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Industrial uses for crops: markets for bioplastics

by

Myles Barker[1] and Richard Safford[1]

[1]HGCA, Caledonia House, 223 Pentonville Road, Kings Cross, London, N1 9HY

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Abbreviations

ABPR	-	Animal by-products
AD	-	Anaerobic digestion
ADM	-	Archer Daniels Midland
APME	-	Association of Plastics Manufacturers in Europe
ASP	-	Aerated Static Pile
BDO	-	Butanediol

BMT - Biological Mechanical Treatment
BRC - British Retail Consortium
BSI - British Standards Institution
CA - Cellulose acetate
CBL - Compression bonded loosefill
CD - Compact disc
CEN - Comité Européen de Normalisation
CLR - Closed Loop Recycling
CSR - Corporate Social Responsibility
DEFRA - Department of the Environment, Food and Rural Affairs
DDGS - Dried Distillers Grains and Solubles
DSD - Duales System Deutschland
DTI - Department for Trade and Industry
DVD - Digital Versatile Disc
EC - European Community
EfW - Energy from Waste
EU - European Union
FIIA - French Industrial Innovation Ageny
GHG - Greenhouse gas
GM - Genetically modified
GMO - Genetically modified organism
GPO - German Packaging Ordinance
HDPE - High density polyethylene
ISO - International Standards Organisation
IVC - In-vessel composting
KTPA - Kilo tonnes per annum
LA - Local authority
LAX - Landfill tax
LCA - Life cycle analysis
LDPE - Low density polyethylene
LIFFE - London International Financial Futures and Options Exchange
MAP - Modified Atmosphere Packaging
MBT - Mechanical Biological Treatment
MRF - Material Recovery Facility
MSW - Municipal Solid Waste
MTPA - Million tonnes per annum
NIR - Near infrared
OECD - Organisation for Economic Co-operation and Development
OPEC - Organisation of the Petroleum Exporting Countries
OSB - Oriented Strand Board
PA - Polyamide
PAS - Publicly Available Specification
PBT - Polybutylene terephthalate
PCS - Producer Compliance Scheme
PDO - Propanediol
PE - Polyethylene

PERN - Packaging Export Recovery Note
PET - Polyethylene terephthalate
PHA - Polyhydroxyalkanoate
PHB - Polyhydroxy butyrate
PLA - Polylactic acid
PMMA - Polymethyl methacrylate
PP - Polypropylene
PRN - Packaging Recovery Note
PS - Polystyrene
PSM - Plastarch Material
PU - Polyurethane
PVC - Polyvinyl chloride
RDF - Refuse Derived Fuel
rPET - Recycled polyethylene terephthalate
RPS - Regular Packing and Stacking
RTFO - Renewable Transport Fuel Obligation
SPI - Society of the Plastics Industry
TPA - Tonnes per annum
TPS - Thermoplastic Starch
WID - Waste Incineration Directive
WRAP - Waste and Resources Action Programme

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Executive Summary

Plastics are essential and are used in coatings, construction, containers, furniture, packaging and textiles. They provide us with a means of protecting goods and chemicals, prolonging the shelf-life of foodstuffs and waterproofing to name but a few applications. However, we currently rely heavily upon fossil fuel as a feedstock and energy source for plastic manufacture. This situation is not sustainable because crude oil stocks are finite. In addition, the manufacture of fossil fuel-based plastics (petroplastics) is energy intensive and results in the emission of large quantities of greenhouse gasses (GHGs) such as carbon dioxide that contribute to global warming.

Renewable plastics

Several companies are researching, manufacturing, processing and disposing of plastics made from renewable resources in an attempt to move to a more sustainable position. These so-called 'bioplastics' are made from replenishable crop components such as starch and vegetable oils and are usually broken down by micro-organisms in the environment (biodegradeable). However, the bioplastics industry is in its infancy with low material volumes and relatively high prices when compared to petroplastics. At the moment there are several types of bioplastics available, but there is a greater range of petroplastic materials on the market. As bioplastic research and manufacturing processes evolve there will inevitably be new types released onto the market. In addition, there are also likely to be enhancements in production efficiency and volume demand to drive down costs. In short, bioplastics show potential to reduce our oil dependency and to help mitigate our environmental impact through reducing the levels of waste sent for landfill and through GHG emission reductions. However, further research, up-scale and marketing is required to reduce production costs and enable greater penetration of bioplastics into a petroplastic-dominated market.

The main challenge for bioplastics

The utilisation of renewable feedstocks and biodegradability are two major drivers for the use of bioplastics. Other benefits of bioplastics include unique functional properties and an equivalent or lower carbon footprint when compared to petroplastics. However, possessing and using the correct disposal methods, or 'end of life options', is critical to the success of bioplastics.

When bioplastics come to the end of their useful life there are several disposal options available including: 1) composting; 2) recycling; 3) energy from waste options (e.g. anaerobic digestion and incineration); 5) landfill. Landfill is considered to be the worst option both economically and environmentally. The UK is running out of landfill space and current EU legislation (the Landfill Directive) obliges a reduction in the amount of biodegradable waste sent to landfill to reduce emissions of methane (a GHG 23 times worse than carbon dioxide). In an attempt to comply with this directive, a Landfill Tax escalator has been introduced. Landfill Tax is currently set at £40 per tonne of waste and is set to rise by £8 per year until at least 2010/2011. Currently, the main disposal routes available to bioplastics are composting and landfill. The other options are not widespread in the UK. Furthermore, Local Authorities differ considerably in the methods of waste collection they use. Clearly, investment is required, standard procedures for waste collection and processing are needed and greater public awareness of what to do with bioplastics is necessary in order to minimise the environmental impact of bioplastic waste disposal. When this occurs the UK will be in a better position to deal with its own waste. However, there are several regulations covering disposal options including: 1) the Waste Incineration Directive relating to energy from waste options; 2) EN 13432, Publicly Available Specification (PAS 100) and Animal By-Products Regulations (ABPR) for composting and anaerobic digestion. These regulations are a hurdle to be surmounted by companies involved in waste disposal. End of life disposal is the main issue, but there are other challenges to be met before bioplastics achieve widespread plastic market penetration. These challenges include the cost of plant, resin production and processing, high resin prices (typically two to four times more expensive than corresponding petroplastics), compatibility of resins with processing equipment, low volumes of material, packaging regulations and company resistance to using them. At all levels of the supply chain there is a need to raise awareness of bioplastic materials, what they can be used for and the benefits they offer. In addition, are consumers willing to accept such new packaging materials? All of these challenges provide an opportunity for improvements to be made through research and development, process development, investment, marketing and knowledge transfer. Such work is justified because bioplastics offer large benefits over petroplastics: because they are sustainable, biodegradable and possess some novel and superior functional properties over petroplastics.

Environmental benefits of bioplastics

Bioplastics are renewable and can be disposed of in a number of environmentally-friendly ways. However, if global carbon footprint and GHG emissions targets, such as those set out in the Climate Change Bill (80% reduction in GHG emissions from 1990 levels by 2050) are to be met, a holistic approach is required throughout the life cycle of bioplastics to make sure that their environmentally-friendly potential is maximised. Realistically, this has not been fully achieved yet because: 1) there is little awareness of what to do with bioplastic materials at the end of their life; 2) Local Authorities do not have a standardised collection method for plastics to ensure quality material for recycling or composting; 3) most of the disposal options available to bioplastics require further development. However, energy, GHG and carbon footprint savings are being achieved through improved raw material and bioplastic manufacturing process efficiency.

In order to try and ascertain the environmental impact of materials such as bioplastics, life cycle analysis is usually performed. This method is an all-encompassing approach to auditing the energy and carbon footprint of materials during their production, use and disposal. Life cycle analysis is relatively new and, at the moment, there is no standard methodology. This presents certain difficulties in determining the relative environmental impact of different materials suitable for the same application. However, a recent Publicly Available Specification (PAS 2050) has been formulated to provide a standard LCA model for products and services in the UK.

The bioplastics market

At the moment, the world uses about 260 million tonnes per annum (tpa) of plastics, Europe consumes around 53 million tpa of plastics and the UK uses approximately five million tpa of plastics, approximately half of which is used in packaging. In comparison, around 300 ktpa (thousand tpa) of bioplastics are consumed worldwide equating to a 0.1% share of the current plastics market. In Europe, bioplastic consumption is currently around 60-100 ktpa and, specifically, the UK uses around 15 ktpa for packaging, waste collection and food serviceware. Clearly, there is potential for growth in this sector and, in fact, experts predict a six-fold expansion in the global bioplastics market by 2011.

Bioplastic manufacture in the UK

The bioplastics industry is a fledgling activity in the UK with only a few resin manufacturing sites. There are two facilities that manufacture cellulose acetate from wood pulp and at least one manufacturer of dried starches produced from local wheat suitable for bioplastics. Other starch producers in the UK focus on the manufacture of high dextrose (glucose) syrups for food and beverage production. A feasibility study has recently shown that it may be commercially viable to manufacture polylactic acid (PLA), one of the most commonly used bioplastics, from home-grown cereals in the UK. This development may be fundamental in building a bioplastic industry in the UK and may provide a new market for the UK farming industry.

HGCA role in developing a UK bioplastic market

HGCA has a long-term commitment to developing the market for home-grown cereals and oilseeds in industrial applications such as biofuels and bioplastics and currently funds the R&D and market development of many industrial uses projects. For example; Cambridge Biopolymers, a HGCA Enterprise Award winner, has developed a renewable biopolymer resin based on oilseed rape oil which is suitable for a number of applications that currently use petrochemical-based resins. HGCA also funds research into the production of eco-composite materials from wheat starch and straw.

Looking forward, HGCA plans to expand its industrial uses activities to help develop innovation in the bioplastics industry and, in particular, to facilitate end of life disposal systems that will capture the full benefits of bioplastics.

Marketing activities will include:

- Continued support for companies to develop novel bioplastic uses
- Work with manufacturers and retailers to develop supply chains
- Participation in a UK PLA manufacturing thematic working group
- A supply chain symposium with speakers from each industry sector
- Presentations to the farming community on new market opportunities

HGCA will also contribute to:

- Trials for the disposal routes of mixed bioplastics
- A supermarket survey of bioplastic usage
- A Non-Governmental Organisation attitude survey on biopolymers
- A survey of Local Authority and service company attitudes to biopolymers

Research and development activities will include:

- Ongoing support of Defra LINK renewable materials projects
- A report on the disposal best practices for bioplastics

1.0 Introduction

The Oxford English Dictionary defines a polymer and a plastic as:

Polymer - A substance with a molecular structure formed from many identical small molecules or other units bonded together {1}.

Plastic - A synthetic material made from a wide range of organic polymers such as polyethylene, which can be moulded into shape while soft and then set into a rigid or slightly elastic form{1}.

Biopolymer - A polymer derived from renewable biomass.

Bioplastic - A plastic made using biopolymers with or without oil-based polymers.

"Polymers and plastics, what would we do without them?"

In this modern, fast paced world we take for granted our reliance upon plastics for everyday packaging, storage and construction products. In fact, farming would be a lot harder without plastics. They provide a good means of silage feed storage, fertiliser and chemical containment and are useful for machinery parts and weatherproofing.

Plastics take on a simple form and function in the eye of the consumer. However, they are actually complex materials which have to provide highly specified functional properties. This is exemplified in food packaging where specific light, temperature and moisture resistance properties may be required. Also, in the factories that make, process, package, recycle and recover plastics there are strict technical requirements and government regulations to adhere to.

Plastics are vital, but they do present challenges: What do you make them out of and what do you do with them at the end of their useful life? Currently we make most of our plastics out of by-products produced from the process of refining oil (around 2% of a barrel of crude oil{2}).

