastics sourced from municipal waste for recycling.

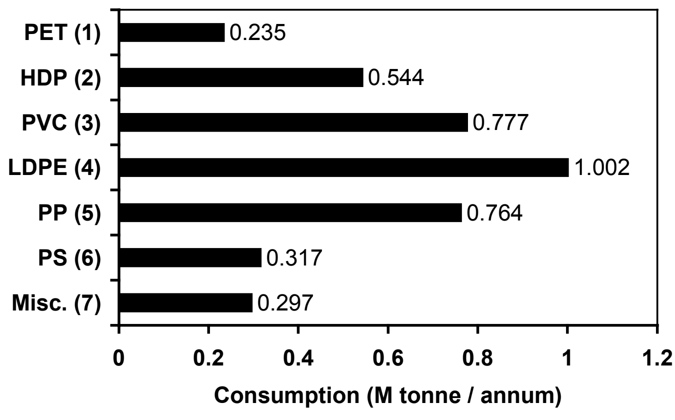


Figure 5.1 Plastics Consumption in the UK for the year 2000

The plastic used in each sector of the economy is shown in Table 5.1. The information for this table has been sifted from the Waste Watch, 2003 publication, in an attempt to show at a glance which plastics are being <u>used</u> in each sector. The <u>availability</u> of the plastics for recovery and recycling will be a proportion of these figures. The data for household packaging and the automotive sector, in contrast, shows the amount of plastics <u>becoming available</u> from these two sectors. The household packaging includes contamination so it is suggested that the actual available plastic would be 85% of this figure.

Table 5.1 Plastic utilisation in the UK for year 2000, with approximate proportions used in eight market sectors (tonnes per annum)

No	Polymer type	Total in UK	Plastic used by each sector						Recycled material on market	
			Commercial & industrial packaging	Electrical & electronics	Building & construction	Agricultural	Medical	Furniture & Housewares	Household Packaging	Automotive sector
1	PET	235,000		3,550					189,400	
2	HDPE	544,000	89,000	3,550	105,000	14,670			243,900	11,000
3	PVC	777,000		14,200	500,000				20,100	15,000
4	LDPE	1,002,000							769,500	
5	PP	764,000	75,000	64,000	35,000	37,960		99,000		65,000
6	PS/EPS	317,000	43,000	67,450	24,000		10,000	7,000		
	Other plastic packaging		400,000						344,600	
	Other dense plastics		83,000	24,850	29,000				259,900	26,000
	Unspecified plastics					40,300	85,000	272,000		
	ABS/ASA/SAN	89,000		117,150	21,000					33,000
	PA	46,000		10,650	13,000					
	PBT	9,000								
	PC/ABS	4,000								
	PC	38,000		14,200	14,000					
	PMA/PMMA	40,000			14,000					
	POM	16,000		7,100						
	PUR	55,000		28,400	45,000					
	Total	3,936,00	690,000	355,100	800,000	92,930	95,000	378,000	1,827,400	150,000

Consideration has to be given as to how long the plastics will be locked up in the product. Packaging will become available soon after manufacture. Building and construction plastics may be in use for 50 years before they become available. Underground items like gas and water pipes may never be retrieved at all. Only a fraction of the 800,000 tonnes going into building and construction is therefore likely to come on to the recycling market. Since 63% of the material is PVC, there is a considerable potential business now, increasing in the future, in recycling this material if PVC is to be recycled within a closed-loop.

5.2.2 Calculating Plastics Waste Potential Tonnage

In estimating the amount of plastic that will become available in any area, a very basic calculation can be made on the basis of the UK having a population of 59 M. If the population of greater Aberdeen, for example, is assumed to be 0.25 M, then all the quantities in Table 5.1 can be multiplied by 0.25/59 = 0.00424 to find the tonnage of plastics that will be available. For example, for PET from household packaging, the tonnage will be: -

Tonnage of PET = 189,400 x 0.00424 = 803 tonne per annum.

The figure for useable plastic will have to be reduced due to the contamination.

For electrical and electronics, the amount of polypropylene would be: -

Tonnage of PP = 64,000 x 0.00424 = 271 tonne per annum.

Again, there will be contamination and losses due to some material going to landfill, but the calculation does give an approximate figure.

No differentiation needs to be made between normal Polystyrene and expanded Polystyrene, as the entrained bubbles of gas in the latter will be given off during reprocessing.

5.3 Proportions of Plastics in the Municipal Waste Stream

The proportion of plastics in the municipal waste stream for West Europe is shown in Figure 5.2. The analysis of the samples of plastic collected in Aberdeenshire Council's civic amenity skips is shown in Figure 5.3. This shows a reduced proportion of PVC, which is of benefit in the manufacture of plastic lumber.

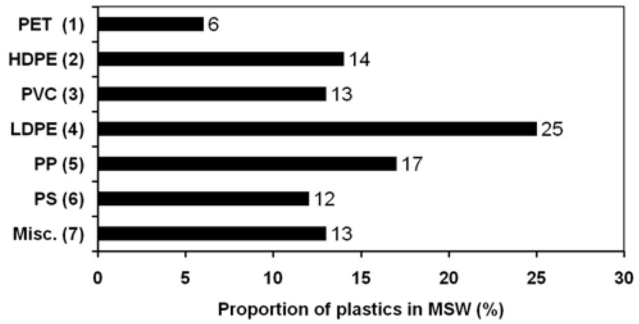


Figure 5.2 Proportion of Plastics in MSW (%) (IPAD, 1994)

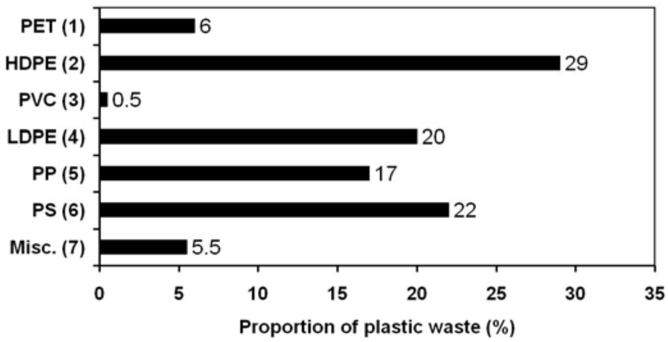


Figure 5.3 Proportions of Plastic in mixed plastics collection skip, Aberdeen

5.4 Recycling Rates of Plastics Compared with Other Materials

The rates of recycling of plastic are small compared with other materials. Recyclers of steel, aluminium and paper run viable businesses, which were previously unsupported by government. Recycling rates for the UK (Figure 5.4) are Steel 43%, Aluminium 44% Glass 26 % Paper 38 %. Plastic recycling in comparison is only 5%. This low figure suggests that plastic recycling is neither greatly profitable nor easy.

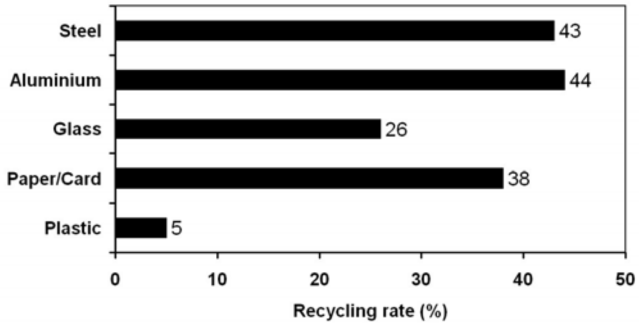


Figure 5.4 Recycling Rates for all material in the UK (AEAT, 1999)

5.5 Economics of Plastics Recycling

Evidence from the European "Green Dot" system (Green Dot – Dulaes system, 2002-3) suggests plastic is the most expensive material to recycle. The scheme pays recyclers for recovering material for reprocessing. The payment for plastics is £1000/t, compared to £136/t for paper and card and £51/t for glass (Figure 5.5). To back up the contention that plastic recycling is uneconomic in the UK, the report Plastics, (DTI, August 2002) suggests that the cost of treating post-consumer waste is about £400/tonne. This excludes the cost of collection or any payment to the supplier of the waste. If virgin polymer (e.g. LLDPE) averages £450 per tonne, it is unlikely that the £50 difference is going to pay for collection, running the business and paying for the sales force. The present value for PRNs (Materials Recycling Week, June 2003) of £10-12/ tonne is of little help. That an increasing amount of reprocessing of plastic is being carried out in China (Bond, 2003) only confirms that at present processing such material in the UK is hardly viable.

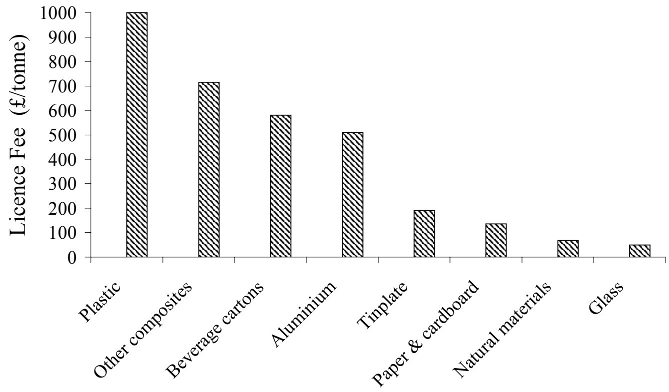


Figure 5.5 "Green Dot" Recycling Costs

5.6 Single Plastics in Municipal Waste Stream that are being Targeted

The plastics in the municipal waste stream that are being targeted are PET and HDPE bottles. At the moment a large proportion of this plastic is loaded into 12 m (40 ft long) containers for shipment and processing in China (Bond, 2003). This raises the question why more processing of plastics from the municipal waste stream is not being carried out in the UK. China's lower labour costs, their plastic manufacturing industry that requires plastic feedstock and possibly their lower environmental standards are all factors favouring reprocessing there. A 12 m container will take 72 bales, or approximately 18 tonne of plastic (See Chapter 7.14). If the cost is £110-140/tonne, (see Chapter 7.14) the lower labour costs in China may compensate for the shipping costs.

In considering reprocessing this plastic, if the UK moves from single-trip to returnable bottles that can be refilled up to 20 times, the quantity of bottles to reprocess will reduce dramatically.

5.7 Mixed Plastics in Municipal Waste Stream that are being Targeted

Mixed waste can be purchased at £25-45/tonne compared to £100-130 /tonne for single polymer colourless PET or Natural HDP (Materials Recycling Week, June 2003). If mixed waste can be reprocessed into a useful product a cost saving can be made. A few plastic recyclers are targeting mixed waste for processing into street furniture, posts and bollards. So long as gross contaminants can be excluded from the mixed plastics, and sufficient LDPE is in the mix to provide the "glue" to bond the mixed waste it can be processed without the expense of separating out the different plastics.

5.8 Plastics that are Disposed of by Commerce

Plastics are increasingly being used where their lightweight, low cost, long life and ease of moulding into a final shape, makes them the material of first choice. Very stringent performance requirements have resulted in the development of specialised polymers (e.g. Teflon, Kevlar) with particular qualities. It is important therefore that these plastics are kept separate from materials with lesser properties which by mixing will devalue the resultant product. Their value, compared to common domestic plastics, can however make reprocessing much more financially attractive. The major applications of plastic types are listed in Table 5.2 below. A number of these plastics were available to Scottish Recycling.

Table 5.2 Uses of major plastics for industrial applications (EA, 2001, and Brydson, 1999)

Number if available	Thermoplastic or thermoset? Thermoplastics	Main Application
1	PET	Bottles, film, food packaging, synthetic insulation
2	HDPE	Containers, toys, industrial wrapping and film for goods, gas pipes, and drill-pipe thread protectors
3	PVC*	Window frames, pipes, flooring, wallpaper, bottles, cling film, toys, guttering, cable insulation, credit cards, medical products, car mats, car seats
4	LDPE	Film, bags, toys, coatings, containers, pipes, cable insulation
5	Polypropylene	Film, battery cases, microwave containers, crates for bottles and food, car parts, electrical components, drainage pipe, woven materials (bags, ropes, carpets)
6	PS	Electrical appliances, thermal insulation, tape cassettes, cups, plates, CD cases
	Acrylics	Car rear lamp housings, aircraft windows, and transparent guards for food processors and motorcycle windscreens, general appliance mouldings
	Polycarbonates	Compact discs, casings for electrical equipment, power tools and kitchen food processors.
	Polyamide	Films for packaging of foods (oil, cheese, boil-in-the-bag) and high temperature engineering applications
	ABS/SAN	Transparent all-weather sheet, electrical insulators, domestic appliances, piping
	Nylon	Ropes, clothing, fastenings
	Thermosetting plastics	
	Epoxy resins	Adhesives, car components, sports equipment, boats
	Polyurethane	Adhesives, appliances, car parts, electrical components, trainer soles, furniture foam
	Phenolics (phenol-formaldehyde, urea-formaldehyde)	Adhesives, appliances, car parts, electrical components

* Contains high proportion of additives

The optimum approach to recovery of industrial plastics is to target a specific plastic or plastics and produce high quality, shredded single polymer or re-extruded pellet or granule. This can be sold on to existing plastic product manufacturers to allow them to substitute the recycled granule for more costly virgin product. This allows the plastic product manufacturers to specialise in the manufacture of products, leaving the collection and processing of waste plastics to firms specialising in this area.

5.9 Biodegradable Plastics

Biodegradable plastics in future will have to be clearly marked as such if they are not to enter into the plastic recycling chain.

5.10 Low Density of Plastics

To add to the problem of the huge range of polymers used in food packaging, the low bulk density of the material means that collection and transport of the plastic is very inefficient. Loose plastic containers have a bulk density of 32-48 kg/m^3 (Diaz, 1993). Hand operated compactors (Container Systems Gmbh) claim that their machines can reduce the volume taken up by loose plastic by a fifth, which would give a density of 160-240 kg/m^3. Hydraulic operated balers (Harris Eurobalers, 2003) compress plastic to 380 kg/m^3 to maximise the plastic carried in a container.

5.11 Summary

For recovery and reprocessing of waste plastics to be worthwhile, they must be easy to obtain and have a market for the processed product. Suitable plastics are:

- PET bottles, domestic, post consumer.
- HDPE bottles, domestic, post consumer.
- LDPE film, industrial, flawed batches.
- LDPE agricultural film, contaminated with soil.
- Polypropylene, commercial, post consumer.
- Polystyrene (PS), including expanded PS, commercial, post consumer.
- Mixed plastic waste with a minimum of 40% polyolefins, for plastic lumber manufacture.
- Spurges and runways from plastic component manufacture.
- Thermosets for use as filler in plastic lumber.
- PVC products, closed-loop recycling.
- Contaminated batches of virgin product for cleaning up and resale.
- Special, single type, commercial plastics (e.g. ABS, Nylon, acrylics, polycarbonates).

Wastes from industry and commerce are likely to be collected as individual polymers, and should be reprocessed as such. The recycler will probably produce shredded plastic or re-extruded granules, for plastic product manufacturers to purchase instead of virgin polymer.

Biodegradable plastics will have to be kept out of the plastic recycling waste stream. Their use in agriculture to replace LDPE crop cover and cloche would ease disposal of what is at present a difficult product to reprocess.

Plastic lumber production, using mixed waste, provides a useful sink for reject plastic from the single polymer recovery systems. Alternatively, suitable waste streams can be made into plastic lumber without the high labour cost involved in plastic separation. By adding milled, thermoset plastics or organic fibre fillers to the mix, a low cost product, which can compete with timber, can be produced.

6. ALTERNATIVE PLASTIC RECYCLING STRATEGIES

6.1 Introduction

Waste plastics become available for recycling by a variety of routes. These include waste from manufacturers of plastic products, commercial waste disposed of by industry and businesses, waste plastic retrieved by recyclers of cars or fridges, and waste from the domestic sector. If the material is a single type polymer, then reprocessing will be the preferred option. If the waste consists of unseparated plastic containers, plastic films and paper, the high cost of separating the plastics may make single polymer recycling uneconomic. It may be better to process the mixed material into plastic lumber. An alternative is to use the mix as a waste derived fuel (Wdf) to produce energy-from-waste. In selecting the preferred option, it is important to avoid spending excessively on separation and transportation on what is essentially a low value product.

6.2 Material Streams

The routes through which waste plastic comes on to the market for recycling are listed below in decreasing order of value to the reprocessor: -

1. Reject material from the plastics manufacturing industry (e.g. reject LDPE film or pellets)
2. Commercial companies or farms disposing of single type plastics (e.g. grease drums)
3. Retail take-back schemes (e.g. printer toner cartridges, CD cases)
4. Mixed plastics from dismantlers of returned products, appliances or vehicles
5. Blue box type "recyclables" separated by plastic type in Materials Recovery Facilities (MRFs)
6. Bottles only "bring skips" in local authority Civic Amenity sites (Figure 6.1)
7. Mixed plastics "bring skips" in local authority (CA) sites (Figure 2.2, Chapter 2)
8. Plastics from un-segregated household waste screened out after composting (Figure 6.2).

Figure 6.1 Bottles-only bring skip at local amenity site

Figure 6.2 Plastic and paper waste separated from municipal solid waste

Where plastics are mixed, or consist of large items such as barrels or bottle crates, there must be both the facilities and space in either the plastic recycler's premises or a third party processor business to separate, cut up and shred these disparate products.

6.3 Linking with a Waste Producer

While linking the waste produced by one company, with the feedstock required by a recycling company appears attractive there is considerable risk involved. Wastes have to be disposed of daily or weekly. Any interruption to the disposal process can result in large stocks of waste building up, possible smells being produced and, at worst, the halting of the company's production.

Disposal of waste to a recycling company is therefore less secure than disposal to a nearby landfill site. The recycling company may suffer a breakdown in its machinery, a fall off in sales of its products, or at worst bankruptcy. Suddenly the viability of the manufacturing company supplying the waste can be jeopardised by the difficulties of finding alternative waste disposal routes at short notice.

In the same way, the recycling company is totally dependent on the supplier of the feedstock material. Should the manufacturing company supplying the waste go out of business, or change its working practices, the recycling company can loose its supply of material overnight.

There is real benefit therefore in selling shredded material or pellets from single polymer or mixed plastic waste on to the open market. In this way there is no direct linkage between companies, as both parties can shop around to find the best price and most secure supplies. The loss of any one company is then of lesser significance.

Where both companies do have access to alternative disposal and supply routes, a degree of linkage with each other can be of mutual benefit, as then the cost savings from minimising transport, avoiding the need for baling or pellet production, etc., can be realised.

A fairly reliable partner for supplying separated material is a Materials Recycling Facility (MRF, pronounced "murf"). The municipal waste stream is very predictable and secure. Whether it is run by the local authority or by a waste disposal company, the community will expect the MRF to recycle as much waste as is financially viable. There is therefore pressure on the MRF to maintain the supply of material to the recycler.

6.4 Preferred Location of the Plastic Recycling Company

Separation of clean mixed wastes of all descriptions into single plastics and other recyclable materials should be carried out on the one site, in a "clean" MRF. This allows the large quantity of unusable material to be bulked up, for disposal to landfill or possibly for conversion into a waste derived fuel.

Domestic "blue box" recyclable material is usually delivered to such a facility. The paper, plastic, aluminium and steel cans are separated into their component fractions and baled. Much commercial waste will go to the same facility.

If the proposed plastic recycling company is to deal only with pre-sorted, clean waste, it can be sited in any convenient location close to its suppliers. These can either be MRFs or commercial companies with significant quantities of waste plastic. Waste plastic will come into the plant in standard sized bales, so the reception can be designed to suit.

If plastic lumber is to be produced, it can utilise some of the material in the MRF that would normally go to landfill. It can therefore either take reject from the MRF, or source mixed plastics and filler material direct from civic amenity sites and material from commercial companies.

6.5 Processing Options

There are five processing options for a potential plastic recycler: -

1. Single source, single polymer shredding
2. Multi-source, single polymer or polyolefin shredding, mixing and re-extrusion into pellets
3. Mixed waste shredding for supply to plastic lumber manufacturers
4. Mixed waste shredding and intrusion for plastic lumber production
5. Chemical feedstock recycling

6.5.1 Single Source, Single Polymer Shredding

While plastics can be separated into polymer types, the extrusion characteristics of any batch of the polymer will vary depending on the formulation that was used to produce the original product. If a single, clean, polymer of known formulation is to be recycled, it is only necessary to shred the material to produce a feedstock that can be used or sold for re-extrusion. The product can be sold together with the details of the formulation, so that the processor extruding the shredded material knows its extrusion and strength characteristics.

6.5.2 Multi-source, Single Polymer or Polyolefin Shredding and Re-extrusion

Usually waste or reject polymers come in small batches, all with different formulations. These need to be shredded into a single large batch, which is then thoroughly mixed. The mix is then put through an extruder to melt it to form new pellets. The formulation of the mix will be the average of the material put into the mix. The characteristics of the formulation can be assessed using the equipment described in Section II, Chapters 8 and 9. It can then be sold with the accompanying physical and strength properties.

6.5.3 Mixed Waste Shredding for Supply to Plastic Lumber Manufacturers

Mixed plastic waste can be shredded suitable for forming into thick walled items such as fence posts, boards, street furniture and bollards (Figures 6.3 and 6.4).

Figure 6.3 Plastic Lumber used for Park Benches (Sweepwise Municipal Services)

Figure 6.4 Potato Storage Boxes made from Plastic Lumber

The mixture for the final plastic lumber requires that: -

- There is a minimum of 40% polyolefins to act as the "glue"
- Polypropylene should not exceed a third of the polyolefin content
- PVC should not exceed 1-2% of the plastics in the mix
- Nylon should be excluded
- The remaining 60% can be in the form of non-thermoplastic filler, or other compatible plastics.

Excessive polypropylene in the mix causes the material to shatter at low temperatures and affects the flow into the mould. The sample of mixed plastics collected in a civic amenity site and analysed by Scottish Recycling (Figure 5.3) shows that polypropylene constituted 25% of the polyolefins (HDPE, LDPE and PP), so was within the limit of acceptability.

PVC emits hydrogen chloride when melted, forming hydrochloric acid if it comes into contact with water. The acid can affect workers respiratory system and may corrode processing machinery. When nylon is present, toxic fumes can be produced.

Filler material can be wood flour, ground thermoset plastics, and other fibrous materials. Experiments with plastic lumber production tested mixes ranging to a maximum of 60% filler in the mix.

If a shredded mix of plastics is being produced as a feedstock for plastic lumber production, there is a danger that the components will separate out in the bags during transport. Each bag should therefore be remixed at the production site to ensure reasonable homogeneity.