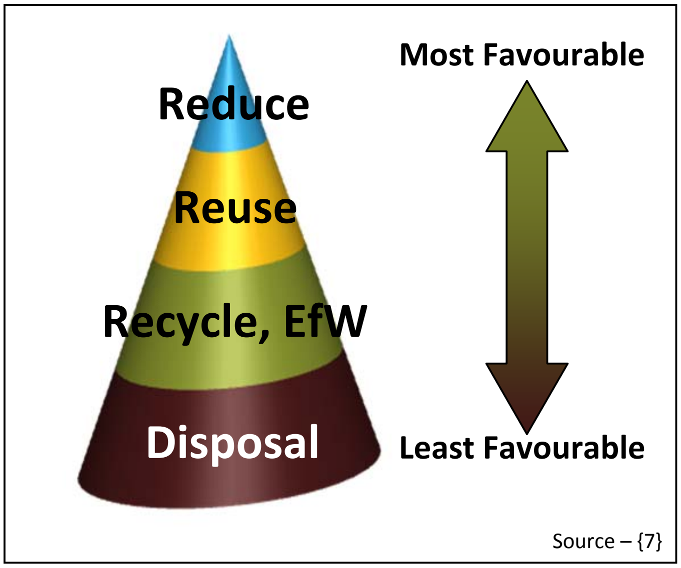
This means we essentially rely upon non-renewable carbon sources for plastics. Such carbon sources have received a bad press because of the global warming potential of their combustion/breakdown products such as carbon dioxide and methane (CO_2 and CH_4). In addition, petroleum-based plastics (petroplastics) are considered non-environmentally friendly because they are not renewable and some persist in the environment.

At the moment the world consumes over 260 million tpa of plastics. Europe consumes approximately 53 million tpa and, specifically, the UK consumes around five million tpa of plastics {3;4}.

Plastic production creates waste and CO_2 emissions, so any means of reducing the environmental impact of plastics is being welcomed by governments, manufacturers and, importantly, consumers. Plastics made from renewable materials may help reduce GHG emissions and may also supplement the current petroplastics market.

Recently, plastic environmental pollution has come to the media forefront. In February 2008 The Daily Mail led a campaign called 'Banish The Bags' to end the use of free plastic shopping bags {5}. In the same month the Independent newspaper published an article on "The World's Rubbish Dump" after research performed by Charles Moore, a US marine researcher, identified a large mass of swirling rubbish in the Pacific Ocean off the coast of California {6}. It is therefore important to carefully consider the management options for wastes (including bioplastics) to reduce their environmental impact. However, it is also imperative that other resource management opportunities are considered such as reducing and reusing packaging materials. Figure 1.01 shows the Waste Framework Directive (EC regulation 2006/12/EC) 'pyramid model' situation that the UK is in now where waste is mainly disposed of through landfill with diminishing focus on recycling, energy from waste (EfW, e.g. incineration), reuse of materials and reduction of waste. In future there will be a move to a model where waste prevention is maximal and waste disposal is minimised {7}.

Figure 1.01 The Waste Framework Directive Pyramid Model



Source – {7}

Biodegradable bioplastics may help towards the goal of a cleaner and greener environment because they are made using renewable materials such as starch/sugars, vegetable oil and wood pulp. Using renewable feedstocks for plastic production can reduce the amount of global warming greenhouse gasses (GHGs such as CO_2 and CH_4) released into the atmosphere when compared to conventional plastic production from fossil fuels. In addition, biodegradable bioplastics break down in the environment and are clearly not as persistent as conventional non-degradable petroplastics.

Biodegradable bioplastics should not be confused with degradable plastics currently available. Degradable plastics, or 'oxo-degradable' plastics, are usually conventional petroplastics impregnated with a catalyst that breaks down the polymer in the environment by chemical means. Products of this break down are usually small plastic fragments and CO_2.

At the moment bioplastics are marketed mainly upon their green environmental credentials, but the bioplastics industry is a fledgling activity and currently has low production volumes and high polymer prices.

In 2007 Europe consumed nearly 53 million tonnes of conventional petroplastics, but only around 60-100 thousand tonnes of bioplastics. This equates to about 0.1-0.2% of the European plastics market {3;4}.

Currently, bioplastics are mainly used for packaging high-value organic foods. In future there could be mainstream expansion into packaging of all foods requiring plastic containers. Several companies have invested in research into using bioplastics for electronics housings, car components and recordable media such as CDs and DVDs (see appendix section 11.1) {8;9;10}. This shows that there is significant interest and room for growth in this environmentally-friendly industry.

So where do UK farmers fit in? At the moment bioplastics are mainly derived from maize starch or sugars, potato starch, soya bean oil, wood pulp and cotton cellulose. In principle wheat starch or oil seed rape oil could be utilised more as feedstocks for bioplastic production. HGCA is engaged in promoting the use of bioplastics in the UK because they offer an opportunity to increase the use of UK cereals and oilseeds in industrial applications.

At the moment there are few specific regulations relating to the production of bioplastics. The most widely cited requirement is the EN 13432 European standard which outlines the length of time a bioplastic should take to biodegrade if it is to be described as 'compostable' (see glossary for definition) {11}. Packaging regulations such as the 94/62/EC (2004/12/EC) Packaging Directive provide EU recycling targets (see appendix section 11.2) but, they place an onus on the packaging manufacturer to reduce material use and recycle more {12;13}. However, on the flipside, such regulations provide a competitive advantage to packaging companies if they are seen to be more environmentally-friendly. Also, regulations like 94/62/EC boost consumer confidence that the packaging they receive is the most efficient use of materials available and that the producers are environmentally responsible businesses.

When bioplastic products come to the end of their life they can be disposed of in a variety of ways including composting, landfill, mechanical biological treatment (MBT) and EfW options such as anaerobic digestion, gasification, incineration and pyrolysis (see glossary for definitions). All of these end-of-life options have advantages and disadvantages. For instance, in the UK we do not possess a fully developed infrastructure to dispose of bioplastics through recycling, composting, incineration, pyrolysis or gasification. In some instances bioplastics present a challenge to the recycling industry because they can contaminate existing petroplastic recycling streams causing the production of inferior recycled material {14}. However, if bioplastics are labeled clearly and comprehensibly to enable efficient consumer (or local authority) sorting for recycling, there are appropriate methods of recycling some of them.

The 1418/2007/EC European regulations on waste export for recycling provide a barrier against exporting recyclable bioplastics, whereas they promote the use of compostable bioplastics {15}. This is because 1418/2007/EC promotes more communication between sorting facilities in the UK and foreign recycling companies to ensure that waste is processed correctly abroad. As a result of regulation 1418/2007/EC in combination with a volatile market for their products, plastic sorting facilities in the UK may be reluctant to export their sorted materials {16}. This is a driver for the use of compostable bioplastics because they can be industrially composted here in the UK. Composting in the UK predominantly consists of aerated static piles (ASPs), or 'windrows' that, if not properly aerated, can release methane (CH_4, a GHG 23 times more potent than carbon dioxide {17}) into the atmosphere. In addition, ASP composting may not always reach temperatures high enough to biodegrade certain bioplastics. However, in-vessel composting facilities (IVCs) have tighter control over temperature and aeration conditions and may cope better with bioplastics {18}. At the moment the majority of composting companies are currently reluctant to take bioplastic materials that are not labeled properly or material batches that are not guaranteed to be non-degradable petroplastic-free. However, enclosed windrow composters and IVC facilities will take food and green garden waste wrapped in starch-based bioplastic bags for composting. In addition, incineration may be seen as an indirect driver for the use of biodegradable bioplastics because composting diverts bioplastics away from incinerator plants that are reluctant to accept high levels of plastic waste in the first place. With regard to landfill, Europe is focused on redirecting biodegradable materials from landfill to composting, AD or MBT facilities in an attempt to reduce methane emissions. This is dictated by the 1999/31/EC Landfill Directive which serves as an indirect driver for the use of bioplastics because they may be diverted to composting sites or recycling facilities {19;20}.

A final and significant driver for adopting bioplastics is high crude oil prices. Since petroplastics are made from oil their price follows crude oil price trends. As mentioned earlier, bioplastics are currently produced on a small scale and are, as a result, expensive, but if petroplastic prices are high they will become competitive.

Demosthenes, an Athenian politician (384-322 BC), once said **'small opportunities are often the beginning of great enterprises'**. Certainly, the bioplastics industry is only in its infancy at the moment, but it does have the potential to expand its market territory. In the future, UK arable farms could have the opportunity to supply this fledgling industry with feedstock.

2.0 Market drivers for bioplastics

Bioplastics offer a wide range of properties that will help their penetration into the plastics market. Principally, they offer superior environmental benefits over petroplastics and different desirable functional properties which may help reduce our reliance upon fossil fuels. UK and EU legislation promotes the use of biodegradable and recyclable bioplastics because they offer an opportunity to reduce the amount of waste sent to landfill and also assist an increase in the level of composting, energy from waste (EfW) generation and recycling. Certain disposal routes such as incineration and export of plastics also offer indirect drivers for the use of bioplastics. Furthermore, companies are realising they have a commitment to help the environment through their Corporate Social Responsibility (CSR) schemes. This code of practice may help boost the use of products made from renewable bioplastics. Finally, consumers themselves are a driver because they are becoming more aware of bioplastics and their environmental benefits.

2.0.1 Environment

In this day and age consumers are more concerned about their environmental impact. One of the main reasons why bioplastics are becoming popular as an alternative to petroplastics is the environmental advantages they offer:

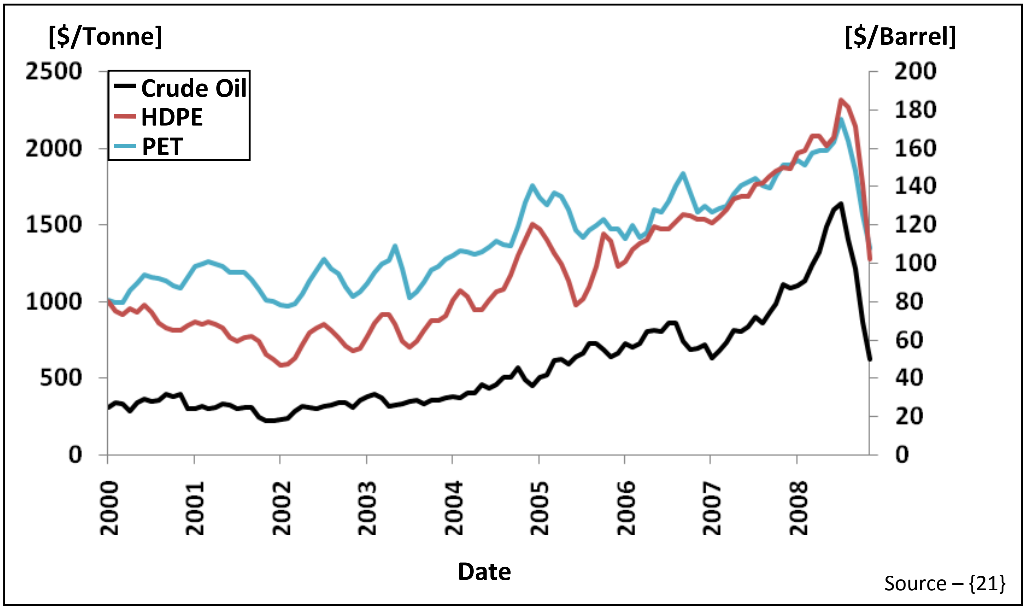
1. made from renewable resources
2. lower carbon footprint
3. biodegradable
4. compostable

(for definitions see glossary)

2.0.2 Oil supply

With an ever increasing demand for fuel, diminishing stocks and ease of their extraction and political turmoil, the price of crude oil has risen dramatically in recent years from around $30 at the turn of the 21st century peaking at above $130 per barrel (OPEC monthly average) in July 2008. Note that at the time of writing oil prices had slumped to $50 per barrel in November 2008 (see figure 2.01) {21}. This price volatility is an issue especially for the manufacture of petroplastics since they are made from the by-products of refining crude oil {2}.

Figure 2.01 OPEC Crude Oil and European Petroplastic Resin Prices



Source – {21}

64 out of 98 oil producing countries are thought to have reached and/or passed their peak crude oil production volume (peak oil) {22;23}. As a result it has become more economically attractive to consider bioplastics as a supplement to, and potential replacement for, petroplastics. However, pricing of the current leading source of starch and sugars for bioplastics production, maize, is also linked to the price of oil and must be taken into account when considering the economics of producing bioplastics from corn/grain feedstocks.

2.0.3 Technical properties and functionality

Many plastic items require precise specifications and precision manufacturing. For example, food packaging requires strict adherence to European guidelines regarding food contact (2005/79/EC) and may need to have a complex range of properties such as [24].