As Scottish Recycling found, when shredding loose films, the major problem is to achieve a reasonable throughput through the shredder and a dense enough granule to give sufficient throughput through the intrusion line. Throughputs of material likely to be sourced for processing must be thoroughly determined by machinery suppliers prior to purchase of production machinery. Manufacturers quoted production rates should not be relied upon without prior assessment.

Any product manufactured in this way must be properly tested for chemical, physical and structural properties prior to the market launch.

6.5.4 Mixed Waste Shredding and Intrusion for Plastic Lumber Production

This is the same process as in Section 6.5.3 above except the plastic shredding is being carried out on the same site as plastic lumber production. It requires more room on site and means the lumber producer has to concentrate on both shredding and lumber production, with the attendant risk of problems in one area affecting production at the other.

6.5.5 Chemical Feedstock Recycling

Chemical feedstock recycling, where plastics are cracked (chemically separated) into their component chemicals in large chemical plants, allows a mix of plastics to be chemically taken apart, reprocessed and reformulated into single polymer type pellets. Plants on the continent using such technology tend to be large scale, are run by large chemical companies and are outside the scope of this publication.

6.6 Closed-loop Processing for PVC

It is likely that PVC, like other specialist plastics such as ABS and Nylon, will be subject to "closed-loop" reprocessing. This is where the plastic is continually reprocessed, with some virgin material added, similar to the approach taken by newsprint recyclers. This results in as little material as possible ending up in the commercial or municipal waste stream. This is to be commended, as PVC in the waste stream is a source of dioxins, furans and heavy metals when waste is burnt. The absence of PVC in waste would reduce the dioxin and heavy metal problem and make the production of energy from suitable, high calorific waste more environmentally acceptable.

Close-loop recycling is already being carried out on electric power cables (MMH Recycling Systems Ltd, 2003). Since PVC tends to be used for long life products, the reprocessing market may be 20-30 years after initial manufacture. PVC production figures should therefore not be used as a guide as to the quantity of PVC coming on the market for reprocessing.

6.7 Role for Existing Plastic Component Manufacturers

Plastic product manufacturers are expert in producing plastic products, knowing the available markets and in designing new products. In addition there is at present an over supply of plastic manufacturing capability in the UK. Rather than potential plastic recyclers trying to learn how to manufacture and market plastic products themselves, they should produce shredded plastics or re-extruded pellets, for plastic manufacturers to use if the quality and the price are right.

6.8 Alternative Disposal Options

Mixed waste plastics, paper and card have a high calorific value and can be converted into a waste derived fuel using the Stabilat production system (Herhof, 2003) or other systems, which shred and dry the material to make it suitable for burning. The less PVC there is in the plastic mix and the newer the combustion plant used, the less concern there is for dioxin release from the chimneys of energy-from-waste plant (Warmer, 2003).

6.9 Survey of Plastics Recyclers

A recent survey (Bond, 2003) of UK plastics recyclers produced 37 responses. Average waste plastic through the plants was 7,000 tonne per annum (Range 50 – 31,000). The types of plastic with percentage of total material recovered was LDPE 40%, PP 22%, HDPE and PVC 9% each, PET 6%, PS 5% and other plastics 9%. Half the companies put their core business activity as recycling, 29% as purely recovery, while 22% were actively manufacturing a product such as street furniture or new film. Half received no support funding at all, while 39% received PRNs, 8% recycling grants, with 3% receiving other funding.

The main barriers to recycling from a given list, listed in order of importance were

- Not financially viable
- Plastic too contaminated
- Lack of source separation
- Lack of grants
- Lack of collection systems
- Lack of legislation encouraging recycling
- Cost of installing a water treatment plant for cleaning up wash water.

Comments offered, in order of frequency, was the need to create more end-use markets for recycled products, the need for more government grants and subsidies, improved collection management, stronger legislation to encourage recycling, more emphasis on waste reduction and reuse and improved segregation at source.

6.10 A Successful Plastics Recycling Company

To ascertain how it is possible to recycle plastics profitably, the authors on different dates visited a plastic's recycling company in Grangemouth, in Scotland's central belt.

The success of Plastic Polymer Processors Ltd as a plastics recycling business is due primarily to its managing director, Charles Forrest. Addressed as "Boss" by his staff, Mr Forrest knows the ways of the waste industry intimately, can identify polymer type with ease, and has developed a plastic recycling business focussed on supplying the client with a consistent, precisely specified product.

Mr Forrest learnt his skills as a former tool-maker for plastic moulds followed by a period of running his own business recovering cardboard and paper packaging material. With the growth of plastic in the reclaimed packaging, he decided to concentrate on the collection of the plastic fraction of the packaging. In 1994 he set up his first plastics reprocessing business in Cumbernauld.

Rather than expand production in Cumbernauld, Charles Forrest decided on a second factory in Grangemouth. This was attractive due to the proximity of the companies nearby producing plastic polymer feedstock and products made from plastics.

With a staff of 16, Mr Forrest sells 3,600 tonnes of plastic granules per year. What is not processed in the plant, is shipped out in containers to China for reprocessing.

Mr Forrest's strategy is simple. His company will lift pre-consumer recovered plastics from companies at no charge, if the plastic is free from contamination. If the plastic is already granulated, he may pay up to £180 for this material. If the material is contaminated, it is delivered to another site for cleaning, prior to bringing it into the factory. The material is shredded into 20 mm particles then granulated into 8 mm particles. The resultant granules are blended with material from other sources, put through a "master batching" process where colour can be added and then compounded (i.e. heated and extruded) to produce a uniform batch of material.

The aim is to produce a 5 tonne batch of pellets with a single uniform melt flow rate from a variety of plastics having different melt flow rates. In this way the product will behave in a predictable manner when the client uses the material in his extruder.

The company concentrates on reprocessing polyethylenes (PE). Nylon and Acetals are never brought into the factory for fear of the toxic gas they give off when heated. PVC is avoided, as it does not mix with any other plastics.

Plastics that have become wet from storage in the open are shredded and granulated, then dried in a special purpose recirculating drier to remove any trace of moisture.

The company does issue Packaging Recovery notes (PRN's), but while these started at a value of £180 /tonne, they have now reduced in value to £10/tonne.

Mr Forrest purchased the Starlinger plastic lumber intrusion line sold by Scottish Recycling when it went into voluntary liquidation. He uses it to process the waste plastic that would otherwise be discarded. He is still trying to find a satisfactory market for this material (Figure 6.5). DIY stores charge a 100% mark up and put material on display on a sale or return basis. There is however interest in the product from potato box manufacturers and garden furniture producers.

Figure 6.5 Polymer Processors Ltd Fence Posts awaiting a Buyer

Mr Forrest affirmed that while the business was a viable concern, it was not hugely profitable. If he could find more plastic to process he would take it. He felt that material like milk bottles could be reprocessed if householders rinsed the bottles prior to putting them in a recycling container. From the authors' perspective, entrepreneurs like Mr Forrest should be supported to expand their enterprises utilising their sound technical base.

6.11 Summary

There are a number of plastic recovery and recycling strategies that a recycling business can follow. Each approach has its attendant risks and benefits. These are listed below: -

- A hierarchy of material to process exists, with single polymer, reject material from the plastics manufacturing industry being at the top, and mixed plastics from non-segregated household waste being at the bottom.
- Linking waste producer with waste recycler is risky as interruptions in waste production or an inability to take the waste produced can affect the viability of both businesses.
- Separation of heavily contaminated plastics should be carried out in materials recovery facilities (MRFs) so that the reject material can be sent to landfill or for burning with the other reject material.
- The recycling of separated engineering plastics will provide the highest return, with separated packaging type plastics next.
- Clean material from a single known source need only be shredded prior to sale.
- Small batches of plastics with differing formulations can be shredded, mixed and re-extruded to form large batches of a single formulation.
- If plastic lumber is being produced, production should be close to a supply of filler material (e.g. a MRF), so that transport of filler material is minimised.
- Plastic lumber production requires the removal of contaminants and minimum quantities of certain polymers, so feedstock material has to pass over a picking table.
- Chemical feedstock recycling is an alternative recycling strategy, but is unsuitable at present for smaller processors.
- Specialist plastics like Nylon and ABS yield a high value product so should be processed in a closed-loop.
- As PVC causes problems with other plastics in plastic recycling and may produce dioxins when burnt, it too should be processed in a closed-loop.
- Waste plastic recyclers should provide shredded plastic or re-extruded pellets for established plastic component manufacturers, rather than try to manufacture a product as well. The possible exception is in plastic lumber production.
- Plastic Polymer Processors Ltd shows that it is possible for a plastic recycling business to be profitable, but only if the company’s staff has a sound technical appreciation of plastics and a thorough understanding of the waste recycling industry.
- Low quality plastics waste may be more sensibly converted to a waste derived fuel or burnt directly.

7. SETTING UP A PLASTICS RECYCLING BUSINESS

7.1 Introduction

Companies and local authorities placing waste plastics on the open market may do so for a number of reasons. These may include:

- Making money by selling plastics to recycling companies
- Obtaining Packaging Recovery Notes (PRNs) which can be redeemed to organisations such as Valpak for cash
- Avoidance of landfill gate fees and tax (commonly £30-40/tonne) charged for plastics waste
- A company ethos of sustainability, even though the cost is greater than landfilling
- Local Authorities attempting to assure their community council tax payers that plastics collected at a civic amenity site, is actually being recycled
- Satisfying their company EMS, IS0 14001 policy or Quality Assurance Scheme that plastics are being recycled
- The disposal of a “problem waste” camouflaged as a good will gesture.

Staff running recycling companies should only take waste that is easily recycled. Recycling companies have had salad cream bottles offered for recycling, still full of dressing, but past the “display-till” date. The oil pipe thread protectors processed by Scottish Recycling, made with a combination of plastic and 10 gauge, pressed-steel reinforcement, posed a disposal problem needing a solution. Scottish Recycling solved the Oil Company’s problem but suffered high wear rates in their shredder as a result.

Depending on the quality and cleanliness of plastics being offered, the recycling company can either charge a gate fee for taking the plastics or pay for the material. What determines the rate of fee or price is the quality of material delivered and how much cleaning or processing is required to produce a saleable product.

7.2 Standards for Receivers of Recovered Plastics

RECOUP (Recycling of used plastics) Ltd (RECOUP, 2003a) is a wholly owned subsidiary of the national plastic container-recycling organisation RECOUP. The company will help new plastics recycling companies to obtain the legal requirements for a waste carrier licence, shipment-tracking documentation, and provide guidance on which plastics are best to recover for recycling. Selected recommendations from their website are given below.

7.2.1 Preferred Waste Plastics to be Recovered for Reprocessing

The preferred materials are bottles separated into the following grades:

1 PET - colourless

1 PET - green

HDPE – natural

HDPE – mixed colours

PVC

RECOUP recommends that householders collecting bottles remove the caps to allow bottles to compress better. The bottles should be compressed into bales 1.1 m long, 1.0 m x 0.8 m cross section. They should be compressed to a weight of between 200–325 kg, and tied with 19 mm wide x 0.6 mm deep black flat band metal strip or 22/28TSI (ton/in^2) "cut and loop" wire of 6 mm diameter. Storage can be outside, but if the area is muddy, storage should be on pallets. It is preferred that the bales are supplied without pallets, in curtain-sided lorries, stacked in 3 bale high columns (rather than brickwork stacking), with the largest face horizontal for maximum stability. If bales are supplied on pallets, 20 kg per pallet will be deducted from the load. Maximum contamination is 2%, with bottle caps being excluded from this figure.

7.2.2 Individual Requirements for Types of Plastic

PET (Polyethylene terephthalate) - colourless

PET bales should consist of compacted PET plastic bottles normally used in the home, i.e. squashes, mineral water, carbonated drinks. These bottles are transparent, sometimes with a faint blue tint, and with a noticeable white moulded spot in the centre of the base of the bottle. The bottles may have a code "1 PET" or " 1 PETE" embossed on the base or printed on the label. Coloured and strongly tinted PET bottles are not acceptable.

PET - green

The potential market for green PET should be checked prior to collection, as there may be no suitable market for this material.

Green PET bales should consist of compacted PET plastic bottles normally used in the home; i.e. for squashes, mineral water, carbonated drinks. These bottles are transparent, with a green tint, and the characteristic white moulded spot in the base and 1 PET or 1 PETE symbol.

Mixed coloured (e.g. red, black, green) PET bottles are not acceptable.

HDPE (High density polyethylene) – natural

HDPE natural bales should consist only of non-coloured plastic bottles. These are typically milk and fruit juice, cloudy but translucent, bottles and may have a code "2HDPE" or "2 PE-HD" embossed on the base or printed on the label.

Items that should be excluded are transparent plastic bottles; coloured HDPE bottles: any opaque bottles, which are identified as non-HDPE (e.g. black or silver fizzy drink bottles); plastic pots and tubs; paint cans; tubes; buckets and drinking cups.

2 HDPE – mixed colours

HDPE bales should only contain HDPE bottles used in the home. These are typically opaque, and may have a code "2 HDPE" or "2 PE-HD" embossed on their bases or printed on their labels. Examples include bottles that contained detergents, bleach, dishwashing liquid, household cleaning fluids, shampoo and hair care products. Mixed colour HDPE can also contain natural HDPE bottles too.

Items that should be excluded are clear plastic bottles; any opaque bottles that are non-HDPE (e.g. black or silver fizzy drink bottles); plastic pots and tubs; paint cans; tubes; buckets and drink cups.

3 PVC (Polyvinyl Chloride)

The potential market for PVC should be checked prior to collection, as there may be no suitable market for this material.

PVC bales should consist of compacted PVC plastic bottles normally used in the home, i.e. squashes, still mineral water and other non-carbonated soft drink bottles. These bottles are transparent, colourless or tinted blue, and are characterised by having a moulded line running across their base. The bottles may have a code number "3PVC" or "3 V" embossed on their base or printed on their label.

Note that PET and PVC bottles are similar in appearance. Care should be taken to ensure that only PVC bottles are baled under this specification.

7.3 Identification of Plastics

Identification of plastics is not easy. The presence of additives, fillers, pigments and plasticisers may alter the nature of the basic plastic. A plastic, which floats when pure, may sink when filled with additive. A résumé of the main identifying factors is given below.

a) Number

The easiest way to identify a plastic is to look for the number within the recycling triangle 1 (1= PET) if the plastic is a container. It is usually on the base of a bottle, inside a cap, or written on a paper label.

b) Floats

If a plastic floats it is probably polyethylene, polypropylene (e.g. bottle caps), or polybutylene, all members of the polyolefin family. This makes for ease of separation of blow-moulded bottles and injection moulded caps. Once the plastic is shredded into granules, the floating polypropylene granules float, while the PET or PVC bottle material granules sink. Butyl rubbers and methylpentene polymers also float.

c) Appearance and Texture

Clear bottles are either PET or PVC. Cloudy, but translucent bottles such as milk bottles are HDPE. Strongly coloured shampoo or detergent bottles are usually HDPE. Caps for all these bottles are usually polypropylene. Polystyrene, with no blowing agent, has a hard metallic feel and emits a "tinny" sound when flicked with a fingernail. When expanded polystyrene (EPS) is made with a blowing agent, it has the soft, warm feel of polystyrene coffee cups. Polypropylene and nylon have a hard, greasy, slippery, feel.

d) Heating Tests

If the plastic is slowly heated in a flame and it melts and bends, it is probably a thermoplastic. If it stays rigid then starts to char, it is likely to be a thermoset.

7.4 Conveying System and Picking Line

The bales of plastic from the MRF have to be converted into a continuous stream of plastic, so as to feed the shredder at a uniform rate. This requires a hopper system and conveyor belt (Figure 7.1), with pickers on one or both sides. It is imperative to inspect the flow of material to check that harmful contaminants are removed before they can do damage in the shredder.

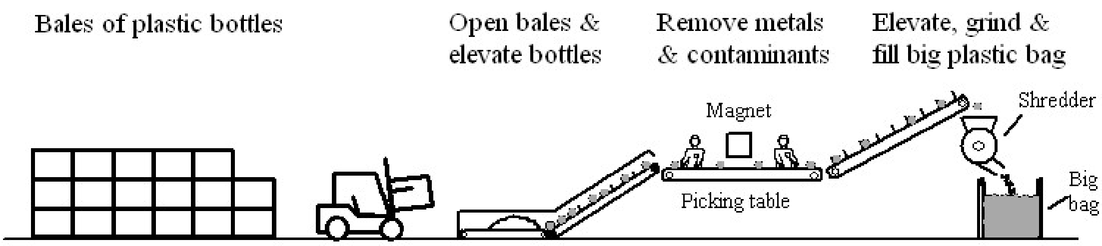


Figure 7.1 Bale Opening and Inspection Line

A metal detector should be fitted at the intake to the shredder to stop the conveyor if there is any ferrous contamination.

For larger items of waste plastic such as plastic crates for glass lemonade bottles, old wheeled refuse bins, fish boxes, etc, a large aperature shredder (Figure 7.2) needs to be inserted in the line to break down the containers into pieces small enough to enter the shredder. For smaller quantities of large items, these may be sawn using a band saw into smaller sections to fit the shredder intake. Scottish Recycling received large quantities of valuable crates for recycling but had no means of getting them small enough to put through the shredder. They took up space and impeded other operations.

Figure 7.2 Large Aperture Shredder to pre-shred large items of plastics, shown here shredding timber

7.5 Dry Shredding of Plastics

The shredder consists of a heavy rotor fitted with teeth, which rotates within a cylindrical screen (Figure 7.3). Plastic is fed into a hopper above the rotor, and a ram pushes the material against the rotor at a rate, which automatically keeps the shredder loaded at an optimum throughput. The screen of the shredder ensures that the plastic is ejected from the base of the screen in a range of sizes between 15-50 mm.

Figure 7.3 Shredder to reduce plastics to 15-50 mm pieces (Untha)

Where material that melts below 100°C is to be shredded, such as LDPE plastic film, water-cooling is supplied to the rotor to ensure that the material does not melt within the shredder. For light fluffy material or film, an additional compaction device can be fitted to ensure that a high throughput is maintained.

A machine with a design throughput of 400 kg per hour, fitted with a 1.400 x 1.050 m aperture and two 22 kW motors, would cost approximately £42,000 plus VAT (UNTHA, 2002). The water-cooling would add a further £5,300 plus VAT.

7.6 Washing, Floatation Separation and Drying System

To clean the shredded material and separate off the polypropylene, a system for washing, floatation, separation and drying is required (Figure 7.4). The use of water has benefits and disadvantages:

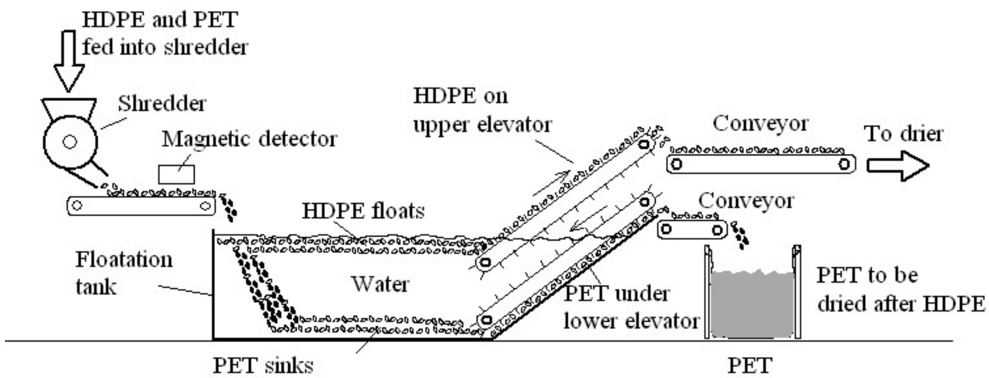


Figure 7.4 Separating Plastic Types by Floatation

Benefits of water treatment are that it: -

- softens paper labels and some adhesives, causing paper to separate from the plastic
- dissolves the remaining contents in bottles
- washes food and liquid residues from plastics
- allows floatation separation of polypropylene.

Disadvantages of water treatment are that it: -

- wets the plastic granules, requiring them to be thoroughly dried prior to extrusion moulding
- the process contaminates the water, requiring a water treatment plant to be installed.

The floatation separation system can be a tank with a high level and low level of discharge for low-density and high-density plastics respectively. Alternatively it can be a cyclone separation system where the action of gravity causes the two categories to separate.

The drier should circulate the washed shredded material, while forcing heated air through the material. Moisture content should be less that 1% by weight for polyolefins, ABS and Polystyrene, and zero for Polyamides (La Mantia, 2002), to avoid the generation of steam in moulds when heated plastic is injected.

7.7 Dry Shredding, Extrusion, and Reforming of Pellets

The baled plastic can be shredded, passed through a heated extruder to melt it and to produce plastic in a “spaghetti” like form, which is then chopped with a rotating knife to produce new pellets. This process has three benefits (Figure 7.5).

Figure 7.5 Pellets produced from an Extruder

- When the plastic is in a liquid state, it can be filtered of any contaminants. A very pure form of pellet is the result.

- If the plastic includes any moisture, or in the case of expanded polystyrene a gas, a vented extruder can be put in the line, to allow the vapour or gas to escape before the plastic is repelletised. The resultant pellets can be used subsequently in the non-vented extruders used in the established plastic manufacturing industry.

- Small batches of a single polymer with different formulations, or a mix of polyolefins, can be bulked up into a large batch of material, mixed prior to extruding, then extruded into pellets having a consistent set of properties of viscosity (melt flow rate), impact hardness and structural strength.

7.8 Removal of Contaminants and Gas during Pelletising

Equipment, such as the Starlinger Recostar, (Figure 7.6) has been developed to carry out this process.

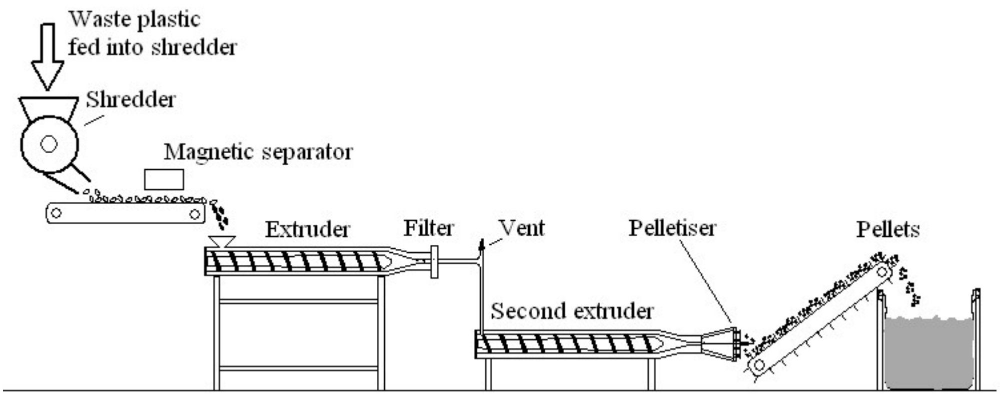


Figure 7.6 Schematic Diagram of Starlinger "Intrustion" Vented Extruder

The output from the shredder, or already pelletised material, is fed passed a magnetic separator, into an extruder, which melts the mix. At the end of the extruder is a pre-filter, followed by a round piston filter. The pre-filter protects the downstream round piston filter from damage, and is periodically back-flushed, to remove any contaminants that build up. The round piston filter serves to purify the melt. During the automatic back-flush procedure, the line keeps running, though at a reduced discharge rate. The material coming from the round piston filter is fed to a degassing device, which creates a vacuum within the molten plastic, removing any gasses in solution. The resultant plastic is then fed to a second extruder with pelletising head. The final pellets are passed through a dewatering unit and drying centrifuge prior to final discharge into a silo.

The materials it can process are LDPE, LLDPE, HDPE, PP, PS, PS-HI, ABS, PC and others. Models have a potential throughput of 140, 220, 500 and 800 kg/h, but throughput depends on the density of the material fed into the machine.

Since this process requires heated extrusion equipment in addition to a mechanical shredder this is a more expensive process than the simple mechanical shredding discussed in section 7.5. It may however allow higher value product, such as films, to be made and this may pay for the extra processing cost involved.

7.9 Production of Plastic Lumber

A second version of the Starlinger is the Intrustar. This was the equipment purchased by Scottish Recycling. It works in the same manner as the Recostar, but instead of the second extruder feeding molten plastic into the pelletising unit, it feeds it into intrusion moulds provided by the customer. In the case of Scottish Recycling, these moulds were sized to make fence posts.

The Intrustar is a vented extruder, which allows any gasses to escape during the melting phase. This allows mixed, contaminated plastics to be extruded, without the need for de-gassifying first.

7.10 Addition of Fillers, Chemicals and Pigments to Plastic Lumber Production

Fillers, chemicals and pigments can all be added at the point where the shredded plastic or pre-prepared pellets are fed into the extruder. Fillers significantly alter the engineering properties of the resultant material, but can extend the more costly plastic over a greater number of products. The addition of chemicals such as plasticisers, compatiblisers, stabilisers, UV blockers and fire retardants all add cost to what may well be a low value final product. Pigments also add cost so their use should be minimised.

7.10.1 Fillers

Fillers can be used to extend or alter the characteristics of any plastic. Their use with mixed plastic waste to produce plastic lumber has proven popular in the USA in particular. Not only can otherwise unusable plastic be used to bond the filler and un-melted shredded plastics, but the recycler can charge a gate fee to take the plastic waste and filler material, which helps to pay the cost of processing.

Potential particulate materials include:

- Talc or silica – to reduce the amount of polymer used but adds weight
- Waste glass fibre insulation – to improve strength
- Glass fibre reinforced plastic – to improve strength and add bulk
- Ground thermoset plastic material
- Wood fibre – to improve strength, stiffen, add bulk and reduce weight
- Wood flour – to add bulk and reduce weight
- Sand or soil – to add bulk, but adds weight
- Gas beads – to aerate the plastic to lighten it or improve its insulation value.

Since there may be no chemical bonding between the plastic and filler, the mix may resemble the honeycomb created by blowing agents, but with filler in the spaces rather than gas. Fillers are usually in the form of "flour" or finely ground material such as talc, calcium carbonate, fibreglass, mica and wood flour. Large particles are likely to reduce the strength of the mix if there is no bond between filler and the polymer used.

Dry inert fillers such as talc have been the most commonly used materials in the past. Wood is the least used filler (English, 1998a) as it contains moisture, which turns to steam when the plastic mix is heated above 100°C, sometimes with explosive results. It will also char at temperatures at above 200°C, so that it can only be used with plastics, which melt at below this temperature, such as PE, PP and PS. PVC, styrene acrylonitrile (SAN) and some forms of acrylonitrile butadiene styrene (ABS) can also be used. A proportion of fillers as high as 60% can be included (English, 1998b). Companies in the USA which use such fillers are Temple Inland/Lumberlast, N.E.W Plastics, The Plastic Lumber Company, Duraboard and Superwood.

Talc and silica both make the plastic considerably more dense, and cost money to buy. In comparison, the recycling company may be paid to take the fibreglass, plastic thermosets or waste wood. Their cost will therefore only be the cost of grinding. Straw in comparison will probably need to be purchased, and is more difficult to grind due to its fluffy nature.

7.10.2 Additives

Additives such as antioxidants, UV stabilisers, plasticisers, etc. will already be present in some or all of the plastics recovered (See Chapter 8.5). Unless the origin of the plastic is known, the presence of additives and their percentage in the mix will be unknown. For this reason the quality and life of a reprocessed polymer is less predictable than a virgin product.

As the inclusion of additives in the plastic adds cost, their use should be kept to a minimum. Additives can however improve the weathering ability of recycled plastics (Figure 7.7).

The best solution is to try a sample of the mix without an additive, test the result and if there is a problem, consult additive suppliers as to which additive could be of help.

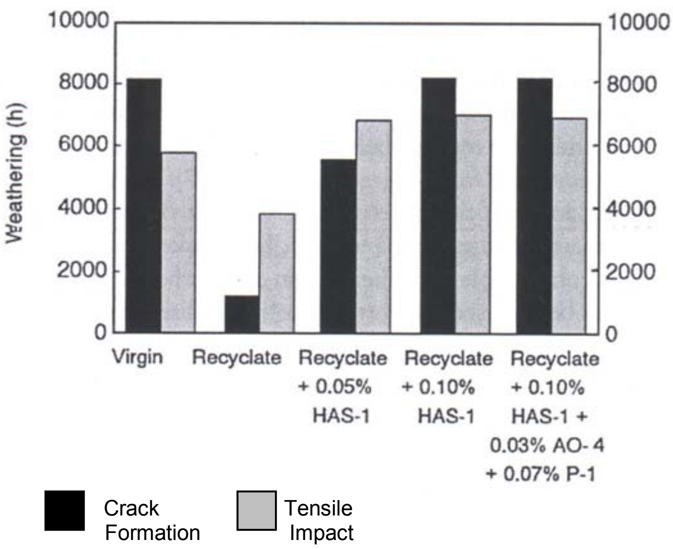


Figure 7.7 Effect of Stabilising Additives to extend Plastic Life (La Mantia, 2002)

7.10.3 Pigments

To save on costs, pigments should only be added when necessary. Plastics with strong colours will need most pigment if a uniform colour is required. Scottish Recycling added 2.5% pigment at a cost of £2.60/kg, or £65 per tonne to colour the fence posts black or brown. The cost of a brown pigment was quoted recently at £7.00/kg, with a recommended inclusion rate or 1-2%, which would cost £70-140 per tonne of product. Dumfries Plastic Recycling needed no pigment, as the LDPE they used was already black. They therefore had a cost advantage from the start. Plastic lumber manufacturers in the USA have used coal dust to blacken plastic. This approach uses a waste as a resource.

7.11 Batch or Continuous Production of Plastic Lumber

Batch processing of plastic lumber is a relatively simple operation, but takes time to complete a cycle. The plastic is first extruded into the moulds. Chilled cooling water is circulated round the jacket of the mould until the plastic has solidified. The mould is opened, the post removed and the cycle repeated.

In order to speed up board production at Scottish Recycling a continuous-flow board-making machine was tested. The experiment ended in acrimony between the company's staff and the supplier of the machine. The supplier complained of staff continually altering the manually controlled extrusion valve settings.

In the authors' view, when using plastics from a mixed polymer source this was inevitable. Any changes in polymer mix would change the melt flow rate and affect the rate that the polymer was extruded into the board forming area. For the successful operation of continuous plastic lumber manufacturing systems, the batch of recycled material should be thoroughly mixed at the start so that the resultant material has a constant melt flow rate.

7.12 Stacking Posts and Lumber Following Manufacture

The method of stacking plastic lumber is crucial if the product is not to bend during cooling. The material should be supported with strips of timber at 20 cm intervals, to both support the lumber and to allow air to circulate between the boards or posts to let them cool. For prolonged storage, the material should be similarly supported, as otherwise it may sag between supports.

7.13 Storage and Supply

The most convenient containers to hold granulated plastics are in 1m^3 capacity, polypropylene mesh plastic bags, the same as those used in the fertiliser and livestock feed industry. These can be supported by a frame during filling, then removed by forklift and stacked two high, brick fashion, with care being taken to avoid the upper bags toppling. The density of loose shredded LDPE plastics is low at 160 kg/m^3 (Table 7.1) so at two bags high (2.4 m), one can only store 0.32 tonnes per m^2. Large areas are, therefore necessary if storage for any period is required.

Table 7.1 Bulk Densities of Plastic Materials

Item	**Density (kg/m^3)**	
	From	**To**
Plastic containers, loose*	32	48
Shredded LDPE – low compaction +	160	-
Shredded LDPE – Highly compacted +	220	-
Plastic LDPE pellets$^+$	570	-
Mixed plastic pellets$^+$	420	-
Baled PET*	210	305
Baled HDPE*	275	390

* Diaz, 1993. $^+$Authors' approximate measurements

7.14 Dispatch

The bags can be dispatched on curtain-sided lorries, with the bags stacked 2 high, giving a 2.4 m high load. At this height, a curtain sider, with a 12.2 m (40 foot) bed will still only carry 48 bags or 7.7 tonne of shredded plastic. If instead extruded plastic pellets are transported, the load would be increased to 48 x 0.57 = 27.4 tonne, provided the vehicle can carry this payload.

For shipment of baled material, RECOUP recommends 1.1 m wide bales, 1.0 m deep and 0.8 m high, which should weigh 200-325 kg each. If each bale weighs 250 kg, a 12.2 m bed curtain-sided lorry with bales stacked three high will hold 60 bales or 15 tonne.

The sizes of transport containers are given in Table 7.2. If the tallest container is selected and bales are put in three high, they will hold 72 at a tight fit, i.e. 72 x 0.25 = 18 tonne.

The cost of transporting a container from UK to China is about £2000–2500. So cost per tonne of baled plastic sent will be about £110–140.

Table 7.2 Sizes of Containers (CIC Materials Handling Equipment, 2003)

Dimension	External (m)	Internal (m)	Vol (m^3)
Length	12.2	12.0	
Width	2.44	2.31	
Height	2.44	2.20	61
	2.59	2.35	65
	2.90	2.66	70

7.15 Economics of Recovery and Reprocessing

A manufacturer using recovered plastic will be doing so mainly to reduce feedstock costs and perhaps to target the "made from recycled" market. To establish the savings in feedstock costs that can be made, the cost of the virgin polymer compared to the cost of the recycled pellet should be known.

7.15.1 Virgin Versus Recovered Polymer Cost

The costs shown in Table 7.1 are based on USA average prices converted into pounds. It is likely that UK prices will be very similar.

Table 7.3 Costs of Virgin Polymers ($1.45 =£1.00, Plastics News May 2002)

No	Polymer	Price £/tonne
1	PET	960
2	HDPE (Milk bottle grade)	580
3	PVC	500
4	LDPE (Extrusion film liner grade)	670
5	Polypropylene (Injection moulding)	530
6	Polystyrene (Injection moulding)	710
6	Polystyrene (expanded, cup grade)	1190

UK prices for clean, uncontaminated baled plastic bottles and film are given in Table 7.4. These bales have to be broken open, inspected, picked over, have metal contaminants removed and shredded to make them into granules similar to virgin material. If bottle tops are of a different polymer compared to the bottles, they may have to be put through a water floatation separation system and then air-dried before they can be used. Considerable cost may therefore have to be incurred to achieve an acceptable feedstock.

Table 7.4 Prices of Clean, Uncontaminated Baled Material, delivered to merchant business (Lets Recycle 2002)

No	**Polymer**	**Price £/tonne**
1	PET, clear and light blue bottles	100-130
	PET, coloured bottles	0-50
2	HDPE, mixed colour bottles*	100-120
	HDPE, single colour/natural film	150 -205
	HDPE, mixed colour/printed film	75 -135
3	PVC bottles	0 -20
4	LDPE, single colour/natural	160 -220
	LDPE, mixed colour/printed	70-155
	Mixed plastics	0-35

* Separated, natural HDPE bottles will attract a higher price

7.15.2 High Value or Low Value Product

The next decision is to decide whether to deal in high value or low value product, be they pellets or plastic products.

The selling price for plastic products, per kg of material, is shown in Table 7.5 below.

Table 7.5 Comparative price for plastic products and material used

Recovered Material	**Cost £/tonne**	**Sale value as product £/tonne**	**Margin to pay for processing, marketing, etc £/tonne**	**Typical use**
HDPE, separated, baled	75-135	1800	£1725-1665	Wheeled waste bins
LDPE Silage wrap	Zero or gate fee charged	630	£ 550	Fence posts, Dumfries Plastics Recycling
Mixed plastic	0-35	315	£315-270	Fence posts, Scottish Recycling
Plastic combustion	10	120*	£110	Energy-from-waste
For comparison				
Fuel oil	80			Plastic feedstock
Silage wrap, virgin	Zero or gate fee charged	1500	£1500 +	Wrapping silage

*The value is the same as for oil plus the avoidance of a £40 landfill fee.

The cost of transporting a bale of plastic 100 miles is about £12/tonne. Land filling cost per tonne in NE Scotland is approximately £35-40. This cost includes landfill tax at £14/t in 2003, rising £1 per annum.

7.15.3 Processing Costs

Processing costs are hard to find, but the costings below give some idea of possible costs for the various processes. Some recyclers will simply bale plastic film. Others will sort, shred, and clean, and put into big bags. Others may sort, shred, clean and re-extrude into new pellets.

Processing costs will not therefore include all the costs listed in Table 7.6.

Table 7.6 Approximate Costs of Recycling Processes

Process	**USA data (£) ***	**UK data (£) +**
Collection	NA	50 (Range 20-150)
Sorting	41	50 (Range 30-65)
Cleaning	206	50 (Range 40-125)
Baling	55	NA
Shredding	55	NA
Pelletising	96	70 (Range 50-90)

* Hegburg, 1992 + Murphy, 1996

7.15.4 High Value, Single Material Granules and Products

The margin between recovered material and selling price of the final product (Table 7.5) illustrates that where possible high value pellets and products should be produced. A pellet producer would shred and re-extrude single type polymers for selling to manufacturers of plastic products, who simply substitute recycled pellets for virgin feedstock. This will give the highest value added to both pellet producer and the plastic product manufacturer.

The worst case is to source expensive, single-type, shredded plastic or re-extruded pellets to keep factory plant running, yet produce a low value product such as fence posts. This is the situation Scottish Recycling was forced into prior to their demise.

7.15.5 Low Value, Multiple Material Granules and Products

The price of mixed plastics waste is considerably lower than single type plastics (Table 7.4). Savings in material costs can be made using this material to manufacture pellets or products, particularly for the manufacture of fence posts and similar items. However this material has still to be put over an inspection table to ensure items such as rope (which caused Scottish Recycling a problem) and PVC are removed. The incorporation of film plastics into the mix requires the use of water-cooled shredders to ensure the material does not melt on shredding. This adds to the cost of the shredders. All the material has to be shredded to a 10-15 mm particle size to ensure that the strength of the mix is not weakened. This problem occurred at Scottish Recycling when 10 mm diameter pieces of plastic, with no bond with the molten plastic, caused the post to fracture.

7.15.6 Addition of Fillers to make Polymer go Further

The incorporation of other components such as wood flour, ground fibreglass waste, ground straw, hemp, etc, to inclusion rates of up to 60%, can all reduce the cost of the feedstock considerably. These additions can also stiffen the plastic, reduce creep and make them easier to hammer in nails. Most benefit is made from these components if they too can be wastes. As such the recycling company can charge a gate fee for the materials, which is only just lower than the disposal charge levied by the landfill operator.

7.15.7 Gate Fees

Suppliers of plastic waste to a recycler may need to get their plastic recycled more than you, the recycler, may know. Farm assurance scheme inspectors are continually pressing growers to dispose of their plastic film in a sustainable way (Figure 7.8). EMAS accreditation for businesses may depend on the recycling of waste. The recycling company should therefore demand as high a gate fee as possible before accepting waste. At a minimum this should be no less than the local landfill-site disposal charge.

Figure 7.8 Agricultural Fleece awaiting disposal by burning in an energy from waste plant

If material is separated into polymer types and is free from contamination, it is well above the negative value of a waste suitable only for landfill and will, therefore, have the positive values shown in Table 7.5.

7.16 Summary

When setting up a recycling business, a number of aspects need to be considered.

- A gate fee to take the plastic should be set at a level just below the alternative disposal cost unless there is competition for the material.
- Beware of being used to solve someone else's disposal problem.
- For recycling plastic bottles follow RECOUP advice.
- Small sized items can be fed directly into shredders.
- Large sized items need first to be coarse shredded in a shredder with a large aperture size.
- For small quantities of large items, a band or circular saw can be used to reduce the initial size of plastic components to be shredded.
- Clean, single formulation plastics only need to be shredded.
- Water can be used to clean plastics and separate them by floatation, but subsequent drying is required prior to re-extrusion.
- Plants to treat wash water are very expensive and can affect the viability of the plastic recycling business.

- Waste plastic shredding followed by extrusion allows small batches of single polymer with different formulations to be bulked up into a large batch of polymer with a single formulation and single set of physical characteristics.
- Polyolefins can be shredded and mixed together to form a single formulation mix after re-extrusion.
- Plastic granule or pellet storage is usually in large, 1.00 m^3 polypropylene bags.
- Bags can be transported in curtain sided lorries, with bags stacked two high, but well strapped in place.

8. PHYSICAL PROPERTIES OF PLASTIC MATERIALS

8.1 Introduction

Chapter 4, "Types of Plastic Materials", gave an overview of the types of plastics available for recycling, which plastics can be mixed, contaminants which must be removed, the risks involved in recycling plastics, and how mixed plastics can be collected together for reprocessing into plastic lumber. This section in contrast provides information on the physical properties of plastics, which characterise one plastic from another. Tests are described, which allow potential recyclers to characterise the plastics they process, so that their product can be sold with defined properties.

Chapter 9 deals with structural aspects of polymers, which is essential for product design and product quality control.

8.2 Plastic Composition

8.2.1 Molecular Structure

Polymers are huge chain-like molecules in which the atoms forming the backbone of the chain (usually carbon) are linked by covalent bonds (Brydson, 1999). These bonds occur because the atoms share two electrons. A typical polymer polyethylene is made by the catalytic polymerisation of ethylene

H	H		H	H	H	H	H	H	H	H	
I	I		I	I	I	I	I	I	I	I	
C	C	Polymerisation -	C	C	C	C	C	C	C	C	- etc
I	I		I	I	I	I	I	I	I	I	
H	H		H	H	H	H	H	H	H	H	

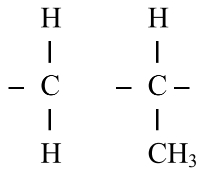
Ethylene Polyethylene

The basic unit, or building block, of a polymer is

H	H	
I	I	
– C	– C	– Where R is a repeat or side group of atoms
I	I	
H	R	

Basic unit of a polymer

In the case of polyethylene above, the repeat or side "group" "R" is a hydrogen (H) atom. In polypropylene, the side group is CH_3 (methyl) and the basic unit looks as below.



Polypropylene

In Polystyrene the side group is C_6H_5, in PVC it is Chlorine. Other polymers have more complex structures but are characterised by their long chains of atoms. Natural polymers such as natural rubber, cellulose, lignin and protein have similar structures.

These long chains pack together in an irregular, twisting, tangled mass of chains of molecules, resembling spaghetti (Figure 8.1). These chains are loosely connected to neighbouring chains by weak secondary bonds. In thermoplastics these secondary bonds weaken as the polymer is heated, allowing the polymer to flow into moulds.

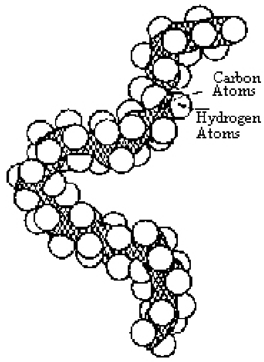


Figure 8.1 Schematic Representation of a short section of a Polythene Molecule

The melting point of these weak bonds is low, not far above room temperature. When thermoplastics are subject to a load at slightly higher than room temperatures, some chain molecules will slip past their neighbours and form weak bonds with the new neighbours. This movement is in the direction of the stress applied. The result is gradual creep of the material, dependent on time and temperature.

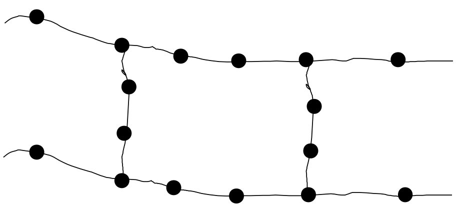


Figure 8.2 Heavy Cross Linking of Molecules in Thermoset Plastics

With thermosets, heavy cross-linking between the molecules occurs (Figure 8.2). When thermosets are heated, although the secondary bonds weaken and allow some deformation when stressed, these strong links prevent flow. The polymer cannot therefore be hot worked and on further heating will start to char.

8.2.2 Anisotropic Plastics

If thermoplastics are heated, and mechanically pulled at the same time (as in making thread), the secondary bonds, weakened by heating, allow the twisted molecules to straighten out. The molecules become aligned with each other and form a stronger material in the direction of stretch. If the material is allowed to solidify when drawn, the molecules will stay aligned. Such drawn materials are termed anisotropic, as they are stronger in one direction than in others.

8.3 Thermal Properties

8.3.1 Plastic Stages of Deformation with Temperature

Plastics like polystyrene have five stages of deformation as their temperature is raised (Figure 8.3). Their stiffness as measured by elastic modulus, measured in GPa (see chapter 9.2.3), reduces as temperature increases.