1. breathability – to allow gas exchange
2. heat resistance – to maintain shape and containment when heated
3. impact stability – to maintain containment and structure when dropped
4. optical clarity – to see the product contained within
5. rigidity – to maintain structure under strain such as vacuum pressure
6. strength – to allow carriage of a product without loss of product or package structure
7. water resistance – to prevent product absorption or loss of water

Another factor considered in packaging design is how to minimise the amount of plastic used without compromising structure or performance. For instance, the Coca-Cola company (UK) managed to reduce the amount of polyethylene terephthalate (PET) in their plastic bottles by 8% without compromising performance [25].

A good example of the sophisticated nature of modern packaging is the containment of coffee. Freshly roasted coffee naturally emits carbon dioxide (CO_2) and becomes stale in the presence of oxygen (O_2). As a result, coffee packaging must be permeable to CO_2 to prevent package swelling, but also be impermeable to O_2 to prevent coffee oxidation [26]. The composition of flexible coffee bags can consist of five layers, each providing different functional properties. For example, an inner polyethylene (PE) layer to enable heat sealing, a secondary metal layer as a gas barrier, a layer of PET for strength, an ink print layer and an outer print protective layer [27]. Finally, the gas exchange properties of a flexible coffee bag are normally controlled by an integrated one-way filter that allows CO_2 out and prevents O_2 entry. Another instance where the gas exchange properties of packaging materials are important is in modified atmosphere packaging (MAP) where packaging air is replaced with gasses such as CO_2 or nitrogen (N_2). MAP is usually applied to meat and dairy products, that are easily spoilt by O_2 and the growth of micro-organisms, in an attempt to slow spoilage and increase food shelf life [28].

Recently there has been a trend towards packaging fruit and vegetables to extend their shelf-life and reduce wastage. For example, wrapping a cucumber in plastic extends its shelf-life from three days to two weeks [29]. Similarly, tomato ripening can be delayed and shelf life extended by wrapping the fruit in plastic such as polyvinyl chloride (PVC) [30]. If fruit and vegetables are wrapped in compostable bioplastic they can be disposed of by composting, if they become spoilt or unsaleable. So bioplastic in this application not only extends shelf-life, but also makes disposal easier as there is no plastic waste to be collected for recycling.

There are a variety of different bioplastics available with varying properties suitable for packaging. For example, cellulose acetate (CA) films produced from wood pulp are available in laminates or with coatings that allow different moisture barrier properties for different food items (see appendix section 11.1) [31].

2.0.4 Consumer acceptance

Surveys have shown that consumers are prepared to buy items containing or wrapped in bioplastics based on their green environmental credentials {32}. However, the Waste and Resources Action Programme (WRAP) found that there is poor consumer understanding with regard to the terminology and disposal of bioplastics. Another noteworthy point is that care must be taken to ensure the right packaging is used to contain items since the wrong bioplastic material (e.g. a hazy film bag) may put off consumers from purchasing certain items due to poor product appearance.

2.0.5 Corporate Social Responsibility and PAS 2050

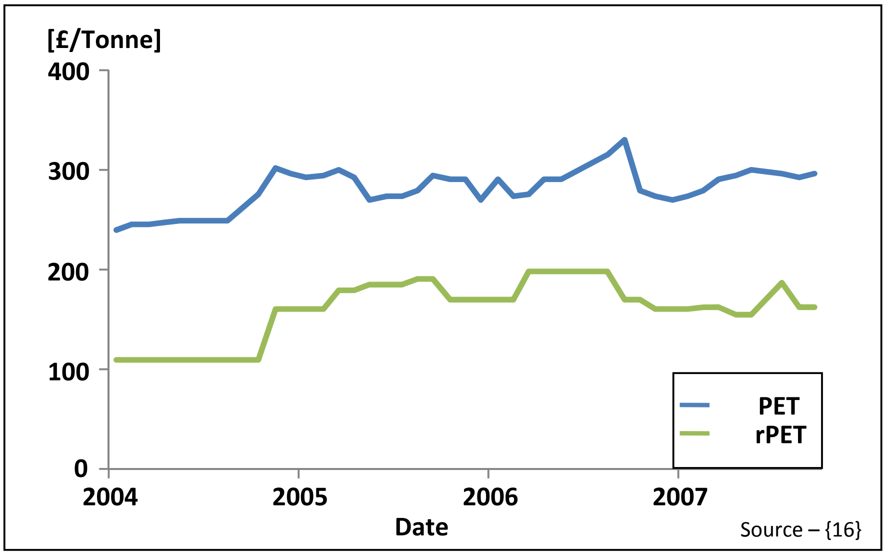
Corporate Social Responsibility, or CSR, is a voluntary code requiring businesses to report on their activities in areas such as environmental performance. In 2005 the government launched the UK sustainable development strategy which provides advice to companies on how to help mitigate climate change and help the environment {33}. Awards are given out by the EC every two years for companies that have made significant contributions to sustainable development. If a greater number of companies report their environmental impact then more may seek to use products (such as plastic packaging) manufactured from renewable resources.

A recent development in legislation produced by the British Standards Institution (BSI) is the Publicly Available Specification (PAS) 2050 funded by the Carbon Trust and Defra {34}. PAS 2050 offers a means of assessing and reporting the GHG emissions of goods and services in the UK in the form of a life cycle assessment (LCA). The PAS 2050 LCA covers either GHG emissions of the whole life cycle of a product (business to consumer) or the life cycle of a product up to the point where it forms an input to a second business (business to business). PAS 2050 also incorporates an assessment of GHGs released by direct land use change related to agricultural feedstock production. PAS 2050 has been formulated for communication purposes and to allow the comparison of GHG emissions between products. However, PAS 2050 does not require communication of results, but it does allow reporting of GHG emissions of supply chains to stakeholders and consumers as part of company CSR commitments. This legislation is to be ratified in 2009 and will help increase the sustainability of products and services in the UK {34}.

2.0.6 Plastic pricing

The cost of virgin (new) plastic resin follows the general trend of oil prices (see figure 2.01) because by-products of the petroleum distillation process (such as naphtha) are key ingredients for the production of plastic polymers {2}. A WRAP report on the price relationship between virgin and recovered plastics found that recycled plastics tend to follow the price pattern of virgin resins, but at a discounted level (see figure 2.02) {16}. In fact, average PET and recycled PET (rPET) prices in October 2008 were around £1,140 and £738 per tonne, respectively {35}. Sorted post-consumer plastic prices also follow the same backbone virgin resin price {16}. This close correlation between oil, virgin resin and recycled plastic prices can impact the profitability of companies involved in recycling. For example; when oil prices are high, the price of recycled plastic is also relatively high (see figure 2.01). Since processing costs remain the same, higher profits are made from recyclate when oil prices are high. Conversely, when oil prices are low, recycling companies struggle to make a profit and stockpile material until prices gain momentum again. This volatile market offers opportunities for price protection to ensure that costs are managed effectively.

Figure 2.02 Virgin and Recycled PET Plastic Prices



Source – {16}

Business planning for the plastics industry can include hedging measures. These work to protect exposure to changes in underlying raw material prices by using futures to effectively fix the price to be paid for raw materials (such as naphtha or crude oil) over a defined period, or using options, to fix a maximum price while insuring against a future market decline. Using these tools can thereby reduce the risk of a price spike in advance of purchases, or a price drop subsequent to buying raw materials. This raw material price protection will offer recycling companies a degree of profit stability since relatively constant oil (or naphtha) prices will result in similar trends in virgin resin prices and, therefore, recycled plastic prices.

At the moment bioplastics are two to four times more expensive than equivalent petroplastics which is a barrier to their expansion into the plastics market {21;36}. One way in which economies of scale could be achieved to counteract high bioplastic prices is through an 'obligation' scheme requiring companies to use a certain amount of bioplastic material in their products. A current example of this is the Renewable Transport Fuel Obligation (RTFO) requiring fuel companies to supplement petrol and diesel with 2.5% bioethanol and biodiesel (by volume), respectively (3.25% for 2009/2010){37}.

However, bioplastics have good environmental credentials and, in some cases, improved functionality which some consumers are willing to pay for {32}. A factor (besides energy prices) governing the price of bioplastics is the variable cost of grain feedstocks {38}. Price fluctuations in the grain market (see figure 2.03) can arise from a number of issues such as variable annual crop yields, grain quality demand and the availability of grain buffer stocks. This means that if grain prices are high due to low supply and high demand then bioplastics may be less competitive with conventional petroplastics.

Inevitably for there to be real competition between bio- and petroplastics the bioplastics industry must gain more market share. What is apparent is that cereal prices are highly variable at the moment (see figure 2.03) which may not help reduce the price differential between bio- and petroplastics. This price volatility can be managed in a similar way to the plastic price protection described above through trading in soft commodity futures and options. In addition, the price of oil, virgin and recovered plastics is currently volatile (see figures 2.01 and 2.02) {16}. This is problematic for MRFs and re-processor businesses because they require investment from sales of their recycled products to deal with new polymers such as recyclable bioplastics.

Figure 2.03 LIFFE Wheat Futures Prices

Source – {38}

2.1 Legislative drivers for bioplastics

2.1.1 Packaging regulations

In Europe the Packaging and Packaging Waste Directive (94/62/EC amended by 2004/12/EC) sets out to reduce packaging and encourage more recovery and recycling of materials {12;13}. In the UK the 94/62/EC Packaging Directive is implemented through the Packaging (Essential Requirements) Regulations 2003 (see section 3.0.3) and the Producer Responsibility Obligations (Packaging Waste) Regulations 2005 {39}. This producer responsibility legislation sets out that businesses with a turnover greater than two million pounds sterling and utilising 50 tonnes of packaging per year are obliged to contribute to EU recycling targets (see appendix section 11.2). This commitment can be fulfilled by a company itself, by subcontracting to a waste processor or through a Producer Compliance Scheme (PCS) where a waste company takes on the recycling responsibilities (the packaging company itself does not hold any responsibility for organising recycling in this case) {39}.

Obligated companies (or PCS companies) must give evidence of their recycling commitment to the Environment Agency in the form of Packaging (waste) Recovery Notes (PRNs) or Packaging (waste) Export Recovery Notes (PERNs). These certificates are given out by accredited re-processors or exporters to companies that fulfil their recycling obligation. However, companies that fall short of their obligation can purchase certificates from a re-processor or exporter to present to the Environment Agency as proof of compliance with their obligation {39;40}. It must be noted that PRN and PERN prices vary depending on the market supply of certificates and the material type they cover. The use of recyclable bioplastics will help earn PRN or PERN certificates for companies that meet their recycling targets. Importantly, there is no specific category of PRNs (or PERNs) for bioplastics. Currently, the Environment Agency recommends that bioplastics containing starch as the major component should be classed in the 'paper' category costing £4-7 per tonne for each PRN (or PERN) (March 2009). Alternatively, bioplastics containing predominantly petroplastic should be placed in the 'plastic' category costing £24-28 per tonne for each PRN (or PERN) (March 2009). Clearly, disposal of packaging classed as 'paper' is considerably cheaper than for packaging classed as 'plastic'. If bioplastics fit into the 'paper' category, the lower PRN (or PERN) price is a driver for using them in packaging (for PRN prices see appendix section 11.2) {41}.

2.1.2 The Landfill Directive, Landfill Tax (LAX) and the Landfill Allowance Trading Scheme (LATS)

The European Landfill Directive (1999/31/EC) {19} aims to: 1) reduce biodegradable waste in landfill; 2) pre-treat waste (promoting recycling and composting); 3) prevent hazardous and non-hazardous wastes from being co-mingled; 4) force the polluter to pay for waste disposal at deposition sites. Bioplastics, which can be recycled and/or composted (depending on the type of polymer), may play an important part in the reduction of biodegradable waste deposition at landfill sites.

Landfill tax (LAX) is an important financial factor in waste disposal and was introduced in 1996 in an attempt to reduce landfill waste. It is currently (2009) pitched at £40 per tonne and is set to rise by £8 per tonne each year until at least 2010/2011{42}. Importantly, LAX may provide an indirect driver for bioplastics since they can be composted or recycled and, therefore, do not incur the extra LAX charge upon disposal (see section 3.1).