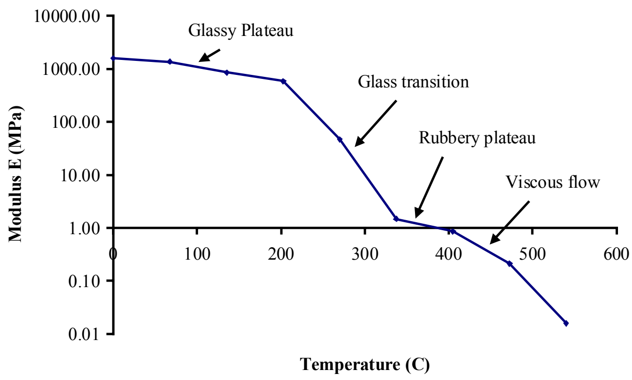


Figure 8.3 Changes in the Stiffness of Modulus with Temperature

1. Glass phase, where their stiffness is a maximum, with a Young's Modulus of 3 giga* Pascal (GPa).
2. Glass – transition stage, where their stiffness drops from 3 giga Pascal to 3 mega* Pascal (MPa).
3. Rubbery stage.
4. Viscous stage when the plastic exhibits significant flow.
5. Decomposition stage when chemical breakdown occurs and the material cannot return to the previous state.

*Mega = 1,000,000 and Giga = 1,000,000,000.

Polymers may have structures that are totally amorphous, with no regular structure at the molecular level, or they may be partially crystalline. The degree of crystallinity depends on the type of polymer and the rate at which it cools, the slower the cooling rate the greater the degree of crystallinity.

8.3.2 Glass Transition Temperature T_g

Metals are often categorised by their melting point. The glass transition temperature, T_g, in contrast, can be used to classify the thermal behaviour of many plastics. The glass transition temperature is the temperature below which the material behaves like a glass, becoming hard and brittle. However, the value for T_g for a particular plastic is not necessarily a low temperature. This explains some of the differences we observe in the mechanical behaviour of plastics materials.

For example, at room temperature, polystyrene is below its T_g and so the material is in a glassy, brittle state. In contrast, polyethylene is significantly above its T_g at room temperature and hence behaves in a much more flexible manner. The transition from flexible to glassy behaviour can occur over a restricted temperature range of say, 10^oC, so mechanical properties can vary a great deal very quickly (Figure 8.3).

The glass transition temperatures of a range of common thermoplastics are presented in Table 8.1, together with an indication of their crystalline melting temperatures and processing temperature ranges. These figures are taken from a range of sources and should only be considered as broad indications. Data for individual plastics grades should be obtained from material suppliers.

Table 8.1 Glass Transition, Crystalline Melting and General Processing Temperatures

	Plastic	**Glass Transition Temperature T_g^{++}**	**Crystalline Melting Temperature T_m^{++}**	**Processing Temperature from Data Sheets$^+$**
		°C	**°C**	**°C**
1	PET	75	250-265	290
2	HDPE	-90	131	180-315
3	PVC (rigid)	77	210	150-205
4	LDPE	-100	115	180-320
5	PP (isotactic)	- 10	176	202-252
6	PS	97	-	209
7	Other (e.g. polyamide 6,6)	56	267	290

$^{++}$ Brydson, 1989, Crawford, (1998), Hall, (1989), and OU, (1998).
$^+$ Polymer database <http://www.matweb.com>.

Plastics operating below their T_g, can fail in a brittle manner if subjected to an appropriate external force. For example, fence posts made from a high proportion of polystyrene could shatter if hit or driven in cold weather or even in relatively warm conditions. The figures in Table 8.1 also explain why Starlinger (Section 2.7) suggests that polypropylene content should be limited in the mix of plastics to prevent material fracture at low temperature. Depending on the grade, polypropylene can become brittle at around 0^oC, so significant proportions of polypropylene in the recycled mix can result in brittle fracture in cold weather.

As a rough guide, processing of plastics materials should take place at $T_g + 100^oC$ or $T_m + 100^oC$. Ashby and Jones (1999) use a more restrictive approach suggesting that moulding of plastics is carried out at temperatures between 1.3 – 1.6 x T_g, where T_g is in K (i.e. °C +273). However, there are considerable differences between the processing ranges calculated using the Ashby and Jones' formula compared with those obtained from other sources. Again it is recommended that material suppliers are consulted prior to product manufacture, in order to obtain optimum processing conditions.

When mixed plastics are processed to form plastic lumber, a moulding temperature is selected which melts the plastics which form the glue for the mix, but does not char the other plastics or filler. Since the plastics in the mix have different viscosities at the moulding temperature selected, the lower melting point plastics will concentrate in the centre of the product with the higher melting point plastics in the perimeter. This phenomenon is clearly illustrated in the analysis made of the broken fence post manufactured by Scottish Recycling (See Chapter 2.11).

8.3.3 Expansion and Contraction

Plastics expand on heating and shrink on cooling. Those which crystallise on cooling, shrink the most. The greater the proportion of crystallisation in the cooled plastic matrix, the greater will be the shrinkage. Plastics mixed with fillers or reinforced with fibres shrink the least (Strong, 2000). The filler or fibre strands keep the long polymer chain molecules apart and prevent them from curling into their characteristic entwined state. Values for shrinkage expressed as mm of shrinkage per mm of original length are shown in Table 8.2.

Table 8.2 Characteristic Shrinkage for Various Plastics (Strong and Brent, 2000)

Plastic Number	Plastic	Shrinkage (mm/mm)	Comparative Shrinkage
1	PET	0.006	Low
2	HDPE	0.020 - 0.040	High
3	PVC	0.002 - 0.003	Low
4	LDPE	0.007 - 0.025	Medium
5	PP	0.010 - 0.020	Medium
6	PS	0.004 - 0.006	Low
7	Other (e.g. Nylon)	0.008 - 0.015	Low/Medium

Shrinkage will differ across an injection moulding, if its thickness varies and if the polymer does crystalise to any extent on cooling (Murphy, 1996). As the hot moulded item is cooled, heat is lost more quickly from thinner sections than from thicker sections. The slower cooling of the thicker section allows more crystallisation to take place, with the result that hollows or voids form (Figure 8.4) adjacent to these sections. Plastic product designers should try to ensure section thickness is uniform to prevent such uneven shrinkage.

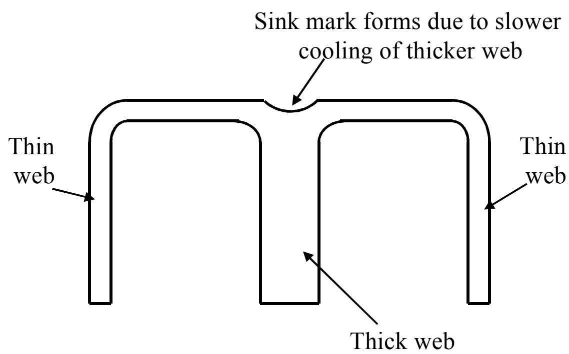


Figure 8.4 Shrinkage in Mouldings if Plastic Sections are of different thickness

8.3.4 Specific Heat and Thermal Conductivity

The specific heat of a polymer is the amount of heat required to raise 1kg of material by a temperature of 1°C. The higher the specific heat, the more heat is required to raise its temperature. When cooling a plastics material in a mould using water flowing through the mould, the higher its specific heat, the more cooling water is required.

The thermal conductivity of a polymer is the rate of heat energy passing per second along a 1 metre length of polymer, when a temperature difference of 1°C is applied between the two ends.

The specific heats and thermal capacities of the various plastics are shown in Table 8.3. These values are for pure polymer. The inclusion of additional and fillers may alter these values considerably.

Table 8.3 Specific Heat and Thermal Conductivity of Polymers (Brydson 1999, Matweb 2003)

Plastic Number	Plastic	Specific Heat (Brydson)] J/kg.°K	Thermal Conductivity (Matweb) W/m.°C
1	PET	2180	0.20
2	HDPE	3375	0.3-0.52
3	PVC	950*	0.14-0.19
4	LDPE	2780	0.30
5	PP	2790	0.10-0.13
6	PS	1720	0.12-0.19
7	Other (e.g. Nylon)	3075	0.25-0.28

*Trade and technical press, 1980.

The specific heats vary from 1720 to 3375 J/kg.°K, a ratio of 1:2. If mixed plastic waste is being processed excluding PVC, and the proportions in the mix change, the time required to cool the product may continually change. Producing a uniform product from a varying mix of plastics will be difficult.

The ratio of thermal conductivities of the different polymers varies from 0.1 to 0.52 W/m°C, a ratio of 1:5.2. The rate of heat transfer through the molten polymer mix, when cooling the mould, will vary considerably if the proportions in the mix changes. Obtaining a consistent product from a mixed plastic waste stream will be doubly difficult as the two factors taken together will combine to cause considerable variations in the rate of cooling.

8.4 Physical Properties

8.4.1 Introduction

Plastics have physical characteristics, which need to be considered when processing any product. They include density, melt flow rate, UV stability, electrical conductivity, flammability and resistance to solvents. A range of additives, to alter the characteristics of the basic polymer may have been added. For successful reprocessing, knowledge of these is required.

8.4.2 Density of Plastics

The density of a plastics mix gives an indication of its components and can be used for quality control. Density also indicates whether or not the plastics will float. Plastics with a density below 1000 kg/m^3 will float.

Densities are shown in Table 8.4. Whether a plastic floats or not can be used to separate mixed plastics into single type polymers. The values are for extrusion grade polymers. When fillers are included, densities can change considerably.

Table 8.4 Density of Extrusion Plastics (Matweb, 2003)

Plastic Number	Plastic	Density kg/m^3	Floats?
1	PET	1160-1290	No
2	HDPE	920-960	Yes
3	PVC	1160-1450	No
4	LDPE	910-940	Yes
5	PP	895-910	Yes
6	PS	1040-1070	No
7	Other (e.g. Nylon 66)	1030-1160	No

Density of a plastic will vary depending on the amount it crystallises during cooling. Slow cooling results in more crystallisation, and a denser material. Fast cooling results in less crystallisation, and a less dense material.

Density can therefore be used as a quality control test to ensure that a product has been cooled at a consistent rate.

8.4.3 Melt Flow Rate (MFR)

The melt flow rate (sometimes called the melt flow index) is the rate at which molten plastic flows through a standard die under specified conditions. It is quoted in grams per 10 minutes. Different polymers at the same temperature will flow at different rates. To operate extrusion equipment, the MFR of the plastic has not only to be known but should be consistent within a batch. The attempt by Scottish Recycling to operate a continuous, board-making extruder, using a manually set flow rate and a polymer with a constantly changing MFR, was bound to produce a very variable product.

The melt flow rate of plastics material for blow moulding has to be higher than for injection moulding, which has to be higher than for extrusion (Murphy, 1996). The higher the melt flow rate of a plastic, the lower will be its viscosity.

8.4.4 UV Stability

Plastics have to resist the effect of sunlight. Ultra violet (UV) radiation can turn a plastic from a strong, durable material to one which cracks or snaps under an applied force. This is a non-reversible process. Since material failure may happen years after the product is made, compensation claims on the product can occur without warning, many years after an apparently profitable production run.

Because UV deterioration of plastics is so slow, accelerated tests using artificial light are used to measure stability. Recovered plastics may have UV stabilisers in them, but this cannot be relied upon. As with all aspects of recovered plastics, it is rarely possible to know exactly what UV stabilisers went into the original mix if any and how much UV degradation has taken place prior to the material being recovered for reprocessing. It is therefore wise to use only a proportion of recycled plastic in new components so that the risk of failure through UV deterioration is minimised.

To guard against further UV attack when using large amounts of recycled plastics, pigments like carbon black can be added to the processed mix.

8.4.5 Colour Stability

Colour can fade with sunlight too. Some assessment of colour stability can be measured by keeping samples of material outside and shielding one half of each sample from the sun. The difference in colour can be determined over six months or a year. The same pieces can be used to assess surface texture changes or surface cracking. But by the time these tests are complete, the results may possibly be too late to be of much use.

8.4.6 Conductive Plastics

Any plastics to be used in conjunction with electrical equipment will need to act as an insulator.

For example, in developing a fence post for electrified fences, the conductivity of the plastic must be low to maintain the voltage on the fence line. As some plastics absorb water better than others, the performance of a plastic as an insulator, when used in wet climates, should also be determined. With the voltages of up to 5000 V used on electric fences, once a conductive path to earth is established in wet weather, leakage can occur along the same path even in dry weather. The electric fence may therefore gradually lose its ability to control livestock over time, as the voltage on the wires is gradually reduced by leakage.

8.4.7 Flammability

Manufactured plastic products to be used in the home or workplace will have to conform to flammability standards. With mixed materials flame-retardant chemicals may well have been added to the original plastic when it was manufactured. However, testing will be vital to confirm this if flammability is an issue. Flammability highlights the value of using supplied plastics with known characteristics from consistent sources, where some reliability of the final product can be achieved.

8.4.8 Resistance to Solvents

Plastics may have to resist attack by solvents, for example, where spills of diesel or petrol are possible. Any re-processed plastics used in such applications will have to be checked for solvent resistance.

8.4.9 Characteristics Peculiar to Polyvinyl Chloride (PVC)

Polyvinyl Chloride (PVC) is best kept separate from other plastics and recycled in a closed-loop (La Mantia, 1996). This is partly because so many different additives are put into PVC to achieve the flexibility, UV resistance, etc. required for the many uses to which it is put. It is necessary to know the history of what additives have been included into the PVC product before it is safe to reuse the material. Wire insulation should therefore preferably be recycled to wire insulation, plastic PVC pipe to plastic pipe and window frame material to new window frames. Some virgin feedstock may need to be added to maintain its natural properties.

PVC has usually to be kept out of plastic recycling feedstock as it has a narrow temperature window (Scheirs and Camino, 1996). If this temperature is exceeded, hydrogen chloride is produced in gaseous form, corroding extrusion machinery and producing harmful vapours for the people working the extruders. It can also degrade to carbonised globules, which can stain the final product.

The requirement to keep PVC out of a plastic waste stream has a very significant affect on plastic recycling. Even if only one part of a plastic waste stream has to be separated out, this requires the whole waste stream to be passed over a separation system. This requires workspace for the separation system, labour to man it, and electricity to run it.

Not only is PVC a problem to plastic recyclers, but the chlorine element can contribute to the production of dioxins and furans when burnt in energy-from-waste plant. The proposed abolition of the manufacture of PVC has been on the European Commission’s agenda for some years. The authors believe, however, that the almost unique usefulness of PVC’s and the PVC manufacturers’ willingness to recycle it in a closed-loop at the end of its life (Vinyl 2010, 2002) will allow it to remain as a useful member of the family of plastics.

8.5 Additives to Plastics

Chemicals are added to plastics to alter their properties to suit particular requirements. For the recycler, this adds to the complexity of recycling plastics into new feedstock as one container labelled with a 2 for HDPE can have quite different additives from another marked with the same symbol. Additives in recovered plastic may be sufficient to provide the required properties in the new product. If however additives have to be put into the recycled feedstock, this can add considerably to the cost of the process, making the process marginal in profitability. When reforming plastics into new products, routine tests during production for the physical and structural tests outlined in Chapters 8 and 9 are vital if a reliable material product is to be produced.

8.5.1 Performance Enhancers

Additives to improve performance include fillers, plasticisers, coupling agents, antioxidants UV stabilisers, colourants, impact modifiers, anti-static agents, flame retardants and preservatives (RAPRA and BRE, 1994). For the recycler, fillers offer a way of reducing the amount of high value polymer used, while providing the opportunity to charge a gate fee for filler material. Fillers can also reduce creep, and give a product such as plastic lumber more "wood" like properties. These include increasing stiffness and taking nails better.

Plasticisers enhance the flexibility of a plastic material, while coupling agents improve the bond between different polymers in the mix or between polymer and filler. Colourants or pigments may have to be added to swamp the other colours in a product made from mixed colour recovered plastics. Colourants such as carbon black also have benefits in blocking UV light, so have a duel preservative and colouring function. Impact modifiers are added to reduce the likelihood of brittle fracture. Anti-static agents may have been added to prevent the build up of static electricity on plastic products, where film is attracted to other items or conversely dust or fluff is attracted to the plastic. Flame retardants are a standard requirement in household furnishings, so may be present in recovered plastic albeit in a diluted form and essential in any products designed for home or commercial use. Fungicides or bactericides may be added to plastics to be used in long-service products, which are exposed to damp.

8.5.2 Processing Aids

Chemicals may be added to polymers to aid processing. These include lubricants to improve surface lubrication during processing and use, and viscosity aids to regulate the viscosity of the polymer additive compound during processing. Heat stabilisers may be added to reduce the degradation of PVC in particular and other vinyl materials during processing and conversion into finished products.

8.5.3 Blowing Agents

Blowing agents which give plastics a honeycomb texture are used to:

- Increase the stiffness to weight ratio (e.g. polystyrene packaging)
- To make insulating materials (e.g. polyurethane foam)

In manufacture, dry pellets or low boiling point liquids are added to the mix. When the mix is heated these turn into gas, creating the characteristic "Aero" chocolate appearance. The gasses created must not condense again at room temperature, as the bubbles would collapse back into solid plastic. Water, heated to steam during extrusion, is therefore unsuitable for use as a blowing agent.

8.5.4 Stabilisers Used in the Production of PVC

Polyvinyl chloride (PVC) stands out from other plastics in having so many useful forms, produced by incorporating additives, potentially harmful to the environment and man. More than 112,400 tonnes of lead (ARGUS, 2000) is added to PVC in Western Europe annually to manufacture pipes, windows, and electrical cable insulation. Calcium and zinc (14,500 tonnes) is added to PVC for food contact and medical applications. Tin (15,200 tonnes) are added to produce rigid packaging film, bottles, flooring, roofing, and rigid sheeting. Stabilisers containing cadmium are added to windows, cladding materials and specific PVC applications that require excellent outdoor weathering resistance.

The presence of these heavy metals together with chlorine makes it essential that PVC is recycled using a closed-loop approach.

8.6 Physical Laboratory Tests

8.6.1 Density

Density test methods are specified in ASTM D792 (2000) and BS EN ISO 1183-3: 1999. To measure density, weigh the specimen in air (W_1) using a fine wire to suspend it, then weigh it in freshly boiled and cooled distilled water (W_2). If bubbles against the plastic are a problem, a minute addition of washing up liquid will disperse these. If the plastic floats, weigh a metal sinker in the water (W_3), then weigh the sinker and plastic together in water (W_4).

For plastics denser than water: -

Density = $W_1/(W_1-W_2) \times 1000$ kg/m^3

For plastics, which float: -

Density = $W_1/(W_1+W_3-W_4) \times 1000$ kg/m^3

Test equipment is available for routine density measurement (Figure 8.5)

Figure 8.5 Equipment for Measuring Density of Samples of Plastic (Ametek, Lloyd Instruments Ltd)

8.6.2 Melt Flow Rate (Index)

The Melt Flow Rate or Melt Flow Index defines the rate of flow of molten plastic through a 2.095 mm diameter die when a 9.5 mm diameter cylinder of plastic is put under pressure, by loading a piston with a load of known weight (Figure 8.6 and 8.7). The material extruded in 10 minutes is periodically cut off with a knife as it comes out from the jet. This material is placed on a balance to weigh the total in grams extruded over the 10 minute period.

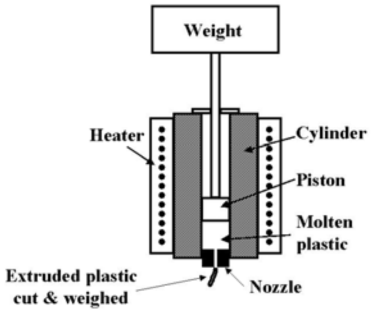


Figure 8.6 Melt Flow Rate (Index), Diagram of Test System

Figure 8.7 Melt Flow Rate Meter (Ray Ran Test Equipment Ltd)

The determination of MFR for thermoplastics is covered by ASTM (D 1238 (2001), BS EN ISO 1133 (2000), BS 2782-7: Method 720A (1997).

8.6.3 Electrical Resistance Tests

Tests on plastics for resistance measurement usually require either the test piece to be submerged in water for 24 hours prior to the test or to be tested in an atmosphere at 23°C, 96% relative humidity. The most appropriate standard is BS 2782 (1996), where a rod or tube is clamped at its two ends between flat plate electrodes or taper pin electrodes and a voltage applied to the clamps.

8.6.4 Flammability tests

A series of tests are available for building materials, which are exposed to temperatures of 750 to 1190°C. These temperatures are mostly too high for plastics (Brown, 1988). Less comprehensive tests are available for plastics. These consist of a conical, electrically heated furnace with a natural or forced air supply directed to the base of the furnace and a pilot ignition flame lit at the top of the furnace (Figure 8.8). A piece of plastic is suspended in the furnace, and the temperature increased in stages until the gas released by the plastic ignites.

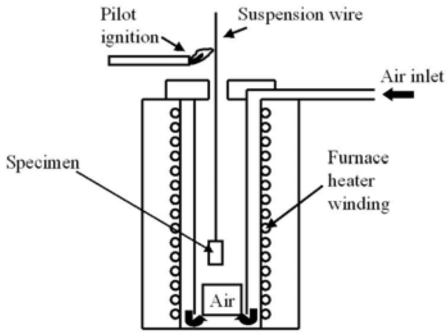


Figure 8.8 Flammability Tests

Other tests for plastics include BS ISO 871 (1996) and ASTM D1929 (2001). These use the principle described above. ASTM D635 (2003) measures the rate of burning a test piece. The most widely used flammability performance standards for plastics materials are the underwriters Laboratories UL94 ratings. These rate the ability of a material to extinguish a flame once ignited (Brydson, 1999).

8.7 Summary

Plastics wastes have an almost infinite spectrum of physical properties, additives, and colours. Plastics are defined by a series of properties, which influence their behaviour during processing and subsequent life of the manufactured product. These are: -

- Polymer type and whether its properties are isotropic (the same in all directions) or anisotropic (different in different directions).
- Glass transition temperature, plastic changes from a brittle solid to a more pliable material
- Shrinkage on cooling in the mould.
- Specific heat and thermal conductivity and how this affects the rate of cooling in the mould.
- Density, and how this can be used for quality control and for separating plastics of different types.
- Melt flow rate, which is required to determine which extrustion process should be used and help establish processing conditions.
- UV stability, which defines its resistance to degradation by light.
- Electrical resistance.
- Flammability, to determine risk of combustion from fire.
- Resistance to solvents, for plastics to be used where contact with solvents is possible.

A range of tests is explained. The manufacturer using re-extruded pellets would routinely undertake at least some of these tests. Companies selling re-processed plastic pellets should provide density and melt flow rate results with the product.

As far as possible PVC should be kept out of the plastic waste stream and processed with other PVC material into similar products.

9. STRUCTURAL PROPERTIES OF PLASTICS

9.1 Introduction

In making any plastic component, it must be strong enough to take the applied load, tough enough not to crack, and it should resist creep over time. Since plastics can soften when warmed above their glassification temperature (T_g) temperature, or harden when cooled below their T_g, such tests have to take temperature into account. Fillers will alter the structural characteristics of plastics, so testing the final product, with filler added, is essential.

Plastic structural properties are defined by a series of British Standard (BS), combined BS and International (BS EN ISO) standards, and American Society for testing materials (ASTM) standards. A typical single BS standard describing a plastic test method will refer to a raft of other BS standards in the text. To carry out a single test, a whole series of BS publications may have to be obtained. The ASTM standards in comparison tend to have all the information required for a test in the one publication. These are therefore easier to use.

The principles behind these tests and the equipment needed to undertake them are described below (Ashby and Jones, 1998). Equations are included; but the non-mathematician can ignore these yet still grasp the information contained within this chapter.

9.2 Structural Tests

9.2.1 Preparation of Test Pieces

Tests on thermoplastics should be carried out at a stated, constant room temperature and humidity (Brown 1988). The ISO standard requires a room temperature of 23°C and a relative humidity of 50%. Test pieces can be moulded, turned in a lathe or milled, but machining can toughen the plastic and give a false reading. Since plastics are likely to be moulded into products, test pieces are best moulded too, with sharp corners avoided to avoid stress points. The preparation of a test piece is covered by ASTM D647 (1998A) and BS 2782-9: Methods 901A, 902A, 910B, 910C, 910D, 910E, 930A.

If products with thick sections are to be produced, test pieces should also be thick, so that the cooling rate for product and test section will be similar. This will result in the test piece and product having the same degree of crystallinity for example and associated mechanical properties.

9.2.2 Yield Strength

When a specimen of plastic (Figure 9.1) is placed in a tensile testing machine and subjected to a force, the applied force, divided by the cross sectional area of the test piece (B x W mm^2) is called the stress. When a stress is applied to the test piece, the plastic will initially extend elastically. During this phase the plastic will revert to its original length once the stress is removed. The point at which it starts to stretch irreversibly is called the yield point. At the yield point the stress is called the yield strength (Figure 9.2). This is the maximum stress that the material can experience without deforming irreversibly. The units of stress and yield strength are mega Newton per square metre (MN/m^2) or mega Pascal (MPa).

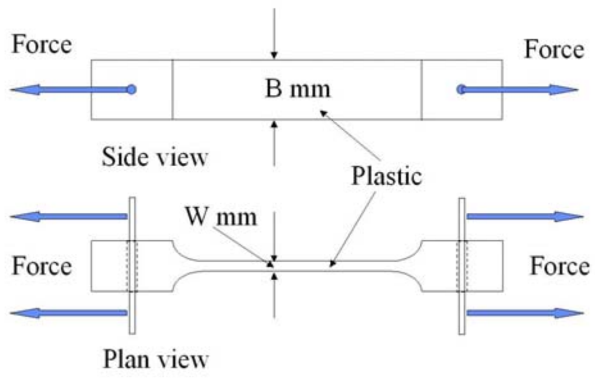


Figure 9.1 Side View and Plan of Dumbbell Shaped Test Piece

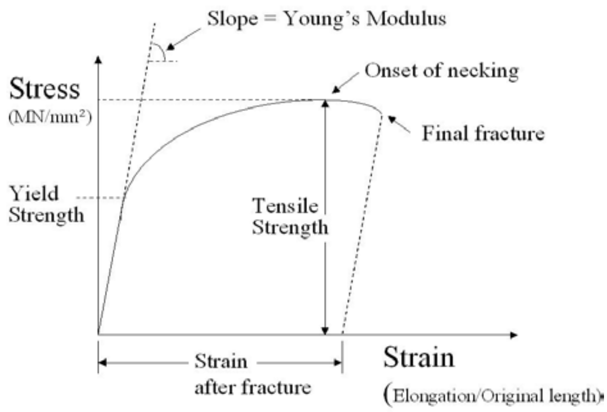


Figure 9.2 How a Plastic Test Piece Deforms under an Imposed Stress

9.2.3 Young's Modulus

The slope of the graph of elastic deformation is called Young's modulus. The stress is measured in N/m^2 while the strain is the length in metres after the stress has been applied, minus the original or "gauge" length, divided by the gauge length. The units are normally in Giga Newton per square metre (GN/m^2), that is GPa.

Test figures for Young's Modulus are routinely given for plastics to indicate their tensile strength during elastic deformation.

9.2.4 Tensile Strength

If the stress on a test piece is increased beyond the yield point, the plastic deforms until it eventually fails. Units of Tensile strength are the same as for Yield strength. The tensile strength of the material is the maximum stress sustained during a typical tensile test.

ASTM D638 (2002A), BS EN ISO 527-1, 2, 3, 4, 5, (1997), BS 2782: Method 327A (1993) and BS 2782-3: Method 327A (1993) are the standards defining tensile strength determination.

9.2.5 Elongation at Break

Another figure often quoted is elongation at break. A look at Figure 9.2 shows that this is the strain after fracture. It has no units, as it is a ratio of the extension divided by the original length multiplied by 100 to make it into a percentage.

9.2.6 Hardness

Hardness is measured by forcing a truncated steel cone a few millimetres into a piece of the plastic using a Durometer. There are a number of such hardness tests, the best known being the Shore hardness test. The force required is measured, then divided by the cross-sectional area of the cone in a plane, level with the plastic surface. BS ISO 868 (2003) or ASTM D2240 (2003) is used for soft plastics. ASTM 785 (1998E1) or BS 2782-3: Method 365C: 1992 Rockwell hardness test is used for harder plastics and ebonites.

At minimum a 6mm thick plastic test piece should be used.

Hardness (kN/m^2) = Applied load / surface area of impression

As this test is not destructive and hardly marks the surface of the plastic at all, it can be used as part of a quality control system for determining approximate yield strength.

9.2.7 Impact Strength

The energy required to fracture a clamped test specimen of plastic, when it is subject to a shock loading is called the impact strength, with units of Joule per metre (J/m). This test uses a pendulum (IZOD) test to produce a measurable quantity of energy.

9.2.8 Flexural Strength

The flexural strength of a test specimen is the flexural stress, or "maximum fibre stress", measured when the test specimen breaks under an imposed load. To determine the flexural strength of a plastic, a load P is applied to a test specimen placed under two supports (Figure 9.3). The stress is calculated using the equation: -

$$\sigma_f = \frac{3PL}{2bh^2}$$

Where	σ_f	=	Stress (MPa)
	P	=	Load (N)
	L	=	Distance between support points mm
	b	=	Width of specimen (mm)
	h	=	Thickness of speciment (mm)

Note 1 N/mm^2 = 1 MPa

The maximum strain, or "maximum fibre strain" in the test specimen is given by the equation : -

$$\varepsilon = \frac{6hX}{L^2}$$

where	ε	=	strain (mm)
	X	=	deflection at the mid point (mm)

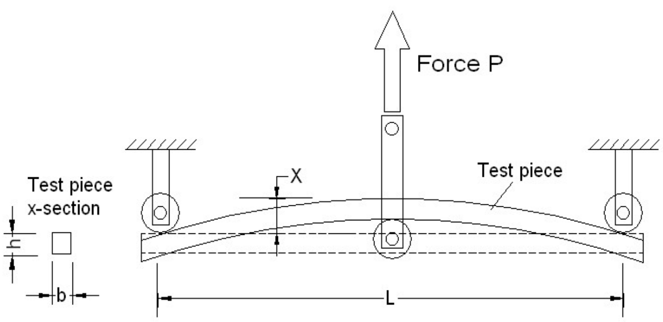


Figure 9.3 Flexural Strength of Plastic Test Piece

The flexural strength figure is usually quoted in MPa or MN/m^2.

9.2.9 Flexural Modulus of Elasticity

The flexural modulus (approximately equal to Young's modulus) is given by : -

$$E_b = \frac{L^3}{4b(h^3)} \frac{P}{X}$$

P/X can also be considered as the slope of the initial linear force-deflection curve.

Flexural modulus is usually quoted in GPa or GN/m^2.

9.2.10 Creep

The temperature when liquid polymer changes on cooling to a solid glass phase, the glassification temperature (T_G), is the equivalent to the melting point in metals. The glassification temperature is usually at about room temperature for polymers. Above T_G, the polymer is in a leathery, rubbery state and creeps rapidly under load. Below T_G it becomes hard and sometimes brittle. As an example rubber, cooled below its glassification temperature with liquid nitrogen, shatters when hit.

The more dense the plastic, the more densely packed are the molecules and the less likely are the long chain molecules to slip past their neighbours. Dense plastics are therefore less prone to creep compared to less dense plastics.

Creep varies with: -

- Temperature
- Stress imposed
- Time over which the stress is imposed.

Testing for creep must therefore be undertaken at a fixed temperature with a load imposed similar to that likely to be found in practice.

The rate of change of strain or extension $\dot{\varepsilon}_{ss}$ is related to stress and temperature by the equation:

$$\dot{\varepsilon}_{ss} = A\sigma^n e^{-(Q/\bar{R}T)}$$

Where $\dot{\varepsilon}_{ss}$ = Rate of change of strain with time

σ = Applied stress

e = Natural log

$\bar{R}$ = Gas constant = 8.31 J $mol^{-1}K^{-1}$

T = Absolute temperature (°K) or (°C +273)

And A, n and Q are all constants, namely

A = Creep constant
n = exponent
Q = Activation energy for creep (J mol^{-1})

The three constants A, n and Q define the characteristics of material being tested and have to be found by testing the material on a creep testing machine.

Standards for testing for creep include ASTM D2990 (2001) and BS EN ISO 899-1 (2003) and ISO 6602 (1985).

9.2.11 Fatigue Testing

In plastic components, which are continually being flexed, it is necessary to simulate this flexing by placing a test piece in a clamp and oscillating the clamp over a long period of time at various temperatures to ensure the plastic will last the stated life of the product.

9.2.12 High and Low Temperature Performance

Plastics may have to maintain their strength at elevated or below freezing temperatures. Fence posts, for example, should not deform in hot sunny weather or shatter when being driven into the ground, or hit by a tractor, during a cold period. Tests are required to check that the material to be used performs satisfactorily over the whole range of conditions expected.

a) Rigidity over a Temperature Range

For performance in high temperature, a torsion stiffness tester can be used. The rectangular cross section test piece is held at its base, and twisted by a load on a pulley at its top (Figure 9.4). The test piece or test strip is immersed in a liquid, a torsional load applied, then the liquid is heated with an electric element in stages, with increasing angular deflections being measured at each stage. For torsional readings at temperatures below room temperature, dry ice (Solid CO_2) can be added.

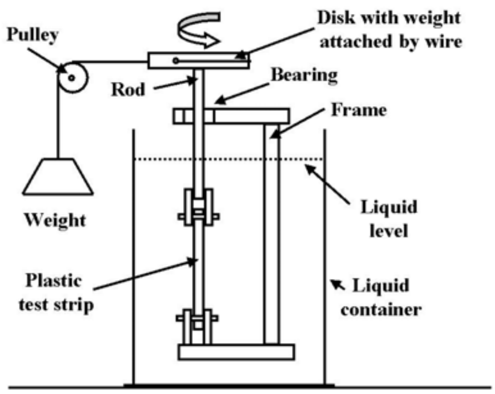


Figure 9.4 Rigidity over a range of Temperatures

Standard methods for these tests are ASTM D1043 (2002), BS 2782-1:Method 153A:(1991), ISO 458-1(1985), and BS 2782-1:Method 153B:(1991), ISO 458-2 (1985).

The apparent modulus of rigidity G for each test temperature is calculated by the relationship:

$$G = (917 \times T \times l) / (b (d^3) \times \mu\theta$$

Where G = apparent modulus of rigidity (Pa)
T = applied torque (Nm)
l = span (mm)
b = test piece width (mm)
d = test piece thickness (mm)
μ = constant depending on ratio b/d
θ = angle of rotation of pulley (degrees)

ASTM specifies a value, T_F, as the temperature when G = 310.3MPa. This allows plastics to be compared, ones with a high T_F maintaining their strength to a higher temperature than the ones with a low T_F.

b) Brittle Failure in Cold Temperatures

Brittle failure is of concern where products are to be hit sharply or dropped at low temperatures. Here the impact strength test using a pendulum impact tester (Section 9.3.5) is probably the most applicable. The only problem is how best to control the temperature of the test piece.

9.2.13 Nail Withdrawal Test

For wood substitute products, like plastics lumber, where nail or staple holding is critical, tests should be carried out on the nail withdrawal force on a test sample. This can be carried out along the lines of BS EN ISO 12777-2 (2000), by hammering a nail into a plastic cylinder of material 8-16 times the nail diameter). The force required to withdraw the nail at a rate of 25 mm/min will give the nail withdrawal force.

9.3 Laboratory Test Equipment Required

Plastic recyclers can shred: -

- pre-consumer waste plastic of known properties and sell as shredded or flake material
- plastic wastes of a single polymer, or polymer group, from various sources, for bulking up to a larger batch to re-extrude into pellets with a single set of characteristics
- mixed plastic waste, mix it with filler, and produce plastic lumber or other products.

These operations require different testing procedures.

9.3.1 Testing Procedures

With pre-consumer waste of known properties no testing will be required. The original specifications on its delivery note will be sufficient, so long as this is still available.

If a consistent type of plastic is being sourced, one-off tests may be carried out from time to time using test equipment from a local technical college or laboratory, to save buying such equipment.

If plastic wastes of a single polymer or polymer group is being sourced, and being made into a larger batch prior to re-extrusion, each batch should be tested prior to dispatch. The buyer will then know the properties of the plastic he is buying and how it compares with the virgin material it is to replace. At minimum, either the tensile strength test or the impact test of the plastic should be assessed.

With a mixed plastic waste facility for plastic lumber production, extruded test pieces of the mixed product should be tested 24 hours ahead of production. Any problems can then be picked up prior to extrusion.

In addition to testing samples prior to extrusion, samples should be cut from the manufactured product coming off the processing line. Test pieces should be taken from both parallel and at right angles to the molten polymer flow. This will ensure that any weaknesses between streamlines, created when the mould is being filled, are being avoided and that the product is similarly strong in the two planes. Had Scottish Recycling carried out such testing on their spacers and fence posts, returns of failed product could have been avoided.

Structural testing will use some or all of the equipment described below. Physical properties will be tested using the equipment described previously in Chapter 8.

9.3.2 Test Piece Manufacture

For rapid manufacture of polymer test pieces, a test-sample injection-moulding machine can be purchased, which moulds the plastic into a test piece in one process (Figure 9.5). This costs £5,200. As mentioned previously, this is the preferred method, since the test pieces better resemble the final moulded product.

Figure 9.5 Test Piece Moulding Machine (Ray-Ran Test Equipment Ltd)

Alternatively a small, batch plastic moulding machine can be used. These may be obtained second hand from plastic component manufacturers, who have discarded their small batch systems in favour of continuous production methods. The resulting product is then stamped out using a test sample cutting press (Figure 9.6) costing £720 plus £520 per cutter. This is a more laborious procedure than using the test-sample moulding machine.

Figure 9.6 Test Piece Cutter (Ray-Ran Test Equipment Ltd)

9.3.3 Tensile Strength Tests

Figure 9.7 Tensile Strength Tester (Ray-Ran Test Equipment Ltd)

A tensile test is carried out by fixing the test piece between two clamps and exerting a tensile force. A machine for tensile tests will cost £6000 (Figure 9.7).

9.3.4 Flexural Test and Flexibility Changes with Temperature

If a polymer has uniform characteristics in all directions, Young's modulus obtained from the tensile test will give a value of flexibility of the material. If the polymer is anisotropic, that is, it is stronger in one direction than another, test pieces can be made to test the modulus in the two directions. Alternatively, a length of plastic can be put between two supports and subject to a bending moment. This allows a flexural modulus of elasticity to be obtained.

If flexibility has to be assessed at different temperatures, the test piece should be put in a bath of oil or water and heated or cooled. For a fence-post test sample, for example, the plastic would be heated to a temperature of 35°C and the modulus compared with the plastic at 20°C. If a low temperature flexibility measurement were required, the test piece would be cooled to approximately –10°C, adding dry ice to cool the liquid in the bath.

9.3.5 Impact Test

The impact test uses a swinging pendulum device (Figure 9.8) to determine whether a material will shatter, particularly in cold weather. If a cold weather simulation is required, a method of keeping the test piece at a specific temperature, say –10°C, will be required. Alternatively test pieces can be rapidly removed from a freezer and tested before they warm up. Such a pendulum device will cost approximately £7500.

Figure 9.8 Impact Tester
(Ray-Ran Test Equipment Ltd)

9.3.6 Puncture Test

If film or thin plastic is being produced, the same swinging pendulum device, as used for the impact test, can be used to measure the force required for a spherical ball to puncture the film. This will provide an assessment of the strength of the material and provide quality control for the production process. A system to support the film, together with a puncture hammer, will add £3000 to the universal pendulum tester.

9.3.7 Hardness Test

To test surface hardness, a steel cone or ball is forced into the surface of the plastic. This will give a measure of the plastic surface hardness and provides a check on the consistency of the plastic being used. It will also give a good indication of the ability of the plastic to take nails. This is obviously important in fence post manufacture. The machine used is usually a Shore hardness meter (Figure 9.9).

Figure 9.9 Shore Hardness Meter
(Ray-Ran Test Equipment Ltd)

9.3.8 Nail Withdrawal Test

The tensile testing machine can also be used to test the “pull out” force required for a nail to be pulled from a plastic test piece, provided a clamping arrangement for sections of plastic is manufactured (Figure 9.10).

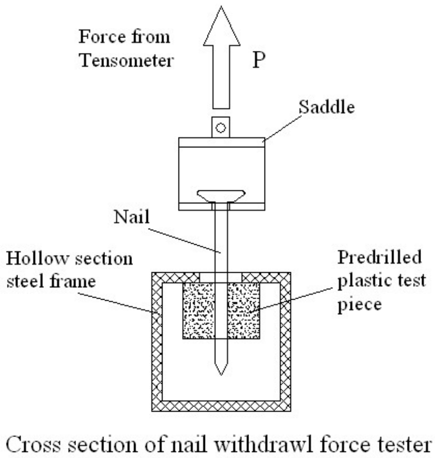


Figure 9.10 Nail Removal Force

9.3.9 Creep

The rate of creep increases with force, temperature and time. To measure creep, a constant load is applied by hanging a weight on a test piece, located within a heater enclosure (Figure 9.11). The extension of the test piece is measured over time.

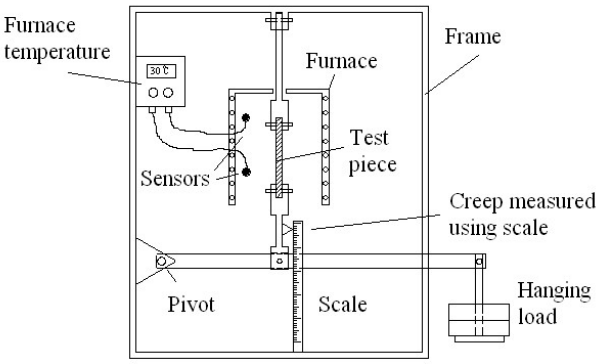


Figure 9.11 Creep at Constant Temperature

To test plastics lumber material for use in a fence strainer post, a force proportional to the actual load applied by the fence wires would be applied, with the test piece kept at a temperature 20–30°C.

9.4 Yield and Tensile Strength of Common Plastics

Values of yield strength and tensile strength for various plastics and some other materials for comparison (Ashby and Jones, 1998) are shown in Table 9.1.

Table 9.1 Yield and Tensile Strengths of Plastics, with Values of Other Material for Comparison

Number	Material	Yield strength MN/m^2 (MPa)	Tensile strength MN/m^2 (MPa)
	Plastics		
1	PET	54	55
2	HDPE	20-30	37
3	PVC	45-48	-
4	LDPE	6-20	20
5	PP	19-36	33-36
6	PS	34-70	40-70
6	EPS (foamed PS)	0.2-10	0.2-10
	Other materials		
	Timber softwoods (compression, // to grain)	-	35-55
	Timber softwoods (Compression, ⊥ to grain)	-	4-10
	Glass fibre reinforced plastics	-	100-300
	Epoxy resin	30-100	30-120
	Mild steel	220	430

The material with the greatest tensile strength is polystyrene, followed by PET, PVC, polypropylene, HDPE, LDPE with foamed polystyrene the weakest. The strongest plastics match timber softwoods. Glass reinforced plastics have tensile strengths four times that of the strongest plastic polystyrene.

9.5 Performance of Mixed Plastic Composites and Plastic Lumber

Polymers can be mixed with fillers to make them go further or change their properties (See Chapter 7.9 –7.11. Fillers can be added to: -

- stiffen the plastic
- reinforce weak plastics
- reduce creep over a range of temperatures
- improve ability of the plastic to accept nails
- reduce product cost.

Wood filled, pelletised feedstocks were produced (English, 1998) using conventional mixing equipment and extrusion equipment designed to allow gasses to escape. The extruder used by North Wood Plastics, Inc., USA, is a 92 mm co-rotating twin-screw extruder with a 36:1 length diameter ratio. Base resin is fed into the main feed throat of the extruder by a loss-in–weight feeder along with any additives, fed by a separate loss-in-weight feeder. After the resin has melted and mixed, wood fibre is added to the melt stream using a side stuffer, itself fed by a third loss-in–weight feeder. After mixing and degassing, the compound is pelletised using air as the cooling medium. The resultant pellets average 0.2% moisture content.

The changes in characteristics are illustrated in the Table below.