In 2005 the Landfill Allowance Trading Scheme (LATS) was introduced by the UK government in an attempt to help meet targets put forward by the Landfill Directive for reducing biodegradable waste sent to landfill (see appendix section 11.2) {19;43}. Under this scheme each UK local authority is given an annual landfill allocation which decreases year on year. If a local authority has a surplus landfill allowance, it can trade this allowance with other local authorities that exceed their allocation. Local authorities can also save up their surplus allowance as long as it does not affect their landfill target of a 'target year'. In addition, local authorities can borrow up to 5% of the allowance of a following year {43}. At the end of each year local authorities have to declare their landfill tonnage to the Environment Agency. If a local authority exceeds its target for a year it can buy or borrow allowance. However, if a local authority cannot meet its landfill target (by any means) it will incur a charge for every tonne over its allowance. This scheme allows flexibility to meet Landfill Directive targets and, with year on year allocation reductions, it also acts as an incentive to use materials that are suitable for composting and recycling such as bioplastics.

2.1.3 PAS 103

The Publicly Available Specification (PAS) 103 waste log is a document introduced in the UK to provide more information about sorted recyclable material to re-processors {44}. It details the level of visible contamination of plastics (sorted by polymer type) with: 1) labels; 2) other plastics; 3) other waste; 4) water. Its aim is to help ease and increase sales between MRFs and re-processors. This is a driver for using recyclable bioplastics (such as PLA) because more information about the product that re-processors are buying will push up prices of post-consumer recyclable plastic waste.

2.1.4 The plastics export 'green-list'

The European 1418/2007/EC regulations provide a list of export material wastes that are either prohibited, require prior consent or do not require controls in the country of destination {15}. In addition, the waste exporter is required to find out where and whether their export materials can be recycled. Importantly, material recovery must also be performed in an environmentally sound manner and all wastes exported must be well documented {45}.

China is one of the major receiving countries for UK sorted post-consumer plastics and on March 1st 2008 a group of five Chinese state organisations produced two catalogues of plastic materials prohibited and restricted from import into China under a bill called Notice 2008 No. 11 {46}. Regulations such as 1418/2007/EC and Notice 2008 No. 11 deter MRFs from selling their products for export because higher quality sorted material is required, more paperwork has to be completed and some materials cannot be imported into certain countries (such as China). The knock-on effect is that pressure is put on UK infrastructure to deal with its own waste. This pressure is a driver for using bioplastics because they offer several avenues for local disposal such as anaerobic digestion, home composting, industrial composting, recycling and EfW options (assuming investment in local infrastructure will be made) (see glossary).

2.1.5 Packaging producer responsibility

Currently the UK places an obligation on packaging producers to help meet recycling targets (see section 2.1.1). This scheme is outlined in the Producer Responsibility Obligations (Packaging Waste) Regulations 2005 (amended 2007 and 2008) {39;47;48}. However, this scheme does not directly inform the consumer (through labeling) that a particular packaging item has been made by a company contributing to UK recycling targets.

In Germany companies have to pay for releasing packaging products onto the market. This scheme is monitored by Duales System Deutschland (DSD) and is called the 'Green Dot' system (Der Grüne Punkt, see figure 2.04). DSD works with German local authorities to collect recyclable materials and contracts companies to manage recovery and delivery of these materials to sorting facilities. DSD also pays recycling companies to accept recyclable materials {49;50}. This system, theoretically, reduces the amount of waste produced by minimising the amount of packaging released onto the market. As a result of this funding initiative, Germany has a well established plastics recycling infrastructure. Importantly, since 2005 the German Packaging Ordinance (GPO) has made bioplastics and biodegradable materials 'Green Dot' fee free as long as companies contribute to the German waste disposal infrastructure {51;52}. Currently, packaging companies in the UK can use the 'Green Dot' logo on their products if they pay a licence fee to Pro Europe S. P. R. L. (trademark owners for Europe excluding Germany). However, curiously, the symbol does not indicate that the company in question has met the recycling targets under the Producer Responsibility Obligations (Packaging Waste) Regulations {53}.

The UK uses a similar system (see section 2.1.1), but there is no PRN (PERN) fee exemption for bioplastics. Starch bioplastics are classed as ‘paper’ in the current PRN (or PERN) system providing an incentive to use bioplastics made from starch, but it is not clear whether starch-derived bioplastics such as PHAs and PLA (see appendix section 11.1) fit into the ‘paper’ category. Clearly, a list of bioplastic materials and the PRN (PERN) categories to which they belong should be drawn up to ease this confusion. It is noteworthy that the UK could make biodegradable bioplastics PRN (PERN) fee free (like the ‘Green Dot’ system) to provide an incentive to packaging companies to use these materials. However, the absence of fees would not help develop the infrastructure for bioplastic disposal. Clearly, if the UK adopts PRN (PERN) fee exemption for bioplastics, there is a need for legislation to ensure that companies that release bioplastic packaging onto the UK market still contribute to disposal infrastructure development.

Figure 2.04 Der Grüne Punkt

Source – {53}

In France the ‘Decret Lalonde’ is an obligation for companies to share responsibility for the disposal of packaging materials. French local authorities have responsibility for setting up infrastructure for recycling. However, this is funded by a levy on the companies that bring packaging to the French market. Under this legislation companies must organise a return system for packaging, set up their own collection and recycling scheme or contribute to an approved scheme such as ‘Point Vert’ (the French Green Dot scheme). The current French ‘Point Vert’ scheme is organised by Eco-Emballages (eco-packaging) SA and has been operating since 1992 {50}. Packaging producers, fillers and distributors pay a packaging levy to Eco-Emballages SA. The levy consists of a flat-rate fee with additional charges for the amount and type of packaging added where necessary. The UK could adapt its legislation to incorporate a charge for placing packaging onto the market based on its detailed material composition. This may, in turn, help improve investment in UK recycling infrastructure.

In the Netherlands there is a packaging tax law that stipulates that any organisation releasing more than 15 ktpa of packaging waste onto the market must pay a tax {54}. Tariffs vary depending on the packaging type and material and are linked to the adverse effects material production has on the environment in terms of GHG release {51}. If the UK were to adapt its legislation to include a GHG factor in its PRN system, bioplastics with lower life cycle GHG emissions would benefit from a lower tax rate providing a driver for their use.

2.2 End-of-life option drivers for bioplastics

Bioplastics are marketed on their renewable, sustainable and compostable credentials worldwide, but little information on how to dispose of them is made public. Currently, UK consumers who participate in recycling have to decipher a plethora of different packaging labels that indicate the recyclability/compostability of materials (discussed in section 4.0). They are also given little information in terms of how to segregate their waste for collection by local authorities. In addition, local authorities do not have nationwide standard procedures for the collection of recyclable/compostable materials (see section 3.0.4). Clearly, more information and standardised national collection procedures are required to help increase recycling and composting rates in the UK.

There are several options for the disposal of bioplastics after their use including anaerobic digestion (AD), composting, gasification, incineration, landfill, mechanical biological treatment (MBT), pyrolysis, and recycling. Each method has its advantages and disadvantages, but all (except landfill) offer significant drivers for bioplastic use (see section 5.0 and glossary).

Plastic recycling in Britain has historically concentrated on plastic bottles due to their relatively high density {16}. Certain bioplastics such as PLA are used for plastic bottles and will enter this recycling stream. PLA can be recycled, but it has to be carefully separated from PET to prevent contamination of recycled PET (rPET). If PLA continues to penetrate the UK plastics market, and provided that it is separated properly from other plastics, it will help contribute to meeting UK recycling targets (see appendix section 11.2) providing a driver for its use. Similarly, if mixed post-consumer plastics are processed in future then other bioplastics may enter the recycling and composting streams rather than entering landfill. In this way mixed plastics recycling will act as a driver for bioplastic use. Currently, most post-consumer sorted plastics are exported for recycling {16}. Exporting recyclable materials acts as a driver for using recyclable bioplastics because it provides an end market for materials sorted in the UK (see section 5.0.2).

Bioplastics are marketed as compostable materials worldwide. However, the UK has a limited infrastructure for dealing with these materials (see section 5.0.3). Composters in the UK currently accept green and food waste bags made from starch/petroplastic hybrids. This acts as a driver for bioplastic use, but it must be noted that few other bioplastics are accepted unless they are labelled as compostable. Anaerobic digestion, the biodegradation of organic matter in the absence of air (see section 5.0.4 and glossary), is a driver for bioplastic use since it provides a means of disposing of bioplastics (contaminated with food waste) and produces methane fuel for energy production.

Energy from waste (EfW) options such as gasification, incineration and pyrolysis all offer drivers for bioplastic use. For instance, bioplastics disposed of by incineration with biomass such as wood have a ‘neutral’ carbon footprint because all the materials burnt originate from a renewable source (see section 5.0.6). Bioplastics may also be disposed of by gasification and pyrolysis (see section 5.0.6 and glossary) providing a driver for their use.

3.0 Barriers faced by the bioplastics industry

There are a number of bioplastics with great potential to compete in a wide range of petroplastic dominated applications. However, petroplastics have been developed and used for over 70 years and are relatively cheap when compared to bioplastics.

Ideally, to compete with petroplastics, a bioplastic should be environmentally-friendly, sustainable, inexpensive and functionally equivalent. Usually bioplastics are both environmentally-friendly and sustainable, but they are still relatively expensive and they cannot replace petroplastics in some applications. However, it is important to note that some bioplastics have novel functional properties (e.g. starch foams exhibit better anti-static properties when compared to petroplastic foams).

3.0.1 Cost

Currently bioplastics are, on average, two to four times more expensive than conventional plastics {21;36}. Some causative factors include: 1) high cost of polymer plant construction; 2) high cost of raw materials; 3) current small scale of production; 4) high research and development costs. There are currently a few options that will help penetration of bioplastics into a petroplastic dominated market. Economies of scale for bioplastic production may be achieved through an 'obligation' scheme (see section 2.06) when petroplastic prices are low and bioplastic prices are high. Conversely, if petroplastic prices are high due to high oil prices the differential between petroplastic and bioplastic prices is likely to narrow. If price competitiveness is realised then more packaging and product manufacturing companies may be enticed to use bioplastics.

3.0.2 Functional properties

Packaging materials can be extremely complex and may sometimes have stringent property requirements (such as gas permeability). At the moment the range of backbone biopolymers available is still fairly limited compared to the plethora of petroplastic polymers currently available. This means that bioplastics are not suitable in all plastic applications. Thus for example, some bioplastics have a low melting temperature, low transparency and some are quite brittle. It is important to note that if the properties of bioplastics are not fit for the purpose of a particular application they will not be used. However, hybrid bio/petroplastics may overcome some of the issues encountered in using bioplastics on their own (see appendix section 11.1). As new biopolymers are developed and improved it is possible they will have the requisite functional properties. For example; first generation polylactic acid (PLA, see appendix sections 11.1 and 11.3) contains a mixture of so-called 'isomers' or forms called PLLA and PDLA. This mixture makes the structure of first generation PLA more amorphous (random) and relatively unstable when compared to pure PLLA. In short, pure PLLA is more stable at higher temperatures than 'mixed' first generation PLA making PLLA a more attractive polymer for applications that require moderate heat tolerance {55}.

Another point to note is that for certain products bioplastics may be functionally ideal, or even superior to petroplastics. However, the manufacturing plant using the bioplastic resin may require adaptation (e.g. replacement of foam extrusion screws) or a complete refit in order to function efficiently. This is a barrier, but most of the biopolymer manufacturers adapt their products so that they can be run on traditional moulding/extruding equipment with few setup alterations.

3.0.3 Packaging requirements

The UK government has introduced specifications for packaging materials outlined in a document called Packaging (Essential Requirements) Regulations originally produced by the Department for Trade and Industry (DTI) {56}. This document forms part of the UK commitment to the European Packaging Directive 94/62/EC (amended 2004/12/EC) {12;13} and stipulates that packaging manufacturers must: 1) ensure packaging volume and weight is minimal, but high enough to maintain levels of safety, hygiene and consumer acceptance; 2) packaging must be manufactured to permit reuse or recovery; 3) noxious or hazardous substances in packaging must be minimised so that emissions, ash and leached chemicals are also minimal at end-of-life processing. The regulations also outline the levels of heavy metals that should not be exceeded in packaging materials.