Table 9.2 Performance of Wood Filler in Co-polymer Polypropylene (English, 1998)

Property	**ASTM Test**	**Unfilled Resin ***	**20% fibre**	**40% fibre**	**60% fibre**
Density (kg/m^3)	D792	900	958	1021	1157
Melt flow Rate (g/10 min)	D1238	22.0	4.8**	2.3**	<0.5**
Mould shrinkage (%)	D955	2.02	0.94	0.50	0.24
Yield strength (MPa)	D638	N/A	13.9	14.9	11.4
Tensile strength @ fail (MPa)	D638	14.6	12.8	14.3	11.4
Tensile modulus (GPa)	D328	0.7	1.8	3.0	5.2
Elongation (%)	D638	10.0	8.3	2.4	0.6
Flexural Modulus (1% Secant @ 1.3 mm/min)	D790	0.5	1.2	1.9	3.7
Flexural strength (MPa)	D790	18.2	22.7	26.0	23.6
Notched Izod Impact (J/m)	D256	675.0	129.0	88.1	55.5
Un-notched Izod Impact (J/m)	D256	780	329	134	40
Heat deflection temperature @ 1.82 MPa (°C)	D648	47	48	57	70

* Unfilled resin data from published sources. **MFR taken at 190°C instead of 230°C to prevent fibre degradation by heat.

From an examination of Table 9.2, as the proportion of fibre increases: -

- Density increases
- Melt flow rate decreases greatly
- Tensile strength decreases slightly
- Tensile modulus (Stress/strain) increases due to decreased strain
- Flexural strength increases slightly
- Flexural modulus (Stress/strain) increases due to decreased strain
- Impact energy decreases (i.e. Ease of nailing increases)
- Heat deflection temperature increases (Softening due to high temperature decreases)

The overall result is a weaker, but considerably stiffer material, easier to hammer nails into, and which will deform less with increasing temperature. Since plastic fence posts tend to be too strong for requirements, the increased stiffness, and good nail-taking capability is of considerable merit. The reduced melt flow rate, is apparently not as serious at it seems, as the material will still flow sufficiently well to fully fill the moulds.

The density of the wood fibre increases in the mould as the individual wood fibres, which are initially hollow tubes, collapse. They reach their maximum density of 1400 kg/m^2. This density is considerably lower than that of mineral or glass fillers, which have a density of 2500-2800 kg/m^3. A 40% mineral filled polypropylene product has a density of about 1240 kg/m^3, while a 40% wood filled polypropylene product has a density of 1050 kg/m^3, a reduction of 15%.

If the poorer tensile strength is a problem, a chemical coupling agent can be added to improve covalent coupling and improve tensile strength, though at the extra expense of the added chemical.

9.6 Summary

To achieve sales of re-processed plastic pellets or to manufacture plastic lumber from mixed plastic waste, the product must be tested prior to sale or processing. Tests are as below: -

- Tensile strength tests define the strength of a plastic.
- Impact tests are simpler than tensile strength tests and provide a guide to material strength, particularly useful for product quality control.
- Bending tests assess the flexural modulus and strength.
- Puncture tests are used to assess the strength of plastic film.
- Hardness tests are used to assess the surface hardness of plastic and are a guide to ease of nailing.
- Nail withdrawal tests are used to test the nail holding ability of a plastic.
- Creep tests evaluate how the plastic will stain over time at a specific temperature and loading.

For selling re-extruded plastic pellets, the batch should be sold with either a value of tensile test or impact test. The other tests would normally be part of the manufacturer's quality control system. In the longer term, buyers may require more tests to be carried out on re-extruded material prior to agreeing a purchase.

For the manufacture of plastic lumber, the mix of plastics and filler should preferably be tested for tensile strength 24 hours prior to extrusion, so that problems in the mix can be sorted prior to extrusion. Tensile tests on lumber following extrusion should be made on samples of product taken from strips lying parallel, and at right angles to the sides of the mould, to ensure planes of weakness are not occurring during extrusion.

10. PRODUCT DEVELOPMENT

10.1 Introduction

As Scottish Recycling were manufacturing fence posts, it seemed appropriate to illustrate a protocol for a product development using a fence post as an example. This chapter therefore examines the structural and physical properties required, how a plastic post fits in with present fencing technology, what price the post could be sold for and whether the process is viable.

10.2 Background to Timber Fence Design

In preparing to manufacture plastic fence posts, it is first necessary to understand why timber and wire fences have evolved to their present form. Plastic posts can then be designed to achieve these same criteria, while using a minimum of material.

10.2.1 Straining Posts

Straining posts are the key components of a fence (Figure 10.1), as they provide the anchor points for the wires at either end of the fence (MAFF, 1980). The wires are tensioned on erection by the fence erector using a wirepuller or radisseur, so the strainers are under a continuous loading.

Figure 10.1 Conventional Strainer Post

Wire tension varies with temperature. As the ambient air temperature rises, so the wire expands and the tension reduces. As ambient temperature cools, the wire contracts and tension increases. With mild steel wire, high summer temperatures cause newly strained wires to deform plastically (stretch), resulting in the slackening of wires after one or two years. The loading on a mild-steel wire-fence strainer can therefore be much reduced within a year or two of erection.

High tensile wire fences (Pringle, 1979) were introduced in the 70's, as a way of maintaining fence line wire tensions. Prior to this, coil springs had been put in the fence line in an attempt to prevent the wire stretching and so maintain wire tension. High tensile wire is naturally springy, so does not need an additional spring. The longer the wire the more spring it has. The wire is strained more tightly than for mild steel fences, to a level where a considerable proportion of the spring is utilised. In high summer temperatures, more of the spring is taken up, in low ambient temperatures, less. There is always sufficient tension in the wire to keep the fence stock proof, but not sufficient to cause the fence wire to stretch beyond its elastic limit. High tensile fences are therefore superior to mild steel fences in keeping their tension, but do require distances between strainers to be greater than 100 m to ensure that there is sufficient spring in the wire to cope with annual temperature variations. Distance between strainers should preferably be in the range 150 m to 1000 m.

10.2.2. Turning Posts

In high tensile fencing, turning posts are put into the line at any change in direction (Figure 10.2). Timber turning posts are often of smaller diameter than strainer posts as the load exerted on them is less. If the angle of the wires is greater than 15° a stay is required to support the post. Like the straining posts they are under constant load.

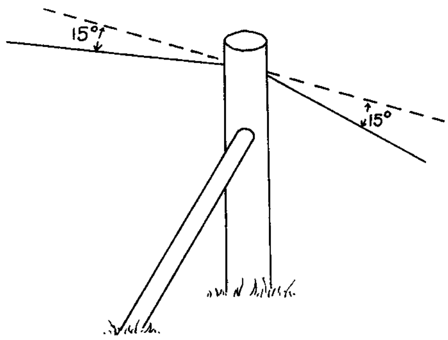


Figure 10.2 Turning Post with Stay

10.2.3 Intermediate Posts

Intermediate posts (i.e. fence posts) are driven at between 2-16 m intervals between straining posts and turning posts. As the wire strains should always be in a straight line, no constant force from the fence wires will come on to the posts. The only force exerted on the posts will be from stock leaning on the fence line to access grass on the other side of the fence. Unlike the strainer posts, where the tension from the fence wire is sustained, the force from stock will be intermittent and only for a few hours per year. While the sideways force exerted by sheep will be negligible, from cattle it can be considerable.

As well as keeping the fence line vertical and at the required height, the posts also serve to keep the wires a fixed distance apart. This prevents stock squeezing between the wires. With high tensile fences, where wire tensions are sufficient to keep the fence vertical with only a few posts, droppers (Figure 10.3), which cost less than posts, can replace a proportion of the posts, to keep the wires together and stop stock squeezing through.

Figure 10.3 Fence using Droppers

10.2.4 Electric Fences

Electric fences use a 5,000 volt alternating current along the fence line to deter stock from touching the fence line. The pulse length is 0.1 second and frequency is 1 second, so there is a dead time of 0.9 seconds to allow for any animal or human to release themselves from the fence. The advantage of the electric fence is that it need only be of lightweight construction, as the shock itself will deter animals leaning against the fence. In addition, as stock will not try to go through the fence wires, the tension in the wires can be less and droppers, or posts positioned to keep the wires together, are not required. Electric fences therefore need fewer posts, less strain on the wire, but they do need to be insulated (Figure 10.4).

Figure 10.4 Electric Fence

The combination of the high voltage, together with the effect of moisture on posts, caused by rain, fog, mist, snow, damp grass and weeds, means that current leakage may be a problem. Ensuring a high electrical resistance is maintained for fence posts and strainers, over time, is critical. Since electric fences are largely a "psychological" barrier, any loss of voltage can result in stock breaking through the fence line.

10.2.5 Post and Rail Fences

While farm fences are predominantly timber and wire, fences for horses, play parks or pubic areas often use post and rail fences (Figure 10.5). Posts used in these situations have no continuous loads imposed on them. The rails however have a load due to gravity, which may cause plastic fences to sag over time.

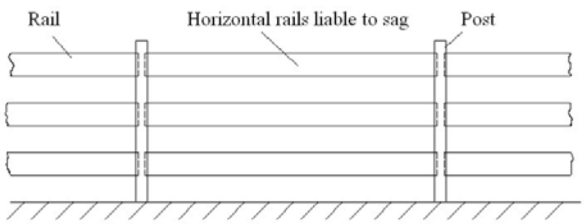


Figure 10.5 Post and Rail Fence

10.3 Life Span of Timber and Wire Fences

The lifespan of a timber and wire fence is normally 15-25 years (Perumbilavil, 2001). First to go are the posts, due to rotting and breaking at just below ground level (Figure 10.6). The strainers and turning posts fail soon after, again due to rotting. At 20-25 years, the fence wire is probably starting to rust where it vibrates in the wind against the staples driven into the post. The constant relative movement of steel against steel causes the galvanising to be worn off and rusting to start. In conventional timber and wire fencing, the posts and wire fail at about the same time.

Figure 10.6 Base of Fence Post Rotting at Ground Level

If the benefits of plastic posts, with their resistance to rotting, are to be realised, it is preferable to use plastic not only for the intermediate posts, but for strainers and turning posts too. A post life of over 40 years could be achieved. The alternative is to use concrete strainers, but they tend to crack when hit by tractor-trailers and implements.

To ensure the wire lasts the same length of time as the posts, the wear between wire and staple, which removes the galvanising, must be minimised. A fence system, rather than simply the production of plastic intermediate fence posts, is therefore required.

10.4 Methods for Erecting Fences

Traditionally a 600 mm square, 0.9 m - 1.1 m deep hole is dug for strainer posts (Figure 10.7). The post is manually lifted and placed in the hole.

Once the post is in position, a groove is taken out the post with a chisel, some 200 mm from the top, and the stay fitted into the groove at the top end and levered into the ground against a flat stone at its base. Intermediate posts are driven in at 2 m intervals with a mel, a large diameter sledgehammer.

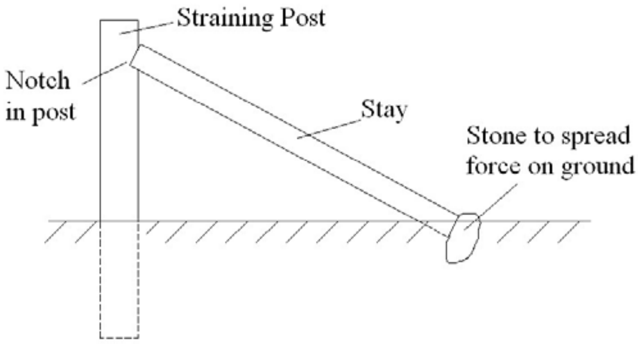


Figure 10.7 Diagram of Traditional Strainer

Over the last 20 years, the majority of fence contractors have converted to using a tractor mounted post driver to drive in intermediate posts. Many have gone further and now use a heavy-duty post driver to drive both intermediate posts and the straining posts. Driving strainer posts is akin to pile driving.

If a fencer prefers to dig a hole rather than drive posts, a tractor digger can be used to make the hole. This tends to slacken all the ground around the strainer, so while easy, it has some disadvantages. If the hole is dug at right angles to the fence line, the post can be braced against the two undisturbed sides of the excavated trench (Figure 10.8).

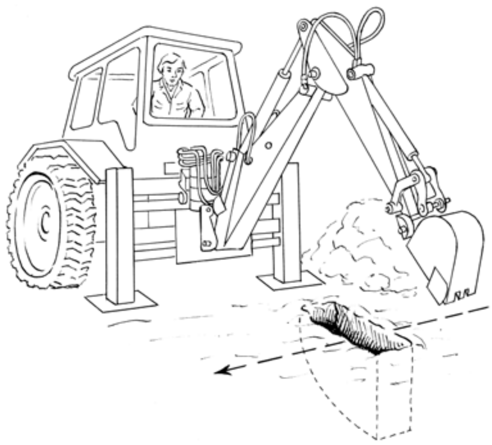


Figure 10.8 Digger Digging a Hole

In developing a plastic fence post system, these numerous approaches to fence erection should be considered. Otherwise sales opportunities could be lost.

10.5 Structural Requirements for Timber Fences

The sizes of timber strainers, turning posts, intermediate posts and droppers are shown in Table 10.1.

Table 10.1 Sizes of Timber Fence Components (SAC, 2002-3)

Component	Traditional Fence*	High Tensile Fence*	Electric Fence*
Strainer	2.1m x180 mm dia	2.4 m x 180 mm dia	2.1 m x 180 mm dia
Stay	2.1m x 100 mm dia	2.7 m x 100 mm dia	No strut used
Turning post	2.1m x 100-180 mm	2.1 m x 150 mm dia	2.1 m x 100-150 mm dia
Intermediate post	1.5 m x 75 mm x 75 mm	1.65m x 75 mm x 75 mm	1.5 m x 75 mm x 75 mm
Timber dropper	NA	1.0 m x 50 mm x 31 mm	Not used

* For continental breeds of cattle add 0.2 m to intermediate posts and 0.6 m to strainer and turning posts.

The standard size of strainers, turning posts, intermediate posts and droppers has been arrived at by trial and error over the years. Fence wire height for traditional British cattle is 1.05 m high and for continental breeds is 1.22 m.

The construction of a strainer post is as shown in Figure 10.9. The purpose of the batten at the base of the post is to stop the strainer lifting when the wires are tensioned. Fitting this batten is not usual in traditional or electric fences, which usually have low wire tensions, but in high tensile fences, failure to fit a batten may result in the strainer post being launched like a rocket from the ground, with the ground end of the stay acting as the pivot.

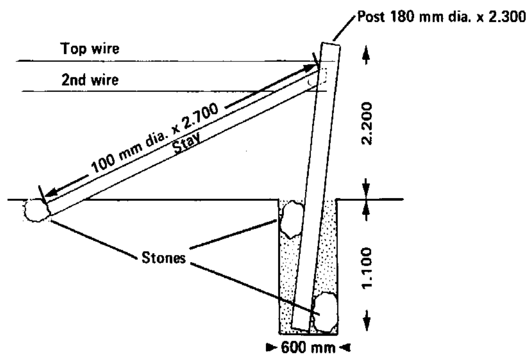


Figure 10.9 Diagram of Strainer Post for High Tensile Fencing

The recommended wire tensions for high tensile fencing are 5 kN when using wire connectors or ratchet winders, or 2.5 kN where knots are used in the wire and 1.7 kN for HT barb wire. The wire used in such fences has a tensile strength of 1850 N/mm^2 with the thickness of the wire being 2.5 mm diameter. Wire tension used in electric fencing or for conventional fencing at maximum is 0.35 kN (BS 4102:1986).

The strength of the strainer can be calculated by assuming these tensions are applied in a maximum of seven wires, applying a load uniformly from the ground to 100 mm from the top of the post. It can be assumed that the base of the post is fixed rigidly in the ground.

It may be felt necessary to add the force of an 800 kg cow rearing up and landing on the top wire of the fence, half way between two posts 8 m apart.

The calculations are likely to indicate that the traditional timber strainer post is much stronger than is required to support the fence line. The large diameter strainer post has been traditionally selected for two reasons.

- To spread the force of the strainer over as large an area as possible, to minimise the pressure on the ground.
- Since rotting organisms take time to penetrate into the centre of the post, the larger the diameter of the post, the longer will rotting take. Since plastic posts should not have this problem, they can be a lesser diameter.

Since the weight of a timber strainer post is at the maximum of what a man can lift, and plastic is more dense than wood, sliming down the diameter of strainers would be a considerable benefit. The problem with reducing the pressure on the ground can either be solved by the use of flat stones, or by the manufacture of flat plastic plates, which can be fitted to the heal and breast of the post.

10.6 Design of Plastic Strainer Post for Wire Fences

The straining post, the stay and turning posts are all continuously loaded due to fence tension. They will therefore be likely to bend over time due to creep, particularly in hot sunny weather. Since the landing of a cattle beast on the top wire will be for a short period only, this will have no effect on creep.

The fence posts or droppers will not be subject to any continuous tension. Creep will therefore not be a problem.

To cope with the continuous load, strainers, stays and turning posts may have to be reinforced with steel tubing, placed in the mould prior to filling with polymer. Posts and droppers do not require reinforcement.

In calculating the size of steel tube reinforcement to use, only the force caused by constant wire tension need be considered. The surrounding plastics will take the sudden force of a cattle beast landing on the wire.

To spread the force exerted by the post on the soil at the breast and heal, plates can be fixed to the post using four Rawlbolts (Figure 10.10). These will not only spread the force over an area of soil, but the base plate will act to prevent the strainer rocket from the ground. This allows the strainer post to be reduced in diameter to 115 mm, sufficient to cope with cattle landing on wires, the odd knock with a tractor-trailer and, although not recommended for HT fencing as it can slacken a strainer, the requirement to hang a gate on the post.

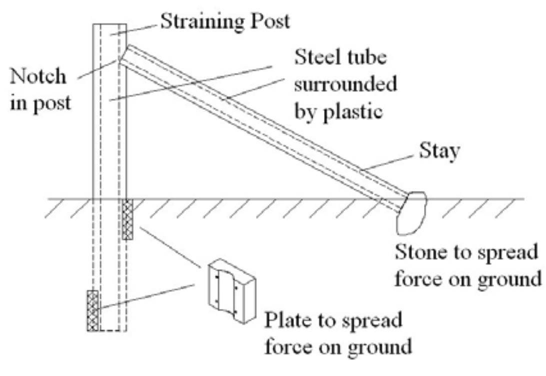


Figure 10.10 Possible Design of Plastic Strainer Post with Spreader Plates

The comparative properties of the conventional timber strainer and plastic strainer are shown in Table 10.2 below. The weight of steel reinforcement has been ignored.

Table 10.2 Comparative Properties of Timber vs Plastic Strainer

Material	Length m	Diameter mm	Volume m^3	Density kg/m^3	Total Weight kg
Timber	2.4	180	0.244	450	110
Plastic	2.4	115	0.099	1.157	115

10.7 Design of Plastic Intermediate Posts

In considering the use of plastic to replace timber fence posts, Table 10.3 below outlines the differences in properties for plastic lumber and those for timber.

Table 10.3 Characteristics of plastic lumber compared with Sitka spruce (Super-wood)

Characteristic	Plastic Lumber	Sitka Spruce (12% mc, dry basis)
Density (kg/m^3)	700	400
Strength yield (MPa)	9.9	6.2-8.0
Flexural Modulus (GPa	0.88	10.8
Flexural strength (MPa)	19.3	11.0 – 31.0
Ring nail pull out force (20 rings embedded) kN	2.16	-

The characteristics for plastic lumber (Super-wood, 2001) shown above indicates that Super-wood has achieved a lower density for their plastic lumber than achieved by English (1998a), it being 700 kg/m^3 rather than English's 1157 kg/m^3. Compared with Sitka spruce, the density is almost twice that of the dry timber. The tensile and flexural strengths are similar, but the flexural modulus of the timber is 12 times that of the plastic lumber. A plank of timber would therefore deform one twelfth as much when walked on than the same cross section of plastic wood.

Their Super-wood plastic lumber therefore is very suitable for fence post manufacture.

10.8 Market Survey for Plastic Fence Posts

A market survey for plastic fence posts was undertaken (Perumbilavil, 2001) at Thainstone Livestock Market, Inverurie, Aberdeenshire, with some additional questionnaires sent to people with a known interest in plastic fence posts. Sixty people answered the questionnaire. Farmers constituted 92% of the respondents.

Less than 5% of respondents were younger than18 years, with 23 % being between 31-45 years and 72% being 46 years and above. This confirms the age structure of the farming industry and in part explains the predominant use of traditional plain wire and barb (41%) and Net and Barbwire (32%) fences (Figure 10.11). The use of the more recently developed fence systems of high tensile (20%) and permanent electric (7%) constituted just over a quarter of all fences used.

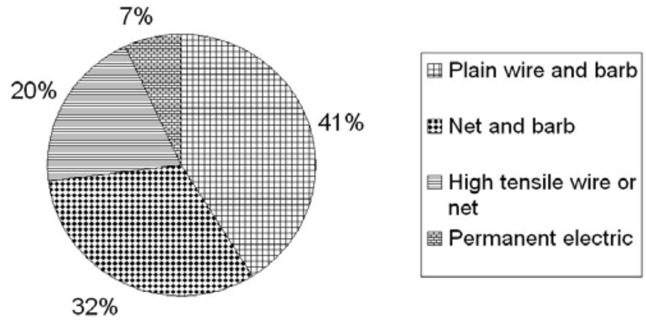


Figure 10.11 Type of Fence used by Farmers

Fences were judged to fail in 67% cases due to rotten posts (Figure 10.12), 15% due to wires corroding and 10% due to strainers rotting and breaking.

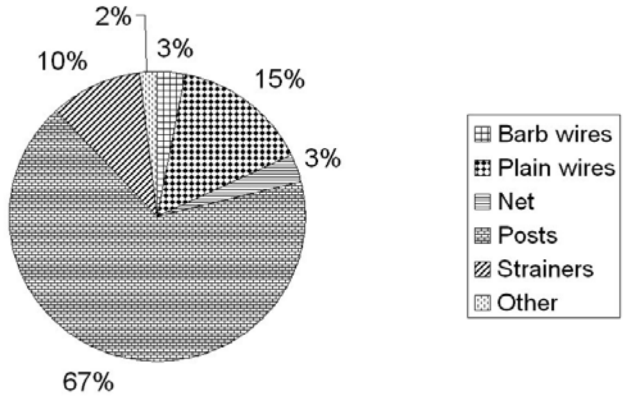


Figure 10.12 What Causes Fences to Fail?

The estimated life of fences using timber posts and strainers was judged to be between 10–25 years (Figure 10.13) with 44% suggesting 15-20 years as the norm.