It is clear that packaging regulations including the 94/62/EC (amended 2004/12/EC) Packaging Directive (see section 2.1.1) can be a barrier to using new materials such as bioplastics because of the costs to companies, both in time and money, to approve new packaging for the EU market {12;13}.

3.0.4 Mixed plastic segregation and collection

When plastic items have been used (and reused) it becomes important to be able to distinguish what the materials are and to separate them into polymer types so that the appropriate recycling or composting procedures can be applied to them. This separation process is split into two levels: 1) consumer door-step waste sorting; 2) local authority waste sorting (kerb-side and/or MRF sorting). The first level is typically separation of plastics from other recyclable and compostable materials. However, with the advent of compostable food and green waste bags, bioplastics may be left in with organic waste collections. The second step is more complex requiring specialised sorting equipment and trained personnel.

Sorting of materials for recycling and composting on the consumer doorstep is complicated. The issues include: 1) a lack of kerb-side recycling collection; 2) a lack of willingness to separate waste; 3) confusion about what to do with materials; 4) a lack of awareness of new material types such as bioplastics.

At the local authority level there are several issues affecting the use of bioplastics. In April 2008 WRAP produced a local authorities plastics collection survey (of bottles) detailing the top concerns and barriers preventing mixed plastic recycling {57}. At the kerb-side the major issue preventing expansion of collections into mixed plastics was the lack of space on vehicles. The study also identified the following as key causes of problems: 1) operational aspects; 2) finding a recyclate market (usually exported to China); 3) recyclate quality; 4) volatile recyclate market; 5) scheme expense.

WRAP also asked local authorities what the ‘off-putting’ factors for mixed plastic recycling were {49}. Their results showed that the major barrier was the lack of a UK market for recyclate and that local authorities were reluctant to export their product. Other inhibitory factors included: 1) the lack of a suitable baling/handling facility; 2) high scheme cost; 3) challenging scheme operation; 4) a volatile recyclate market with concerns of what to do with the material if a downturn in exports is experienced; 5) difficulty to meet recycling targets using low density mixed plastics (concentration on higher density bottle processing).

3.0.5 Mixed plastic sorting and processing

At the moment sorting plastics into their different polymer types is a difficult process and involves several stages of segregation. In June 2008 WRAP produced a report indicating the feasibility of recycling non-bottle mixed plastics {49}. Table 3.01 gives a generic representation of mixed plastic waste studied by WRAP and identifies that there are several possible combinations of polymers and physical forms even with the exclusion of most plastic bottles.

Table 3.01 Generic Polymer Composition of Mixed Plastic Waste

Polymer Type		**Generic Composition [%]**
Flexible	PE	25
	PP	5
Rigid	PP	17.2
	PE	13.5
	PET	15.3
	PVC	3.5
	PS	4
Non-Plastic Contamination		16.5
Total		100

Source – {49}

If the UK is to seriously consider recycling mixed plastics (including bioplastics such as PLA) it needs to develop infrastructure to deal with this type of waste through legislation and other means (see section 2.1). Currently, there are several technologies available to separate plastic types based upon physical characteristics (film or rigid), polymer type and/or colour {58;59}. A technology called near infra-red (NIR) spectroscopy can identify polymer types (e.g. PP and PET at over two tonnes per hour) based on absorption and reflection of light {59}. Black plastics cannot be read by standard NIR machines because they contain high carbon dyes that absorb too much light which produces a poor identification spectrum. Detectors designed to deal with black plastics are available. However, implementing this and other NIR technology is expensive with a sorting plant typically costing £3-15 million {60}. If bioplastics (in various forms) are added to this collection then sorting mixed plastic waste may be made more expensive as more sophisticated equipment may be needed.

3.0.6 Sorted plastic waste and recyclate marketing

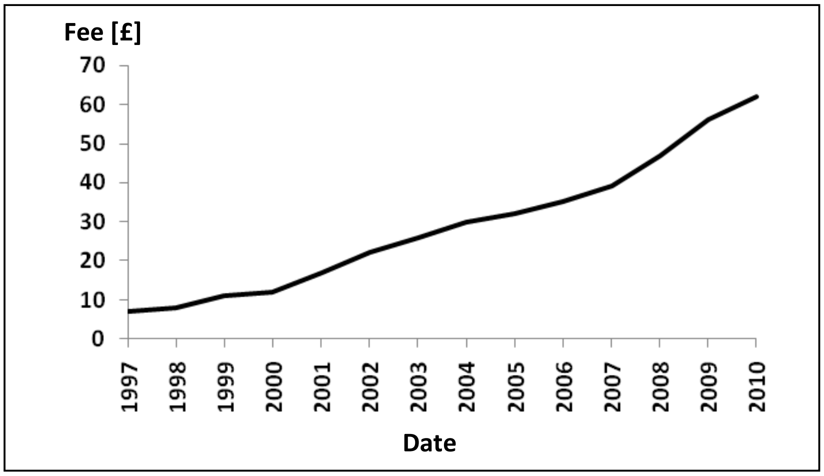
By the end of 2008 EU member states were required to recycle 22.5% of plastics according to the 94/62/EC Packaging Directive (see appendix section 11.2) {12}. At the moment plastic recycling schemes in the UK tend to concentrate on bottles and are different depending on the implementing local authority. In fact, in 2007 less than a quarter of UK local authorities accepted mixed plastic waste for recycling or recovery (the likely waste stream for bioplastics) {57}.

WRAP identified that the major concern for local authorities was what to do with their sorted recyclables. At the moment only a few local authorities collect mixed plastic waste in the UK, most concentrate on plastic bottles. In fact, a WRAP survey found that 25% of local authorities supplied their sorted plastic bottles to the UK market, 8% and 3% knew that they exported bottles to non-EU and EU destinations, respectively and 41% did not know where their bottles were sold (23% of local authorities did not respond) [57]. Clearly, communication between companies that supply and use recyclable materials is an issue to be addressed.

3.1 End-of-life option barriers to bioplastics

The avenues for disposal of bioplastic waste are numerous and include commercial and home composting, AD, EfW options, landfill, MBT and recycling (see section 5.0). Landfill is a mature option in the UK, but incurs Landfill Tax (currently £40 per tonne of waste) that is set to increase by £8 each year until at least 2010/2011. This Landfill Tax escalator is a strong monetary incentive to divert waste from landfill (see Figure 3.01). Landfill waste disposal is not desirable on account of diminishing space and methane GHG output. However, most of the other end-of-life options are desirable, but the UK is under equipped to undertake them. In addition, there are currently few specific end-of-life regulations aimed at bioplastics.

Figure 3.01 Landfill Gate Fees and Tax



Source – {61}

In 2008 WRAP published a report on waste disposal gate fees. This report indicated a range of prices for disposal options (see table 3.02) [62]. Some MRFs paid for waste materials (£4 per tonne). However, other MRF sites charged up to £70 per tonne. In 2007 ASP and IVC composting cost between £17-£33 and £20-£69 per tonne, respectively. Anaerobic digestion cost £30-£60 per tonne, incineration costs ranged from £31 to £136 per tonne of waste and MBT cost £53 per tonne. In 2007 only ASP composting was cheaper than landfill. All the other options were more expensive at the higher end of their cost ranges. Incineration was the most expensive option for waste disposal. However, if Landfill Tax continues to rise it will make other appropriate disposal options cheaper than landfill thereby helping divert more waste from landfill. It must be noted that this assumes that there will not be a significant rise in gate fees for all the disposal options except landfill.

Table 3.02 Gate Fees for Waste Disposal

Treatment	Type of Facility	Median [£]	Range [£]
MRF	cans/plastic/paper/card	21	-4-70
Composting	ASP	22.5	17-33
	IVC	40	20-69
Anaerobic Digestion		n.a.	30-60
Incineration	All facilities	71	31-136
MBT		53	n.a.
Landfill	Gate Fee and Tax	45	35-64

Source – {62}

Currently, bioplastics are marketed on their renewable and end-of-life environmental credentials. However, the end-of-life emphasis is on composting rather than recycling. The annual local authorities plastics collection survey 2008 report produced by WRAP indicated that UK councils are unsure of how to deal with bioplastic waste {57}. It is possible to recycle some bioplastics such as PLA, but not all of them can be re-processed which may cause a barrier to their use {63}.

It is important to note that implementing a plastic recycling scheme with conventional petroplastics, even without bioplastics, is complex due to issues with: 1) packaging labelling 2) consumer waste segregation; 3) collection by the local authority; 4) processing at the recycling plant; 5) the recycled material marketing stage. In addition, appending bioplastics to this equation may cause further challenges. For example; PLA at more than 1% contamination in PET flake can reduce the quality of PET bottles and can cause problems in the manufacturing process of recycled PET {14}.

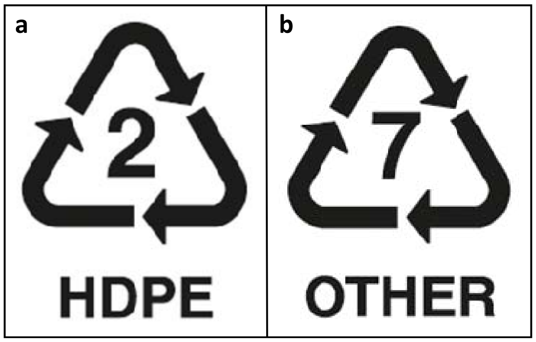
At the moment most bioplastics are advertised as biodegradable and compostable. In order for a packaging material to be termed compostable it must adhere to specifications laid out in the EN 13432:2000 European standard (see section 5.0.3.1) {12}. This 'compostable' description can be confusing to the UK consumer because it suggests that compostable bioplastics are all home compostable. In reality, compostable means 'compostable in an industrial facility' unless packaging items are specifically labelled as 'home compostable' (see section 4.0). At the moment few UK commercial or council composting sites can cope with mixed bioplastic waste which is a barrier to their use. WRAP suggest that to meet the requirements of the Landfill Directive the UK will need to compost five million tonnes of organic waste including one million tonnes of food waste by 2012/2013 {20}. It is noteworthy that the Landfill Allowance Trading Scheme (LATS) will help meet these targets (see appendix section 11.2) {43}. This means that it is important for the UK to invest further in composting infrastructure to cope with an increase in segregated organic waste and new compostable materials such as bioplastics. In addition to EN 13432 the Association for Organics Recycling (formerly the Composting Association) in the UK has compost standards called PAS 100:2005 and Animal By-Products Regulations (ABPR) which outline several criteria that must be fulfilled in order for certification to be granted. Some of these specifications include plant operating procedures (see section 5.0.3.2). Although the above regulations are necessary as safeguards and to improve the environment, they do present a barrier to companies wishing to make or compost bioplastics since they will require EN 13432 and ABPR/PAS 100 certification, respectively.

Incineration and other EfW options also offer a good way of recovering energy from food contaminated plastic waste to heat and power homes and businesses. However, regulations such as the Waste Incineration Directive (WID) 2000/76/EC cause a barrier to disposing of bioplastics in this way (see section 5.0.6) {64}. It is also noteworthy that anaerobic digestion (see glossary) is a good option for the disposal of food contaminated bioplastic packaging waste as it allows the recovery of methane for heat and power generation.

4.0 Packaging labelling

Distinguishing between different types of plastic by sight is very difficult for the consumer without an effective labelling scheme to identify what each material is and whether it can be recycled or composted. At the moment there is no universal labelling system for recyclable or compostable materials. However, in Europe the standards for visual material identification are based upon the European Commission 97/129/EC regulation, the European Committee for Standardisation (CEN) WI 261 070 recommendation and the Association of Plastics Manufacturers in Europe (APME) standard. All three are very similar and consist of a polymer numbering and abbreviation system with or without a triangular cycle arrow symbol (see figure 4.01a) {65;66}.