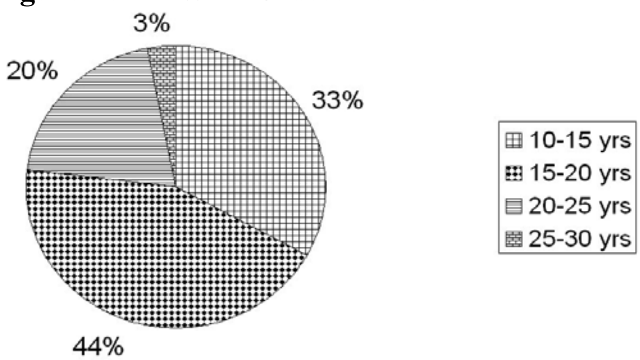


Figure 10.13 Life of Traditional Timber Fences

Over 65% of respondents had heard of plastic posts, and 47% had considered buying them. Only 14% had actually bought any and they had mixed feelings about the product quality. The Royal Scottish Agricultural Benevolent Institution (RSABI) plastic film scheme for charity was the best-known (39%) plastic recycling scheme. Dumfries Plastic Recycling at 13% was next with Harry Birnie, a local agricultural film collector and Scottish Recycling Ltd, equal at 10%.

Of the few respondents who had used plastic posts, most felt that they were more difficult than timber posts to drive into the ground. Hammering in staples was not only difficult, but on the Scottish Recycling posts was actually dangerous. The staples could fly-off when driven and could enter the fencers eye. One respondent used a battery-powered drill to pre-drill holes for staples. The few respondents who had used the plastic posts for electric fencing found the insulation quite adequate.

In the survey the respondents were told that the likely life of plastic posts was over 40 years, compared with 15-20 years for timber posts. They were then asked that if a timber post cost £1.50, how much would they pay for a plastic post? Up to 45% were prepared to pay £1.50-£2.00 for this extended life (Figure 10.14), 23% £2.00-£2.50, and 12% £2.50-£3.00. A group constituting 20% of respondents would pay no more for the posts, suggesting obsolescence and the vulnerability of farming as deterrents to increased investment in longer life fencing.

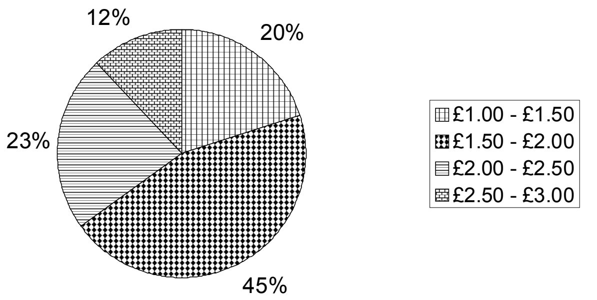


Figure 10.14 Price People would pay for Posts

When it was explained that permanent electric fence insulators (Figure 10.15) would add an extra £0.80 to a timber post, 74% of respondents were prepared to pay between £2.00-£3.00 per post. A typing error in the questionnaire did not allow the £2.00-£3.00 range to be split into two.

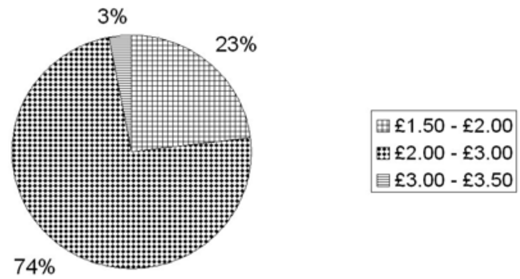


Figure 10.15 Price People would pay for Insulated Posts

One insight made by a farmer (Walker, 2000) was that while timber posts slacken in their holes due to cattle pressure, the plastic posts made from LDPE by Dumfries Plastics Recycling, bent when leaned on by cattle, but did not slacken in their holes. So while his fencer did not like the 50 mm diameter round plastic posts, as holes had to be pinched in the ground prior to driving, to get them to drive at all, the farmer liked them a lot. There may therefore be a market for a bendy post for use with conventional and high tensile fences used for cattle. A stiffer post, more easily driven, could be used for sheep where stock pressure is significantly less. It could also be used for electric fencing for cattle and sheep as the electrified wires deter the stock from pushing the posts.

In summary, there was a potential market for a reliable plastic fence post. For conventional and high tensile fencing, posts could be priced at £2.00-£2.50. For electric fencing the price could be £2.50-£3.00.

10.9 Minimising Feedstock Cost

The last aspect to consider is the comparative cost of timber and plastic. The price paid for un-shredded, but separated, HDPE is £105/tonne (Table 7.4). Converting this cost to a cost per cubic metre of moulded plastic gives a cost of £110/m^3. This compares with a cost for cut fencing timber of £167/m^3. Compared to the timber, the plastic waste has still to be checked for contaminants, shredded, re-extruded and moulded to form plastic fence posts.

Three ways are possible to cheapen the plastic fence posts.

- As they should not rot, strainers, turning posts and intermediate posts can be made slimmer.
- Replace up to 60% of the plastic with wood flour, straw flour or similar material.
- Make wood flour or similar filler (e.g. ground RGF or thermoset) from waste material for which a gate fee can be charged.

Let us assume that the plastic is mixed 40:60 with wood flour, with a gate price charged to accept waste timber at £20 per tonne. The gate price has to be cheaper than the landfill charge of £40/tonne to attract waste producers to supply it to the fence post manufacturer. The cost of HDPE plastic feedstock = £0.40 x 110 = £44. The income from the gate fee for timber is £0.60 x 20 = £12. The net feedstock cost is £44 –12 = £32/tonne. By adding wood flour, the cost of feedstock has reduced from £110 for waste HDPE to £32 for the two materials. While this does not include the cost of grinding the timber into flour, it reduces feedstock costs by £78 and gives a stiffer, more creep resistant product.

10.10 Possible Products

From the previous discussion, a number of potential products could be manufactured for the fencing market. These are listed in order of viability.

10.10.1 Rigid Plastic Lumber Fence Post

This follows the approach taken by Scottish Recycling and concentrates on producing one or two sizes of rigid intermediate posts. These would contain 60% wood fibre, which would reduce the use of valuable polymer and produce a product capable of taking nails or staples. Their cross section would be square section, 50 mm x 50 mm for sheep and 65 mm x 65 mm for cattle, smaller cross sections than used for timber posts to minimise on plastic feedstock used. The square section allows them to be easily stacked.

Strainers for this fencing system would be made from oak, discarded electrical transmission poles, or made from poured reinforced concrete to prolong their lives to 40 years to match the life of the plastic posts. Plastic inserts to staples would ensure wire life matched the life of the posts.

10.10.2 Flexible Plastic Post

This follows the approach taken by the BPI recycling plant in Dumfries. The posts would continue to be made from contaminated recovered LDPE plastic film and would probably be round to minimise feedstock usage, although square posts stack better. This makes a flexible post, which minimises the potential post loosening when cattle push the fence. A steel tube and clamp arrangement could possibly be designed, which would grip the post near its base, yet allow the top of the tube to be driven with a fence post driver. This would minimise the problem of bounce when these posts are being driven into the ground.

10.10.3 Electric Fence System

Since plastic posts have electrical resistance built in, there is potential to develop an electric fence system based on plastic lumber or recovered black farm plastic. It would seem obvious to pre-cut slots in the posts to take the wires. However, buried stones often stop posts being driven their full depth, so posts with pre-cut slots result in the wires rising and falling in relation to the ground surface, making for an unattractive, less than stock proof fence. The provision instead of a portable steel former, to allow staples to be hammered easily into the slippery surface of un-slotted plastic posts, would make such a system more popular.

UV susceptibility would have to be guarded against. One plastic post user reported that after a few years he noticed that the outer layers of plastic were sloughing off. This could be serious with electric fencing, where insulation is so important.

10.10.4 Steel Tube Reinforced Strainer

Unless the problem of creep can be eliminated by use of filler, strainers made from plastic lumber are almost bound to bend. The only solution is to place some form of reinforcement in the mould, prior to filling it with polymer. Since the polymer may not adhere to steel rods like concrete does, steel tubing could be used instead. The strength of the piping would have to be sufficient to take the imposed load from the tension in the wires. The surrounding plastic can take the shock loads of animals charging the fence.

10.10.5 Post and Rail Fences

Post and rail fences can be made of solid material, or extruded into hollow section plastic. Creep in the horizontal bars is the main problem to be overcome. A number of systems have been developed and show that there is a market for such a product.

10.10.6 Other Products

While this section has concentrated on fencing materials, there are obviously many opportunities for plastic lumber to be made into street furniture, pallets, potato boxes and timber for marine applications.

10.11 Summary

When developing a new product, it is necessary to: -

- Gain a thorough background on how the product is to be used and how many forms of product are required.
- Assess the comparative merit of the new product compared with established products.
- Carry out a market survey to
  - assess interest in the product
  - establish the price that potential buyers will pay
  - evaluate the size of the market
  - Carry out a structural design.
- Evaluate the required feedstock that will give the required structural and physical properties.
- Get quotations for the additional cost of moulds and equipment required to produce the new product.
- Cost out the collection, separation, shredding, extrusion, sales and administration costs of producing the new product.
- Make a decision as to whether the venture will be sufficiently profitable.

11. HELP IN STARTING A BUSINESS

11.1 Introduction

Entrepreneurs starting a new small business usually need finance. Their first port of call is likely to be the Small Business Gateway (SBG). Instead of receiving a large cheque made out to the new company to spend on whatever the managing director thinks he or she needs, the SBG staff will offer every sort of assistance but money. While this can be frustrating, this approach is in the best interests of both the new company and the government. At a later date, should the business have aspects, which accord with government grants, the SBG staff will flag these up and help obtain such funding that is available.

11.2 Small Business Gateway

The Small Business Gateway is a government franchise funded in Scotland by Scottish Enterprise, or in the Highland Area, by Highlands and Islands Enterprise. It is the first point of contact for any entrepreneur considering starting up a small business. The SBG franchise is awarded, by competitive tendering, to a suitable organisation to manage, usually a Local Enterprise Company (LEC). In Aberdeen, Enterprise North East Trust runs it.

The SBG provides a number of services:

- A free 3.5 hour “Introduction to Business” Course
- A free two day “Business Start Up” course
- Courses on “Book Keeping” and “Tax” at £25 each
- Personalised help from a nominated business advisor
- Free and unlimited information searches on legislation, market trends, import and export opportunities, advertising costs in various media, sources of funds and assistance and much more. Payment is however required for mailing lists.

Information for browsing is available in the commercial library of most towns and all cites.

The SBG advisor will provide a list of solicitors and accountants, which specialise in particular types of businesses. They will guide you in getting a business plan developed, undertaking a market survey, and generally point you in the right direction in an initial “hand-holding” exercise. The SBG advisors are all trained in business management so they know the usual pitfalls encountered by newly emerging businesses.

In England the equivalent to SBG is Business Link, in Wales it is Business Connect, and in Northern Ireland it is LEDU Regional Information Centre.

11.3 Sectoral Business Support

In addition to providing help to small businesses, the government provides assistance to various special sectors of the economy, such as “Oil and Gas”, “Biotechnology”, etc. Such assistance is routed through the Scottish Enterprise network, with Scottish Enterprise Grampian handling any such enquiries in Aberdeen. There is at present no “recycling” sector.

11.4 Local Authority Support

Support from the local council in the form of available premises for rent and start up loans is available. In Aberdeen this is provided through the Economic Development Council, Aberdeen City Council. Other examples are the Shetlands Islands or Orkney Islands Councils. When Scottish Recycling first started their business to manufacture fence posts, staff at the Aberdeen Economic Development Council obtained premises for the company. They were also instrumental in getting SAC involved in their product development, which has led on to this publication.

11.5 Business Plan and Marketing Policy

In starting any business, the business plan is key. Not only does a plan force the entrepreneur to think through all aspects of the business, but it will inform the bank, venture capitalists and others involved in your business what you intend to do and the likely payback period to any capital investments. The business plan template, below, has been produced by Enterprise North East Trust.

11.5.1 Business to be Set up

a) Business description

Say why you are producing a business plan and give the business name.

b) Business aims and objectives

Describe why you are going into business and what you hope to achieve.

11.5.2 Key People

State their age, experience, educational qualifications, most recent job, etc.

11.5.3 Staff

Do you require any staff? If yes, what type? What will be the cost of employing such staff?

11.5.4 Product or Service

Write a comprehensive description of what you are offering.

11.5.5 Marketing

a) Market

List your potential customers, how many, where, is it a growing market? How often will they buy from you?

b) Research

Compile a comprehensive description of what your research was. How many people were asked, other sources of information – attach a copy of the questionnaire.

c) Existing Competition

Assess the competition, both local and further afield.

d) Your strengths and weaknesses

Carry out an analysis of your business, relating to its Strengths, Weaknesses, Opportunities and Threats, the so-called SWOT analysis. What impact will these have on your business in marketing and financial terms?

Strengths:	Of your market, the effect on income, production, etc.
Weaknesses:	As above
Opportunities:	As above
Threats:	As above.

e) Competitors strengths and weaknesses

List these for your competitors too.

f) Marketing plan

Advertising: Specify types of advertising planned and how its effectiveness will be assessed.

Other forms of promotions and marketing: e.g. talks to groups, direct mail, etc.

11.5.6 Sources of Supply

Specify suppliers, payment terms, delivery terms and any other arrangements.

11.5.7 Premises

Specify space, rent, rates, location, leasing agreement, car parking, access, survey report, any changes to be made.

11.5.8 Equipment

Specify needs; include furniture and fittings, services, decoration costs, and any special requirements.

11.5.9 Transport

Specify type, costs, mileage and any other relevant details.

11.5.10 Legal

Detail requirements for planning permission, building warrants, environmental health, Health and Safety at Work Act, insurance, your own employee's qualifications or memberships and other legal implications.

11.5.11 Pricing

Explain your pricing strategy and how was it arrived at? Give examples of job costs, or price per hour.

11.5.12 Training

a) Skill Analysis: Describe what type of training you need to give to operate your business? Review the skill of managers and others and define training needs. Specify a training schedule.

b) Training needs: Check against list.

11.5.13 Quality

Will ISO9000 or any other quality standards be relevant?

11.5.14 Environmental Policy

Do you have waste emissions to dispose of?

Are you aware of the legislation?

11.5.15 Funding Requirement

How much money do you need to start up your business – what amount are you funding yourself? Do you expect to secure funding from other bodies?

11.5.16 Financial Forecasts and Assumptions

It is essential to prepare a cash flow forecast (Table 11.1) and not just profit forecast. Assumptions should detail how figures were calculated e.g. payment term for debtors/creditors.

CASHFLOW FORECAST FOR PERIOD ________________________ **BUSINESS** ________________________

MONTHS

INCOME	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
Sales & Work Done (include VAT)													
Loans													
Other Income – Self													
Other Income – BSU Grant													
TOTAL £													
EXPENDITURE													
Materials, Stock, Sub-Contractors													
Salaries & Wages													
Proprietors, Directors Remuneration													
Training													
Rent & Rates													
Insurances													
Heating & Lighting													
Repairs & Maintenance													
Postage & Stationary													
Telephone													
Travelling & Motor Expenses													
Advertising													
Professional Fees													
Misc. Expenses													
Finance Charges – Bank													
Finance Charges – HP													
Finance Charges – Other Loan Repayments													
Capital Expenditure													
Taxations (include PAYE & NI)													
Other Payments													
VAT													
TOTAL £													
Movement													
Opening Bank Balance													
Closing Bank Balance													

11.6 Marketing Plan

11.6.1 Introduction

In addition to a business plan, a marketing plan is required. Within this plan there is considerable benefit in involving a third party to assess the market for items to be produced. It is all too easy to believe that customers will be as enthusiastic about your new products as you are. Market testing on friends and colleagues will not provide the impartial views required. Market testing by trained interviewers will. The marketing plan below summarises a business information sheet supplied by the Small Business Gateway.

The writing of a marketing plan will help clarify aims and ideas and raise potential dangers that may arise.

11.6.2 Marketing Plan

The marketing plan should summarise the overall approach to marketing the new products, including objectives, review of existing products on the market, how the new products are going to break in on the established market, product pricing strategy, mode of promotion and timetable for action.

11.6.3 Niche Positioning

Identify the niche, which the business is going to fill.

11.6.4 Identifying Customer Base

The customer base should be clearly identified to aid promotion policies.

11.6.5 Customer Expectations

Identify customer expectations for each product so that both the resultant product and subsequent promotion can satisfy these.

11.6.6 Features and Benefits

The features (e.g. 5 speed gearbox) and benefits (e.g. Fuel economy on motorway) should be identified for inclusion in promotional literature.

11.6.7 Market Size

Evaluate market size from marketing databases or surveys. This may include an estimate of percentage displacement of existing products. This provides feedback from which to target annual production.

11.6.8 Identifying the Competition

Similar to the business plan SWOT analysis (Strengths, Weaknesses, Opportunities and Strengths), but with more detail about particular businesses.

11.6.9 Differentiating the Business

It is important to differentiate the new business from other similar businesses, in this case probably "made from recycled".

11.6.10 Pricing

The greatest danger at start up is to set prices too low. Raising the price later is then very difficult. It is usually better to promote product quality than to sell too cheap.

11.6.11 Communicating with Potential Customers

The Small Business Gateway will advise on getting the best publicity for minimum cost. Well-targeted mail shots and "Fax Back" fliers are cheap and effective.

Once the Business and Marketing plans have been developed, these can be used to secure funding and support any requests for government support.

11.7 Technical Expertise

A number of organisations have been set up in the UK to promote recovery and reprocessing of waste. These include Remade, RAGS, RECOUP and WRAP.

11.7.1 Remade

Remade (Recycled Material Development) is a Scottish based interest group set up to promote the recovery and reprocessing of glass, paper, wood, plastic, biodegradable and other wastes. Seminars are held regularly which focus on one material or process. Speakers from as far as Seattle, USA have been invited to pass on their experience of recycling.

11.7.2 R.A.G.S

The Recycling Advisory Group for Scotland (RAGS) was formed in 1993 to promote, inform, research and facilitate the development and understanding of sustainable waste management. It holds regular meetings to promote collection and recycling activities.

11.7.3 RECOUP

Recycling of used Plastics Ltd (RECOUP) is a UK wide marketing organisation established in 1989 to promote and facilitate post consumer plastic container recycling in the UK and to overcome technical and economic barriers to growth in recycling. In particular it produces detailed standards for bale size, preferred polymer types and maximum acceptable levels of contamination for plastic bottle recovery for processing.

11.7.4 WRAP

The Waste and Resources Action Programme (WRAP) was set up by government in 2000 to promote sustainable waste management by removing barriers to waste minimisation, re-use and recycling and by working to create stable and efficient markets for recycled materials and products. This is a UK wide initiative focussed on recovering and reprocessing paper, glass, plastics, and wood, establishing a reliable supply of material from the waste stream, improving the economics of recycling and developing standards to make trading easier.

Unlike the other organisations, WRAP has funding for project development work in the academic and commercial sector. Funding is targeted at whatever developments appear to offer the greatest sustainable tonnage of waste material recovery and reprocessing per pound sterling invested.

11.7.5 Waste Watch

Waste watch provides funding advice and information for community groups and business in the UK and Europe. Information includes sources of funding and publications.

11.8 Funding Sources

Possible funding sources are: -

- Small Business Gateway Start-Up Award
- LINK
- SMART
- Landfill Tax Credits
- WRAP

Where government is the source of the funding, the arrangements below may be subject to change in the near future as the government's intention is to drastically reduce the number, though not perhaps the monetary value, of funding schemes available.

11.8.1 Small Business Gateway Start-Up Award

This award is 50% of the total cost of the purchase of appropriate Internet ready hardware/software IT equipment of up to £500. Eligible expenditure includes a personal computer, modem, printer and off-the-shelf business applications and/or industry specific software.

To qualify, you will be asked to provide business plans, cash flow projections, business bank account details, and full receipts for items purchased. The application must be between three months before to six months following business start up.

11.8.2 LINK

The government through the Department of Trade and Industry (DTI) LINK will fund 50% of the cost of 2-3 year long collaborative industry and research organisation projects. The businesses concerned must contribute the other 50%. Projects are usually £100,000 plus, and will involve 1-3 businesses and 1-2 research organisations. Funding is discretionary. The work should be innovative and be capable of being commercially developed within a reasonable timeframe.

11.8.3 SMART Awards

SMART awards are available to single companies, which have a technological innovation that they wish to develop. It is not available for collaborative projects. The award is in two stages, a competitive feasibility study lasting 6-18 months and a second non-competitive stage. The feasibility first stage attracts 75% grant on the first £60,000 of cost, with a maximum award of £45,000. The second stage attracts 35% grant, with a maximum grant of £150,000 for both stages.

11.8.4 Knowledge Transfer Partnerships (KTP)

Knowledge transfer partnerships, formerly the teaching company scheme, is government funded and helps companies access the knowledge and skills within the UK's Universities, Colleges and Research organisations. Once a company has been accepted for the scheme for a particular development project, a graduate is recruited to work in the business for a period of two years. The graduate will be responsible to a member of the company staff but will also have a mentor located in an academic institution. The mentor supervises the graduate in the pursuance of the project. The graduate, therefore, becomes a bridge between academia and commerce, providing a two-way flow between both organisations.

11.8.5 Landfill Tax Credits

Seven percent of the landfill tax paid on every tonne of mixed waste sent to landfill is available for investing in community projects, which enhance the environment or contribute to reducing the amount of waste landfilled. Landfill operators may give these Landfill tax credits to worthwhile projects. Alternatively, landfill operators may provide money to registered environmental bodies (EBs), set up primarily to distribute such cash. Examples of such EBs are Score Environmental, SITA Environmental, ONYX Environmental Trust, RMC Environment Fund, and Aberdeen Forward, which has part funded this publication. Up to 90% of the value of the project can be supplied, but the remaining 10% must come from business, local authorities, individuals or clubs and associations. In the case of Aberdeen Forward, co-funding by Scotland Forward and Shell Expo provides the required 10%.

11.8.6 WRAP

The Business Development Service, the focal point of WRAP's Financial Mechanisms Programmes, provides a marriage service for funders and recycling businesses. It offers Small to Medium Enterprises (SMEs) practical help to improve the quality of funding proposals, brokers relationships between businesses and funders, and works with investors to increase their awareness of opportunities in the recycling sector.

The Business Development Service assists in finding and assessing markets for recycled materials and products. It can also advise investors interested in learning more about the investment opportunities presented by the recycling sector.

Their particular interests include plastics recycling and markets for recycled products and processing of wood wastes, which can be used by plastics recyclers as fillers.

Although WRAP is not a funding agency in its own right, it has developed a new £5.5 m Recycling Fund, for providing equity investment for the early stages of a SMEs development. They also have a Residual Value Guarantee Scheme to increase access to operating leases by offering guaranteed residual values on recycling plant or equipment on a competitive basis.

11.8.7 European Structural Funds

Co-finance for waste recycling ventures is available from Europe for economically disadvantaged areas through the LEADER+ fund, so long as it can be shown that the money creates or secures local employment and community sustainability.

11.8.8 Finance for Community Groups

Funding is available to community projects via a number of sources. These include: -

- Forward Scotland
- Edinburgh Environment Partnership Grants Scheme Ltd
- Aberdeen Forward Ltd
- Fife Environment Trust
- Renfrewshire Environment Trust
- South Ayrshire Waste and Environment Trust
- Stirling Landfill Tax Trust.

Contact details for the above are listed in the address list in Appendix IV.

11.9 Further Reading and Web Sites

This chapter gives only a fraction of the information required to start a business. The list below gives publications recommended in the Small Business Gateway Introduction to Business course.

Selection of Book titles from Small Business Gateway
Daily Telegraph Guide to How to Set Up and Run Your Own Business. Kogan Page. (1999)
Daily Telegraph Guide to Working for Yourself. Godfrey Golzen, Helen Kogen, Kogen Page (1999)
Small Business Handbook: an entrepreneur's guide to starting a business and growing a business. P Webb and S Webb. FT/Pitman (1999)
Starting Your Own Business. Jim Green. How to Books. (1998)
Employing Staff – A Guide to Regulatory Requirements (URN 99/933). DTI publications. www.dti.gov.uk/pip/
A Guide to Help for Small Businesses (URN 98?942). DTI publications. www.dti.gov.uk/pip/
A Business plan. Alan West. Prentice Hall (1998)
The 24 hour business plan. Ron Johnston. Century Books (2000)
Business Plans. Brian Finch. Kogan Page. (1998)
Trolley's Professional Partnership Handbook. Williamson Smith Trolley. (1998)
Practical Partnership Agreements. T Sacker Jordans. (1995)
Financial Control for Non-Financial Managers. David Irvin. Pitman. (1995)
How to Prepare a Marketing Plan. John Stapleton and Michael Thomas. Gower Publishing, (1998)
The Marketing Plan. William A Cohen. John Wiley and Sons. (2001)

11.10 Summary

Entrepreneurs planning on starting a recycling business should work on a business plan over a period of at least a year. They should consider: -

- Visiting the Small Business Gateway to discuss their ideas.
- Draw up a business plan for their proposed company.
- Carry out a cash flow forecast to ensure the business stays liquid during the development phase.
- Develop a marketing plan.

- Access technical expertise in the recycling business.
- Access any funds available.

Support funding for developing the business will only be forthcoming if it can be shown that the resulting business will be viable without the support from further handouts.

APPENDIX III

Addresses of Scottish Waste Plastic Recycling Companies

Name	Address	Telephone Website	Contact	Topic
Central Recycling	25 Bonnyside Road Bonnybridge Stirlingshire FK4 2AD	+44 (0)1324 815700 Fax +(0)1324 815922 <http://centraldemolition.co.uk>		Recycling
GP Plastic Materials Ltd	Unit 7, 11 & 12 Armadale Ind Estate Armdale West Lothian	+44 (0)1501 734 483 Fax +44 (01)1501 734 484 <http://www.gpplasticmaterials.co.uk>		PVC & PET recycling, materials distributor.
John Hannay & Co Ltd	Linwood Ave College Milton East Kilbride Glasgow G74 5NE	+44 (0)1355 225455 <http://www.hannay.co.uk>		Plastics, paper
Plastic Polymer Processors Ltd	12 Inchyra Road Grangemouth Stirlingshire	+44 (01)324 484444 Fax +44 (01)324 486666	Charles Forrest	Recycling of commercial plastics and production of plastic lumber
Vencel Resil Ltd	East Wellington St Parkhead Glasgow G31 5HD	+44 (0)141 550 6300 Fax +44 (01)141 550 6310 <http://www.vencel.co.uk>		XPS sheet recycling
Waste Reduction by Waste Reduction Europe Ltd (WRE)	Clydebank Riverside Medi Park Beardmore St Clydebank G81 4SA	+44 (0)141 951 5980 Fax +44 (01)141 951 598 <http://www.wreurope.com>	Sandy Hamilton	Medical waste recycling

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http://business.lycos.com/	Search engine for businesses and business opportunities.
http://europa.eu.int/comm/environment/waste/eucostwaste.pdf	Costs for Municipal Waste Management in the EU. Eunomia Research and Consulting. 2002
www.aeat-env.com/rau/	AEA Technology site for sustainable futures. Links to DEFRA and other government departments on sustainable futures.
www.americanrecycler.com	American Recycler; Magazine on recycling of all wastes
www.amm.com/index2.htm	American Metal Market; Daily newspaper of metals and recycling market, including prices. £500 per annum subscription.
www.apme.org	Association of Plastics Manufacturers in Europe
www.bpf.co.uk/	British Plastics federation including; cost guidance, BS Standards, polymer characteristics, sustainable future, recycling, UK manufacturing plant utilisation.
www.bpipoly.com	British Polythene Industries Plc. Includes details of plastic recycled products.
www.bpiworld.org	International Biodegradable Products Institute, New York. Allow their compostable logo on items like biodegradable plastic bags
www.bpsweb.net	Biodegradable plastics Society. Based in Japan, the society promotes biodegradable plastics. Defines test standards and lists manufacturers.
www.bre.co.uk	Building Research Establishment. Consultancy, research and information on building materials including testing of plastics and composites.
www.ciwmb.ca.gov/MktGuides/	California Integrated Waste Management Board. Describes Plastic properties, reuse opportunities, and market prices in dollars.
www.cpia.ca	Canadian plastic industry association, Ontario, Canada. Sponsors industry initiative committed to responsible recovery of plastics resources. Database and practical publications for plastic recovery and resource information for teachers and environmental bodies.
www.crra.com	California Resource Recovery Association. Advocacy group encouraging recycling. Details of conferences, news and events.
www.environmental-center.com/magazine/emap/index	Materials Recycling Week; Weekly magazine with articles on waste industry, with waste materials prices
www.epa.gov	Environmental Protection Agency, USA. General information on the environment.
www.geocities.com/ledarecycling/e-machinery.html	Italian plastic recycling machinery, including shredders, washing plant, agglomerators plus comments on their use.
www.hotline-fencing.co.uk	Hotline temporary electric fencing
www.letsrecycle.com	Search engine for recycling including machinery guide, manufacturers, prices for recovered baled plastics.

Website	Description
www.matweb.com	Strength, glass transition point, MFR, and other data on 16000 polymer materials and mixes.
www.monitorpress.co.uk	Environmental manager website
www.Msikich@ciwmb.ca.gov	Integrated waste Management Board, California. Organisation committed to reduction and recycling of waste. Waste Search Engine.
www.napcor.com/	National Association for PET Container Resources (NAPCOR) is the trade association for the PET industry in USA and Canada. It has statistics, technical information, and some prices.
www.npl.gov.uk/	National Physical Laboratory. Research into developments in plastics in general.
www.nrf.org.uk	National Recycling Forum, a Waste Watch offshoot. Its aim is to promote waste reduction, reuse of materials and recycling. Lists companies that recycle plastics and other wastes in UK.
www.petcore.org/	PET Container Recycling Europe (PETCORE) is European version of NAPCOR, with aim of facilitating recovery of particularly PET containers. Statistical data, products produced, publications.
www.plasticguide.com/	Plastic magazine for worldwide view of plastics.
www.plasticinsite.org.uk	DTI website displayed by Moores Rowland Management Solutions Ltd for plastic producers. Contains details of new polymers with technical characteristics and manufacturers addresses.
www.plasticnews.com/subscriber/	US Plastics News Magazine website. Has list of polymer prices and large data base.
www.plastics.com	USA database of manufacturers of plastic feedstock, additives, colourants and polymer moulding and test machinery.
www.plasticsnet.com/	Technical specifications of different polymers
www.plasticsrecycling.org	USA Association of Post Consumer Plastic Recyclers. National trade association promoting design guidance for new containers to ease recycling of used containers.
www.plasticsresource.com/recycling.	USA American Plastic Council, Plastics Resource website. Information on US plastic quantities recycled, addresses of US recyclers, uses for plastic lumber, and plastics recycling technologies.
www.plasticssearch.com	Plastics search engine. Has information on plastic materials, additives, extrusion and moulding machinery, including second hand recycling machinery.
www.plasticx.com	USA prices for recovered plastics
www.polargruppen.com	Biodegradable bags from Norway with British Agent Bio-bags (Scotland) Ltd.
www.polymer-search.com/	Plastics search engine set up by Rapra Technology Ltd. Has database, focus groups and links.
www.polysort.com	USA based organisation for group purchase of polymer resins. Gives sample prices in dollars.

Website	Description
www.rapra.net	Rapra Technology Ltd. Formerly Rubber and Plastics Research Association. UK based consultancy and R&D company providing polymer analysis, advice on product manufacture and conferences. Have large data base.
www.recoup.org	Plastic bottle recycling organisation providing specifications and traceability for marketing baled plastics.
www.spra.org.uk	Scottish Plastics and Rubber Association website. Scottish Plastics companies addresses, local news and events, links to companies supplying polymer and machinery.
www.strath.ac.uk/Other/SPTN	Scottish Polymer Technology Network based in Glasgow promoting the consultancy capability of Strathclyde, Napier and Heriot Watt Universities and Bell College of Technology.
www.untha.co.at	Untha Shredding machinery
www.vinyl2010.org/	European PVC industry promotion of sustainable PVC polymer production, recycling and disposal. Includes recycling information for PVC.

APPENDIX I

Addresses of People and Companies Supplying Information for this Publication

Name	**Address**	**Telephone** **Web site**	**Contact**	**Topic**
Aberdeen City Council	Economic Development Department 74-76 Spring Garden Aberdeen AB25 1GN	+44 (01)224 522020	McCorkindale, Morag	Organised funding for Entrust project
Aberdeenshire Council	Aberdeenshire Council Gordon House Blackhall Road Inverurie AB51 3WA	+44 (0)1467 620981	George Niblock Jack Clark	Waste Management of Local Authority
Albyn of Stonehaven	Spurryhillock Industrial Estate Stonehaven AB39 2NH	+44 (0)1569 763296	Hugh Smith	Manufacture plastics, commented on this publication
Ametek (Lloyds Instruments Ltd)	Forum House 12 Barnes Wallis Road Segensworth East Fareham Hampshire PO15 5TT	+44 (0)1489 486 399 Fax +44 (0)1489 885 118 <http://www.lloyds-instruments.co.uk>	Toby Rogers (Photos) Hugh Penderton (Sales) HP Mo. 07976 663314	Polymer test equipment
BioBag Ltd	Comet Road Moss Side Industrial Estate Leyland PR26 7PF	+44 (0)1772 424731 Fax +44 (0)1772 621065 <http://www.polargruppen.com>	Mike Bradley	Plastic bags made from corn starch
BioBags Scotland Ltd	4 St Ninians Monymusk Inverurie Aberdeenshire AB51 7HF	+44 (0)1467 651247 Fax +44 (0)1467 651864 <http://www.biobags.co.uk> <http://www.polargruppen.com>	MacKenzie, Karen	Plastic bags made from corn starch
Birnie, Harry	Whynieton Maud Aberdeenshire	+44 (0)1771 644444	Harry Birnie	Collects LDPE film and plastic bags from farms
BPI Plc	96 Port Glasgow Road Greenock PA15 2RP	+44 (0)1475 501000 Fax +44 (01)1475 743143 <http://www.bpipoly.com>	Andrew Green for recycled products	Polythene films & PE/DE bottles

NB: Contact numbers and addresses cannot be guaranteed to be correct.

Name	Address	Telephone Website	Contact	Topic
C W Components	Derdale Street Todmorden Lancashire OL14 5QX	+44 (0)1422 374499	Chris Olfield	Suppliers shredders
Colour Master	Stock Lane, Off Peel Street, Chadderton, Oldham. OL9 9EY	0161 624 2114	Eddie Maker	Supplier of pigments to plastic industry
Dumfries Plastics Recycling (DPR) Ltd	College Road Dumfries DG2 0BU	+44 (0)1387 247110 Fax +44 (01)1387 247109 <http://www.recycledproducts.bpipoly.com>	Kim Williamson	Bpi.recycled products, new film from dirty used agricultural film. Also plastic lumber
Eurobalers Ltd	2 Edgewood Close Crowthorne Berks RG45 6TA	+44 (0)1344 777088 Fax +44 (01)1344 761649 <http://www.eco-web.com>	John Scholfield John@harris-uk.demon.co.uk	Twin ram balers
KweenB Plastic Engineering	The Old Manse 2 Compton Road Erdlington Birmingham B24 8QA	+44 (0)121 355 2662 Fax +44 (0)121 355 8566 <http://www.kweenb.co.uk>	Keith Bamforth	International Consultant in recycling of plastics
Novamont S.p.A.	Via Fauser, 8 28100 Novara Italy	Tel: +39 0321 69956 Fax: +39 0321 699600 <http://www.novamont.com>	Angela Zanellato	Maize starch plastic bags. Supply Polar-gruppen BioBags
Plastic Polymer Processors Ltd	Unit 1 6 Duniswood Road Wardpark South Cumbernauld G67 3EN	+44 (0)1324 484444 Fax: +44 (0)11324 486666	Charles Forrest	Recycling of plastics
Ray-Ran Test Equipment Ltd	Kelsey Close, Attleborough Fields Industrial Estate Nuneaton Warwickshire CV11 6RS	+44 (0)24 7634 2002 <http://www.ray-ran.com>	Peter Green	Test equipment for MFR index, puncture, impact, softening
RECOUP	9 Metro Centre Welbeck Way Woodston Peterborough PE2 7WH	+44 (0)1733 390021 Fax +44 (0)1733 390031 <http://www.recoup.org>	Andrew Simmons	Promotes & facilitates plastic bottle recycling

Name	Address	Telephone Web site	Contact	Topic
Robert Gordon University	Marketing Department Robert Gordon University Schoolhill Aberdeen	g.stephen@rgu.ac.uk	Graeme Stephen	Lectures in marketing
Scottish Polymer Technology Network (SPTN),	Strathclyde University James Weir Building 75 Montrose Street Glasgow G1 1XJ	+44 (0)141 548 4714 Fax: +44 (0)141 553 4117 Patricia.erskine@strath.ac.uk	Ms Patricia Erskine	Collaborative consultancy group
Starlinger & Co	Sonnenuhrgasse 4 1060 Vienna Austria	+43-1-599 55 Fax +43-1-599 55-25		Intrusion line used in Scottish Recycling Plastic Sacks
Superwood	PO Box 3325, Langley. B.C.	(604) 888 1355 Fax: (604) 430-3007 Warning: Do not use their old www.super-wood.com web address unless you want pornographic literature.		Manufacturers of plastic lumber in North America
Sweepwise Municipal Services	63 Ramsden Wood Road, Walsden, Todmorden, Lancashire. OL14 7UD	Tel: 01706 817000 Fax: 01706 818047	John Tattersall	Plastic lumber benches, and fencing
Texkimp Ltd,	Manchester Road, Northwich, Cheshire. CW9 7NN	Tel: 01606 40345 <http://www.texkimp.co.uk>	Joyce Halliday	Agents for Starlinger extruders
UNTEC Ltd	Burnley Road, Sowerby Bridge, West Yorkshire, UK. HX6 2TF	01422 833933 E-mail: sales@untec.co.uk		Suppliers of shredders for plastics and other wastes
Wilkes Recycling Systems Ltd	Brick Kiln Silchester Road Tadley Hants RG26 3PX	Tel: +44 (0)118 981 6588/6330 Fax: +44 (0)118 9819532		Agent for slow speed, Hammel crusher.

APPENDIX II

Useful Addresses of Plant, Equipment and Information

Name	Address	Telephone Website	Contact	Topic
A.R.T. Engineering SA	Industrielaan 4, B-9660 Brakel, Belgium.			Mixed plastics recycling systems
British Plastics Federation	6 Bath Place Rivington Street London EC2A 3JE	+44 (0)9061 908070 <http://www.pras.com>		See website
Container Systems Gmbh	A-2331 Vienna Nosendorf	+43(1)609-4800 Fax +43(1)609-4800-4	cs@cso.at	Hand operated compaction systems
Engineering Services (Bridgend) Ltd	Shephers Yard Australian Terrace Bridgend South Wales CF 31 1LY	+44 (0)1656-662641 Fax: +44 (0)1656-668041 <http://www.engserv.com>		Recycling equipment
Garden Craft Products	Unit 3 & 4 Farburn Industrial Estate Wellheads Road Dyce Aberdeen AB21 0HT	+44 (0)1224 725479 Fax +44 (0)1224 725479	Jim Gray	Makes street furniture
Glasdon UK Ltd	Preston New Road Blackpool Lancashire Fy4 4UL	+44 (0)1253 600412 Fax +44 (0)1253 792558 <http://www.bricsnet.co.uk>		Supply street furniture made from recycled plastic
Granutech Saturn Systems Corporation	Finney Cote Hawkshaw Nr Bury BL8 4LB	+44 (0)1204 884 475 Fax +44 (0)1204 884 475 <http://www.granutech.co.uk>		Shredders for contaminated plastic crates & barrels
Hamos USA	Skyland North Carolina USA	<http://www.recycle.net>	Jerry Hofman See website	Electrostatic separation of metals in electrical cable shredding
Jackson & Son (Fencing) Ltd	Dragon Hall, Whitchurch Road, Chowley, Nr Tattenhall, Chester. CH3 9DU	01826 770776 <http://www.jacksonsfencing.co.uk>		Farm, garden and industrial fencing

Name	Address	Telephone Website	Contact	Topic
Julien Environmental Technology (J.E.T)	Jet Norseren Lostraat, 49 9850 Merendree Belgium	Tel +00 32-2-534-64-03 Fax: +00 32-2-534-59-28 <http://www.jet-norsemen.com>		Turnkey plastic lumber making plants
Linpac Plastics	Newton Lane Allerton Bywater Castleford West Yorkshire WF10 2AL	+44 (0)1977 604080 Fax +44 (0)1977 603355 <http://www.Linpac-recycling.co.uk>		Polystyrene, PP, HDPE products from recycled plastics
M&N Recycling	Unit 2 Denholm House Farm Halifax Road Bradford BD13 4EN	+44 (0)1274 830360 Fax +44 (0)1274 830360		Waste polythene recycling
MMH Recycling Systems Ltd	Unit 7 College Fields Prince George's Road Wimbledon London SW19 2PT	+44 (0)208 687 5353 Fax +44 (0)208 687 0778 <http://www.mmhrecsys.com>	Philip Keatley	Agent for Eldan Scandinavian Recycling A/S, cable recycling system
North East Recycling	Unit 1, Riverside Court Newburn Haugh Ind Estate Newcastle-upon-Tyne NE15 8SG	+44 (0)191 2645673 Fax +44 (0)191 2645673		Plastics, Aluminium, paper and glass recycling
Plastic Reclamation Ltd	Bold Industrial Park Neills Road Bold St Helens WA9 4TU	+44 (0)1744 810001 Fax +44 (0)1744 810626		Recycling plastics from Ford Jaguar cars
Rutland Electric Fencing Co Ltd	Unit 27, Pillings Road Industrial Estate, Oakham, Leistershire.	<http://Retland-electric-fencing.co.uk/>		Full range of electric fencing materials
Testometric Co Ltd	Unit 1, Lincoln Business Park Lincoln Close Rochdale Lancs OL11 1NR	+44 (0)1706 654039 Fax +44 (0)1706 646089 info@testometric.co.uk <http://www.testometric.co.uk>	Eric Thorpe	Tensile test Equipment

APPENDIX IV

Addresses of Organisations Providing Funding for Recycling Businesses and Agencies

Name	Address	Telephone / website
Aberdeen Forward Ltd	Aberdeen Forward Ltd Aberdeen Business Centre Willowbank Road Aberdeen AB11 6YG	01224 332372
British Venture Capital Association	Essex House 12-13 Essex Street London WC2R 3AA	+44 (0) 20 7025 2950 Fax (0) 20 7025 2951 <http://www.bvca.co.uk>
East of Scotland European Partnership		<http://www.esep.co.uk>
Edinburgh Environment Partnership Grants Scheme Ltd	Edinburgh Environment Partnership, 12 Giles Street, Edinburgh. EH1 1PT	
Fife Environment Trust	Falkirk Council, Abbotsford House, Davids Loan, Falkirk. FK2 7TD	
Forward Scotland		www.forward-scotland.org.uk/FreshFuturesApplicationForm.pdf
Highlands and Islands Partnership		www.hipp.org.uk
Knowledge Transfer Partnerships	KTP Central Office, Brunel House, Volunteer Way, Foringdon, Oxon, SN7 7YR	<http://www.KTPonline.org.uk>
Landfill Tax	HM Customs and Excise, Dobson House, Regent Centre, Gosforth, Newcastle Upon Tyne, NE3 3PF	0645 128484 <http://www.hmce.gov.uk/bus/excise>
LINK Directorarte	Office of Science and Techncology DTI, Eighth Floor, Bridge Place, 88-89 Eccleston Square, London. SW1V 1PT	Tel: 0171 215 0779 E-mail: link.ost@gtnet.gov.uk
Renfrewshire Environment Trust	Department of Environment Services, Renfrewshire Council, South Building, Cotton Street, Paisley. PA1 1BR	
Smart Awards		<http://NICS.gov.uk/irtu/prog/rd/smart.htm>
South Ayrshire Waste and Environment Trust	Development and Client Services, South Ayrshire Council, County Buildings, Wellington Square, Ayr. KA7 1DR	

Name	**Address**	**Telephone / website**
South of Scotland Partnership		<http://www.sosep.org>
Stirling Landfill Tax Trust	Stirling Council, Viewforth, Stirling. FK8 2ET	
Strathclyde European Partnership		<http://www.wsep.co.uk>
WRAP	The Old Academy, 1 Horse Fair, Banbury, Oxon. OX16 0AH	01295 819900 <http://www.wrap.org.uk>