Figure 4.01 Polymer Identification Labels

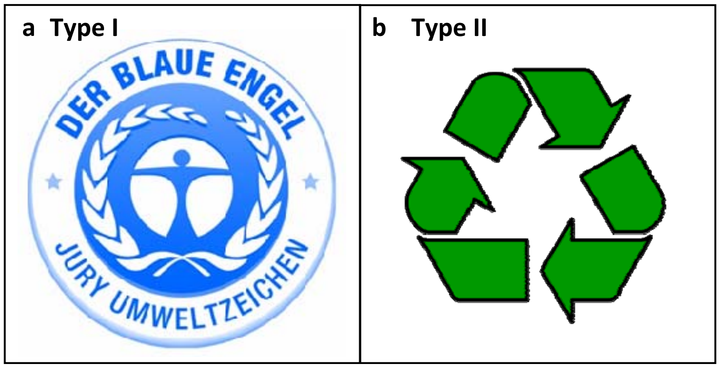


Source – {66}

In the USA the Society of the Plastics Industry (SPI) has a similar numbering and abbreviation system to the EU standards described above {67}. However, for bioplastics, both systems are not particularly useful as biopolymers are given the generic polymer number 7 ('other') attached to the logo (see figure 4.01b). A 2007 state of California Bill (Senate bill No. 898) suggested that '0' should be added to the SPI plastics labelling system to identify PLA separately from 'other'. This was a step in the right direction, but unfortunately amendments were made to the bill and the waste label change was removed before it could be passed by the Senate {68}. However, it should be noted that German packaging manufacturers have started to use an SPI-type label (see figure 4.01b) with a '0' annotation underneath to signify the use of a mixture of petroplastics. A recent step by various retailers in the UK, including a number of supermarkets, has been to adapt polymer identification labels (as shown in figure 4.01) with a diagonal strikethrough to signify that a particular packaging component cannot be recycled. A typical example is a high density PE (HDPE) bottle (e.g. a milk bottle) with a PP cap where the HDPE bottle is recyclable, but the cap is not collected for recycling.

Currently, the international standards ISO 14020, ISO 14021 and ISO 14024 cover and aim to harmonise information presented on packaging about its environmental claims {69}. There are three levels of packaging labelling. Type I labels are awarded by a third party and indicate that a product is environmentally preferable to others based on product life cycle analysis (e.g. the blue angel symbol in Germany, see figure 4.02a). Type II labels are voluntary and provide self-declared environmental claims in the form of symbols and text for a single aspect of the life cycle of a product (e.g. Mobius Loop and recyclable content, see figure 4.02b).

Figure 4.02 ISO 14020 Series Packaging Labels

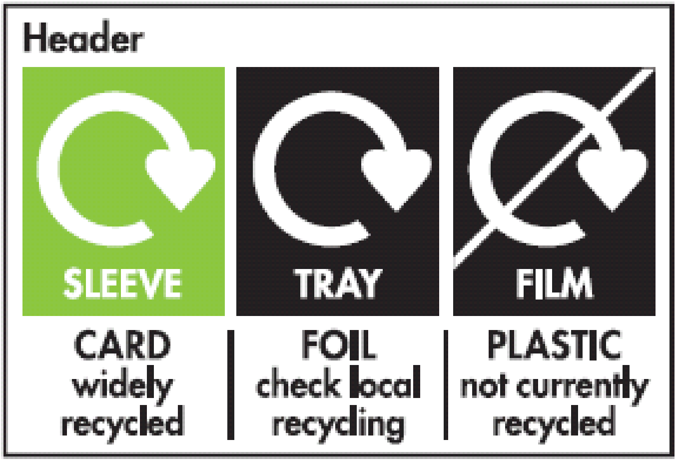

a Type I | **b Type II**

Source – {69}

Type III labelling involves the production of an environmental data sheet and can be either self-declared or awarded by a third party. Unfortunately, type II labelling systems are open to abuse because they do not require substantiation of the claim put forward. They also only cover a small part of the life cycle of a product. However, type II labels are cheaper for companies to implement because they do not require expensive life cycle analysis (LCA) or certification. On the other hand, both type I and III labels usually require costly LCAs and certification and are not as open to abuse.

More recent developments in recyclable packaging labelling include the British Retail Consortium (BRC)/WRAP recyclability label which is informative for the consumer (see figure 4.03). This label identifies the packaging construction parts, the materials used and the recyclability of each part {70}.

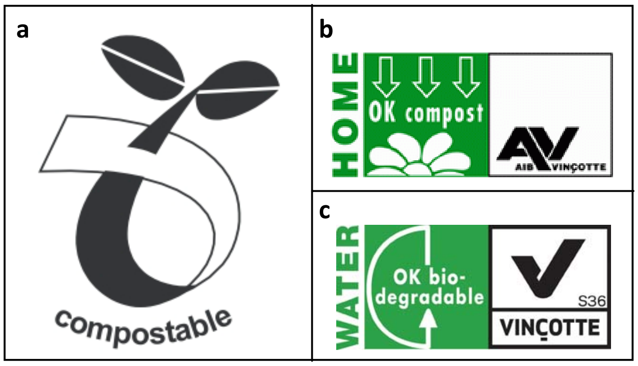
Figure 4.03 BRC/WRAP Packaging Label



Source – {70}

Progress has also been made in compostable packaging labels in the EU. In particular, European Bioplastics developed the 'seedling' logo for compostable EN 13432 compliant packaging materials (see figure 4.04a) {71}. In the UK the Association for Organics Recycling implements the 'seedling' logo for both EN 13432 and PAS 100 compliant packaging materials {72}. However, every three years packaging materials have to be re-tested and even during the three year period market samples are taken to ensure compliance {72}. There is also a Belgian compostable packaging labelling system provided by AIB-Vinçotte termed 'OK Compost' and 'OK Compost Home' (see figure 4.04b). This system is dependent

Figure 4.04 European Labels for Compostability and Biodegradability

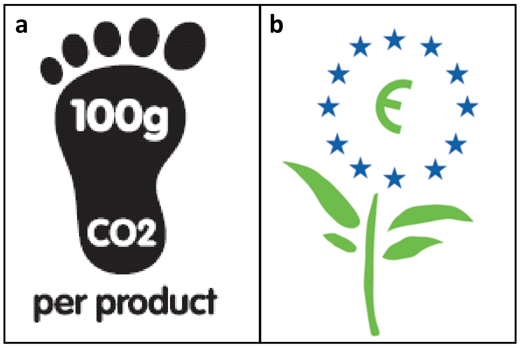


Source – {71;72;73}

upon testing similar to that for EN 13432, but with a few differences in temperatures and composting duration {72}. This system identifies whether a packaging material can be home composted (taking up to 16 weeks) unlike the 'seedling system' which indicates that items may be industrially composted. AIB-Vinçotte are also responsible for certifying packaging products as 'OK biodegradable' (see figure 4.04c). This system specifies whether a packaging product breaks down in air, soil or water, but does not indicate a timescale {73}.

In the UK the Carbon Trust has developed a label that indicates the amount of GHGs produced during the whole life cycle of a product (see figure 4.05a) {70}. Similarly, in Europe there is an 'Eco-label' which has been developed by the European Commission under the European Regulation 1980/2000 (see figure 4.05b) {74}. This 'Eco-label' is a voluntary scheme and is applied to services and product groups (e.g. paper products) that are considered environmentally-friendly based on 'cradle-to-grave' life cycle analysis (LCA) criteria (see section 6.0.1). Both of these labelling systems may provide a good tool for the consumer to identify which products (or services) have a lower impact on the environment. Both label schemes may also increase company competition to reduce environmental emissions. However, by using a carbon footprint label companies are committed to update information when manufacturing processes are altered (e.g. switching between petroplastics and bioplastics) or when energy sources change (e.g. switching to wind power). This may present a barrier to manufacturers and suppliers as it is expensive to perform LCAs and change labels. However, companies that perform LCAs and label their products with a carbon footprint may have a competitive advantage over companies that do not use a carbon footprint labelling system.

Figure 4.05 Carbon Trust GHG label and European Eco-Label



Source – {70;74}

In summary, there are different standards and labelling systems for compostable and recyclable materials which can make disposal decisions confusing for the consumer. In addition, the process of labelling and certification is costly, requires detailed documentation and testing of the materials involved. On the whole, different labelling standards may act as a barrier to the use of bioplastic materials. However, if a standard labelling system is used it will help to market low environmental impact materials such as bioplastics. It would also aid consumer choice and awareness of environmentally-friendly packaging and increase recycling/composting rates.

5.0 Bioplastic disposal options

5.0.1 Recycling

Today Britain has a partially developed recycling infrastructure for processing plastics and other post-consumer materials. However, Britain lags behind other European countries in its material recycling capability which may cause a barrier to the use of recyclable bioplastics such as PLA. Historically, plastic recycling in the UK has focussed mainly on plastic drinks bottles due to their relatively high density and weight-based EU recycling targets (see appendix section 11.2) {16}. In 2006 over two million tonnes of plastic packaging waste was produced (1.4 million tonnes from domestic use). Importantly, plastic packaging waste in the domestic stream is predicted to rise between 2% and 5% per year reaching over two million tonnes by 2015 {49}.

In the UK, plastic bottles are usually collected at a ‘bring’ site (where plastic bottles are mixed) or a kerb-side collection (see later). After collection, plastic bottles are typically sorted from other recyclables in an MRF where they are compacted into mixed polymer bales and either exported or treated by a re-processor in the UK. Closed Loop Recycling Ltd. (CLR, Dagenham, UK) is a good example of HDPE and PET plastic bottle recycling for the production of food-grade packaging plastics (see figure 5.01) {75}.

CLR accepts plastic bottles in the form of mixed bottle bales which are initially mechanically broken up. The plastic bottles are then passed through a trommel (a rotating perforated drum) to remove plastic lids and contaminants such as stones. The plastic bottles are then transported on a conveyor belt system where removal of metal contaminants takes place using a magnet and ‘eddy’ current separator. Paper, plastic bags and plastic film are then removed using air jets that blow them from the belt.

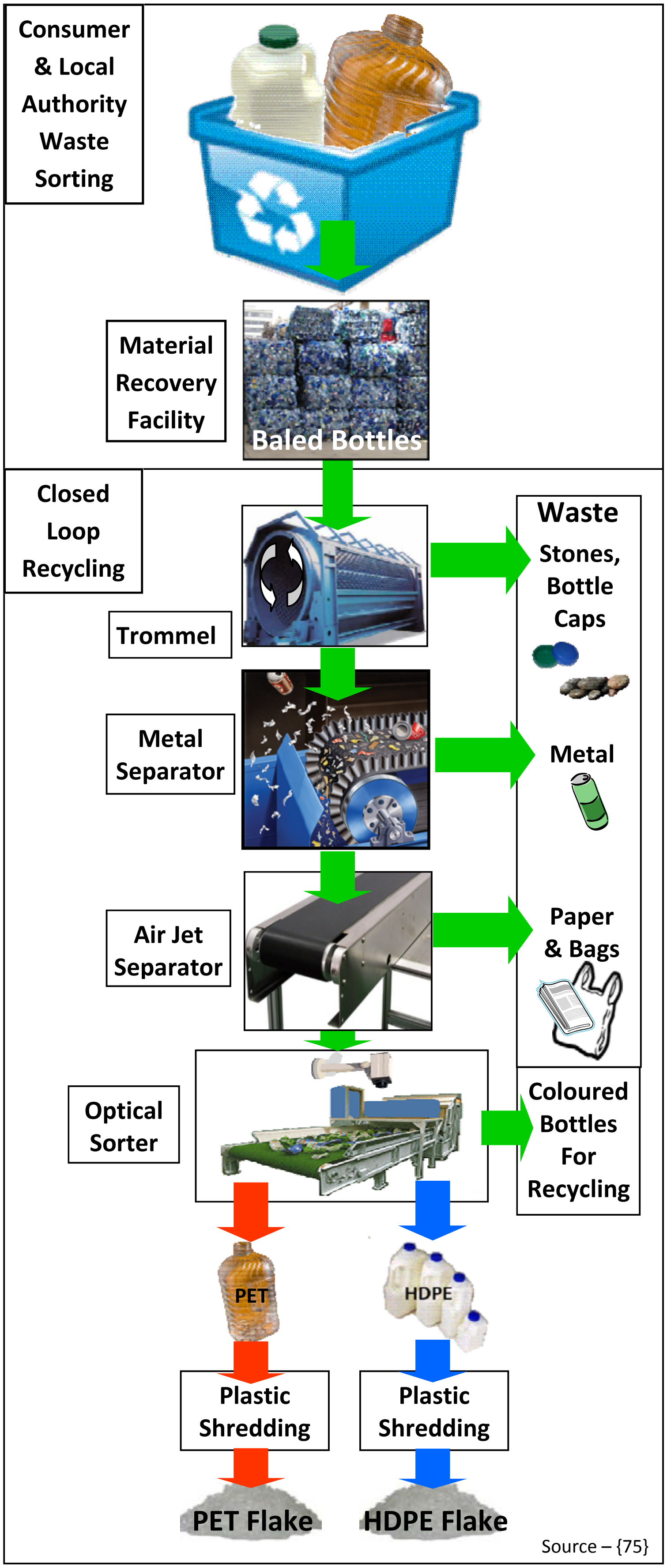
After the removal of most contaminants, bottles are segregated by optical sorting systems. Colour recognition cameras identify colours and NIR scanners detect polymer types (see section 3.0.5). Both of these detection systems control air jets that fire bottles from the conveyor belt into collection bins for the different colours and polymer types. CLR typically collects clear PET, light blue PET and HDPE bottles for processing and sends coloured PET bottles and plastics to other facilities for recycling. The segregated PET bottles recycled by CLR are then manually sorted to remove any remaining contaminants and are then sent for granulation and washing. The HDPE bottles are separated into coloured and non-coloured HDPE by a further colour detection system and the non-coloured HDPE is processed further (the coloured HDPE is sold to other recycling businesses).

Once sorted, the HDPE and PET bottles are shredded into fine flakes and sent through a dry cleaner where small contaminants are removed. The flakes are then washed to remove residual paper, ink and adhesives. Any HDPE flake contamination in PET flake is then removed using a float/sink tank where HDPE floats and PET sinks. PET flake is then treated to remove micro-organisms using caustic soda which etches off the surface of the plastic. This process is completed by heating the PET flake for four hours. After decontamination the PET flake is cooled, rinsed, dried and then sorted again using an optical sorting system to remove any remaining coloured PET. The clean PET flake is then bagged and sold for the production of food packaging (see figure 5.02).

CLR decontaminate non-coloured HDPE by heating the flake to over 200°C under low pressure. The resultant molten plastic is then extruded, filtered, cut into granules and cooled before being bagged for sale (see figure 5.02).

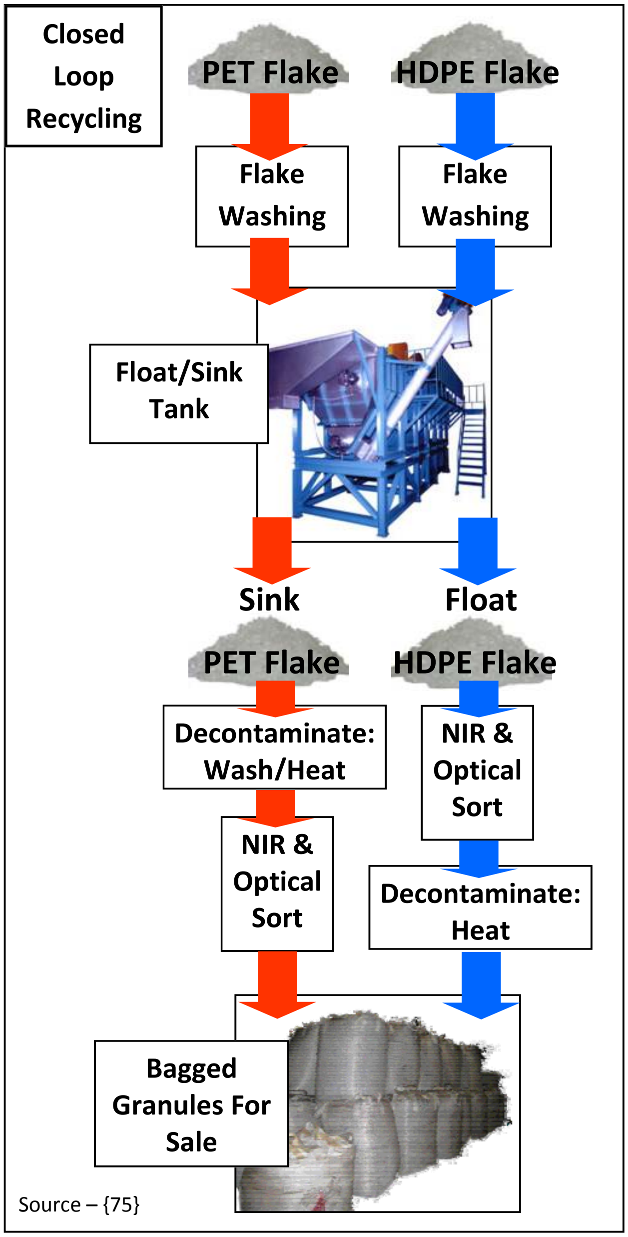
In future a CLR-type system may be important for dealing with recyclable bioplastics because it is a sustainable local option when compared to shipping recyclable materials to countries such as China or India where there may be uncertainty in how the materials are treated. However, it must be noted that the European 1418/2007/EC regulations and the Chinese Notice 2008 No. 11 have recently been implemented to ensure imported recyclable materials are of the correct type and are treated in the correct way (see section 2.1.4) {15}.

Figure 5.01 Recycled PET and HDPE Flake Production



Source – {75}

Figure 5.02 PET and HDPE Flake Purification



Source – {75}

In 2007 437 of the 471 UK councils offered plastic bottle recycling scheme 'bring' sites and kerb-side collections (the latter outperforms the former by four to one). Although these statistics seem promising, kerb-side recycling was only available to about 57% of UK homes and only 108 local authorities reported that they accept plastic materials other than bottles {57}. Since bioplastics will fall into this mixed plastic waste stream it is imperative that investment is made in order to increase the number and variety of processing sites to cope with these new materials. WRAP recently (August 2008) advertised a call for partners to research the feasibility of commercial scale recycling of mixed plastic waste {16}. This means that any study proving the efficacy of mixed plastics recycling may convince local authorities to collect and process such materials. In future, this may aid recycling of the majority of recyclable bioplastics (such as PLA) providing them with a market driver.

In addition, bioplastic manufacturers could share some of the responsibility for recycling their materials. For instance; in the USA, NatureWorks LLC offers a bulk buy-back scheme to chemically recycle PLA [76]. For the UK this would only be economically viable if such a PLA plant were based in the UK or Europe with a sufficiently large volume of PLA material in the market place (e.g. 70 ktpa).

Currently, kerb-side recycling schemes in the UK vary considerably in collection methods (e.g. bins, bags and boxes), scheduling (e.g. weekly and/or fortnightly), material segregation (see below), material sorting (e.g. hand or machine sorted), recycling (e.g. UK or exported) and recyclate marketing (local or global) [61].

Current kerb-side material segregation in the UK may consist of: 1) a 'co-mingled' recyclable waste collection where all dry recyclables are mixed; 2) a 'dual-stream' system where paper is kept separate from other recyclables; 3) a 'multi-stream' system where some recyclable materials are separated and others are mixed; 4) a 'source-segregated' waste collection system where all dry recyclables are separated [61]. For instance; the London Borough of Fulham and Hammersmith collects recyclables in a 'co-mingled' collection 'smart-sack' [77]. Conversely, the London Borough of Ealing has a 'multi-stream' system where plastics are collected in a re-useable sack, other dry recyclables in a box and food waste in a caddy [78]. It is clear that research and trials are required to determine: 1) the most efficient collection method(s); 2) which collection method produces high quality recyclable materials; 3) which collection method is suitable for bioplastic materials such as PLA (to reduce the likelihood of PET contamination).

Although local authorities provide information on their websites and in the form of leaflets there is still a lack of awareness of, and confusion with, what materials can be recycled, what containers they must be placed in and when the materials are collected. If a nationwide recycling collection scheme is adopted in the UK then information dissemination to the public would be made easier. This could be in many forms including a website, leaflets, media advertising and information stickers for containers used for recycling.

5.0.2 Plastic export for recycling

At the moment there are few sites in the UK that actually re-process sorted post-consumer plastic waste into new products (e.g. CLR, see section 5.0.1). As a result, a large proportion of recyclable plastics are exported for re-processing [16]. This trade is a driver for recyclable (but not compostable) bioplastic use because it provides a market for material sorted by MRFs. The downside for the UK is that, whilst sorting facilities gain from this practice, re-processing plants may struggle to survive. This is generally because countries like China have cheaper labour costs and can offer good prices for recyclable materials [79]. If there is a switch to compostable (as well as recyclable) bioplastic use, local authorities reluctant to send waste abroad may be able to process their waste by delivering it to UK composters, AD plants, biomass incinerators or other EfW plants. Local solutions like these may provide a driver for bioplastic use.

5.0.3 Composting

Currently bioplastics are marketed as compostable materials, but there are few facilities capable of adequately processing compostable bioplastics in the UK. In fact, most composters of garden and food waste accept bioplastic bags (starch/petroplastic hybrids) in their feedstock, but little else. However, the fact that bioplastic bags are accepted is a driver for bioplastic use in other applications such as carrier bags and food packaging film. At the moment there are gate fees to dispose of green and food wastes which are roughly equivalent to, or slightly more than, landfill gate fees (see table 3.02) {20}. However, landfill tax (LAX) is not applied to green and food wastes sent for composting. This means that the charges for disposal of compostable waste are relatively low compared with landfill providing a driver for compostable bioplastic use (see figure 3.01 and table 3.02). In addition, landfill allowance trading (LATS) aims to limit the amount of biodegradable waste sent to landfill (see section 2.1.2). This scheme will also provide a driver for using compostable bioplastics because they will help meet biodegradable waste landfill diversion targets (see appendix section 11.2).

Recently, WRAP produced an organic waste market situation report (April 2008) detailing that the UK produces some 25 million tonnes of organic waste per year with around half arising from food waste and half from garden waste {20}. The report also mentions that the UK only commercially composts around four million tonnes of organic waste (2006-2007 data) and that a third of homes with gardens compost their own green garden waste. At the moment roughly half of organic waste composted in the UK is used by the agricultural sector with about 13% utilised in horticulture.

One of the major problems faced by the composting industry is the end market for compost products. Compost, by its very nature, is bulky, has a low retail margin and has to meet several stringent composition targets (discussed in sections 5.0.3.1 and 5.0.3.2). As a result there is resistance to accepting new compostable materials such as bioplastics because they present a few challenges. For example; 1) how do you distinguish between bio- and petroplastics without investing in expensive plastic sorting equipment? 2) what do you do with petroplastics that are left behind after the composting process is completed? 3) what do you do with bioplastics that do not break down in one or two composting cycles?

Currently there are around 168 Association for Organics Recycling-certified (PAS 100, see section 5.0.3.2) composting sites in the UK {80}. Most of these sites participate in windrow-type (ASP) composting which involves piling and turning aerated compost heaps open to the elements. This type of composting is not ideal for processing bioplastic waste because temperatures may not be high enough for long enough to enable biodegradation of all bioplastics incorporated into the green waste stream processed. In addition, most bioplastic products available at the moment are used to contain or serve food and are likely to be contaminated with food. If these items are to be composted they require more stringent processing for composting in order to kill and prevent the growth of disease causing micro-organisms (see section 5.0.3.2). Currently, there are only a few facilities in the UK that can cope with food wastes. These sites are typically enclosed ASPs, in vessel composting (IVC) facilities or AD units that can control moisture, temperature and methane gaseous output. In future, further expansion of composting infrastructure in the UK will help to promote the use of compostable bioplastics.

5.0.3.1 EN 13432 composting legislation

At the moment most bioplastics on the market are advertised as ‘compostable’, a feature which is regulated by the EN 13432:2000 European Standard {11}. EN 13432 lays down definitions of the characteristics a material should have in order to be termed ‘compostable’. This regulation is a safeguard to prevent deterioration of compost quality due to contamination with certain non-compostable items such as glass or non-degradable plastics. EN 13432 has four main criteria for a compostable item:

1) The item must be biodegradable by micro-organisms (bacteria and fungi) with 90% biodegradation to CO_2 achieved in less than six months. The standard test for biodegradability is specified by EN 14046 {11}.

2) The item must disintegrate during composting so that no visible pollution is obvious. The test for this is defined in EN 14045 and requires the material in question to be composted for three months {11}. The resultant compost is then screened with a two millimetre sieve and the mass of items larger than two millimetres is determined. Compost must have less than 10% of its mass larger than two millimetres in order to pass this test.

3) Items must not cause a negative effect on the composting process.

4) Items must contain only low levels of heavy metals (if any at all) such that the composting process is not affected and eco-toxicity is minimal. Chemical analysis and tests of plant eco-toxicity are performed on the compost under the Organisation for Economic Co-operation and Development (OECD) guidelines.

This legislation provides confidence to the consumer, retailer and composter that bioplastics labelled as compostable are really compostable. This, in itself, acts as a driver for the use of bioplastics.

5.0.3.2 PAS 100 and ABPR composting legislation

Both PAS 100 and the Animal By-Products Regulations (ABPR, European Directive 1774/2002/EC) specify composting plant operating procedures, the moisture content and temperature regime to be achieved during composting {34;81}. The ABPR splits animal waste into three categories: Categories one and two are high disease risk and cannot be composted. Category three is low risk material that can be composted as long as strict temperature, mixing and time specifications are adhered to. For example; category three waste processed in enclosed ASP facilities must reach 60°C for a period of eight days with turning every two days. For IVCs the requirements are that the waste material reaches 70°C for a minimum of one hour {81}. This legislation may act as an indirect driver for bioplastic use because it provides assurance that compost produced from such materials is safe and of high quality.

5.0.4 Anaerobic digestion

Anaerobic digestion (AD), biodegradation in the absence of air, offers a means of controlled disposal for bioplastic packaging contaminated with food waste. Currently, there is a lot of interest in AD and there is a possibility that PLA bioplastic could be biodegraded in this way. A typical AD plant accepts food waste in bioplastic bags (currently a starch/petroplastic blend) and produces solid compost or liquid ‘slurry’ and methane (see glossary). One of the benefits of AD is that aeration is not required (in contrast to ASP composting) which has a high energy requirement. The other major advantages are that the methane captured can be used for energy and/or heat production and the compost or slurry can be used to replenish farmland with nutrients. However, the compost and ‘slurry’ that AD plants currently produce does not have a specification or standard and, as a result, cannot be legally sold in the UK. It is worthy of note that PAS 110:2008 is under development to provide a standard for anaerobic digestate {82}. Since compostable bioplastics can be biodegraded in an anaerobic digester, AD is a potential driver for bioplastic use.

5.0.5 Mechanical biological waste treatment

Mechanical biological treatment (MBT) is a term given to waste treatment facilities that combine several waste processing methods and technologies on one site. Typically, an MBT site contains a waste sorting MRF facility with an AD and/or composting plant (see glossary). However, there are several possible plant configurations with currently available methods and equipment. MBT plants typically process 'black bag' municipal solid waste (MSW) by removing recyclable and non-recyclable materials and treating the organic fraction by composting, AD or bio-drying. Bio-drying is a partial microbial treatment of organic waste which produces a dry material suitable for burning. The dried material is usually termed refuse-derived fuel (RDF) which can be burnt in an EfW plant. It is noteworthy that partially treated or sorted material outputs from an MBT plant may be sent for secondary processing or disposal depending on the material.

Biodegradeable bioplastics can be treated in an MBT plant through composting or AD. However, plant design is crucial since 'front-end' sorting of recyclable waste may fail to separate compostable bioplastics from recyclable plastics. The consequence of this would be no composting of compostable bioplastics and contamination of recyclable plastics with compostable bioplastics. An alternative option is biological mechanical waste treatment (BMT) which involves 'back-end' sorting of recyclable materials after initial composting or 'stabilisation'. This method should work for the composting of bioplastics if the conditions and procedures are correct for their biodegradation. For example, biodegradation of PLA requires high temperatures (>37°C) to be effective {63}. If procedures are optimised for bioplastics (such as PLA) then MBT or BMT waste treatment may provide a driver for their use.

5.0.6 Energy from waste

Incineration is a convenient means of plastic disposal for the production of heat and electricity. However, incinerator furnace throughput is slower if plastics are incorporated into the waste at a high percentage. This slower processing is due to the high calorific energy content of plastics when compared to other wastes. At the moment incinerators in the UK generate income by gate incentives per tonne of waste processed (see table 3.02). As a result, companies are reluctant to incinerate 100% plastic and only burn combustible waste containing around 20% plastic {49}. This provides a driver for the use of recyclable and compostable bioplastics because a reduction in the amount of plastics sent for incineration may be achieved. Currently, incineration gate fees are relatively high when compared to composting and recycling fees providing another incentive to use compostable and recyclable bioplastics {62}. However, it must be noted that there is a current lack of uptake in composting of a lot of bioplastic materials in the UK. This means that incineration and other EfW options, such as pyrolysis and gasification (see glossary), may provide a driving force and disposal routes for bioplastics.

Incinerator companies must comply with the waste incineration directive (WID, 2000/76/EC) {64}. These regulations stipulate that burnt waste must reach 850°C. In addition, if the treated material contains plastics or other compounds containing a 'halogen' (such as chlorine) it must be heated to 1100°C for at least two seconds. This treatment ensures that the production of toxic chemical compounds (such as certain 'dioxins') is prevented.

A novel point to mention is that, in future, bioplastics could be separated from the plastics recycling waste stream by an MRF and then treated in biomass burning facilities, if composting is not a preferred or accepted route for them. In fact at the time of writing there were more than 330 planned or operational dedicated biomass processing plants for the production of renewable heat in the UK {83}.

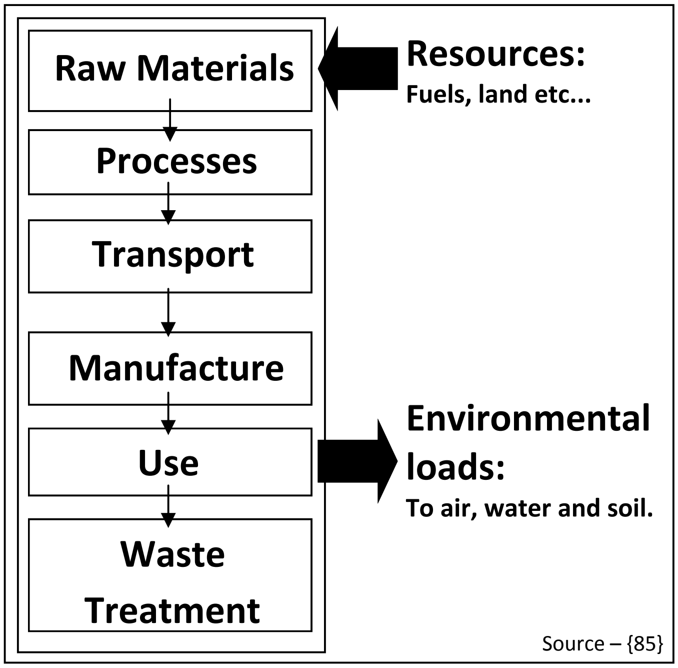
Clearly, with this number of facilities it would be possible to locally dispose of bioplastic waste materials accumulated by local authorities.

6.0 Carbon and energy accounting of bioplastics

6.0.1 Life cycle analysis

Life cycle analysis or LCA is an environmental impact auditing method detailing the energy requirements, carbon footprint, waste and useful co-product output that a particular product or process has. LCAs typically cover raw materials through to processing, use and disposal of a product. They provide a way of benchmarking and comparing the environmental credentials that products (such as bioplastics) have. LCAs may encompass a number of stages in the lifetime of a product, but a clear definition of the system boundaries (stages included in the study) and standards used (e.g. ISO 14040 series) is required to ensure comparisons between products are valid {84}. Common terminology used in LCAs include 'cradle to factory gate' (eco-profiling) or 'cradle to grave'. The former refers to an LCA mainly focusing on raw materials and manufacture of an item. However, the latter is an audit that encompasses activities such as: 1) raw material processing; 2) manufacturing; 3) shipping; 4) consumer use; 5) disposal (see figure 6.01). Typically, at every stage inputs and outputs are considered for their environmental impacts {85}. It is important to note that there is no universal method or standard for LCAs. Recently, other terms have been formulated including 'eco-efficiency assessment' which consists of a 'cradle to grave' analysis combined with an assessment of all life cycle costs. BASF have also proposed an LCA called SEEbalance® which incorporates a socio-economic efficiency analysis

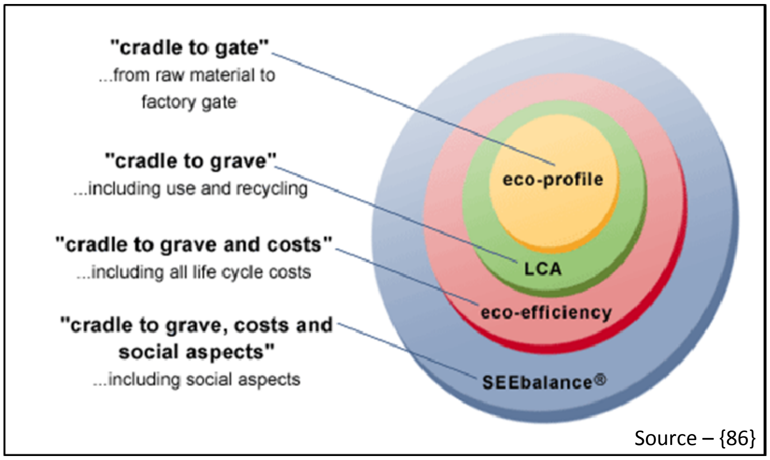
Figure 6.01 The Baumann LCA Model



Source – {85}

combined with an LCA. SEEbalance® is a cradle to grave LCA including life cycle costs and social aspects (see figure 6.02) [86].

Figure 6.02 LCA Forms



Source – {86}

LCA has been performed on a variety of bioplastics. In 2002 an LCA was published comparing BioBags produced by Polar Gruppen AS (Norway) to PE bags [87]. The LCA system boundaries encompassed raw materials through to bag disposal and composting (cradle to grave excluding land application of the resultant compost). The food waste BioBags concerned were constructed using Mater-Bi from Novamont [88]. Raw material production and transportation was considered. Granulate production and bag manufacture were both analysed and the fuel inputs considered. Transportation and end-of-life composting, EfW or landfill options were also assessed. The overall results of this study showed that the life cycle of BioBags in 2002 was more energy intensive and produced more GHG emissions than the life cycle of PE bags (disposed of by composting or landfill). However, an interesting finding in this paper was that incineration of BioBags for heat and power generation produced a global warming potential only slightly higher than incinerated PE due to the oil saved by burning BioBags.

A more recent 'cradle to grave' LCA study of Mater-Bi (the main component of BioBags) provided by Novamont compares Mater-Bi bags with equivalent paper and PE bags [88]. In this study the stages considered were crop production through to bag manufacture and disposal by composting or incineration. Unlike the 2002 BioBag study this LCA did not incorporate transportation. The results indicated that Mater-Bi bag manufacture uses slightly less energy than equivalent PE bags and significantly less than paper bags. Novamont also state that the GHG output/global warming potential for the life of Mater-Bi bags is significantly lower (over 60% reduction) than that for PE bags [88].

Clearly, there is a disparity between the results of the two LCAs described above. However, these can probably be attributed to different LCA specifications, manufacturing procedures and plant efficiency.

Vink *et al*., (2007) [89] describe a 'cradle to factory gate' LCA study of PLA manufactured by NatureWorks LLC in the USA. Their LCA encompasses: 1) maize production and transport; 2) maize milling for starch; 3) starch conversion to dextrose sugar; 4) conversion of dextrose to lactic acid; 5) conversion of lactic acid to lactide; 6) polymerisation of lactide into PLA. For maize production various inputs were considered including seed, fertiliser, limestone, electricity and fuels, irrigation and energy used for herbicide and pesticide manufacture (used on the crop). Various farm outputs were also considered including nitrogen compound, phosphate compound and farm vehicle emissions. At the stage of maize processing considered activities included the separation of corn kernel components, starch hydrolysis to sugars and the production of useful co-products. For the manufacture of PLA several inputs were considered including electricity, fuels, steam, water and chemicals. Outputs included were gypsum and other co-products, waste water, air emissions, and solid waste. The results of this study showed an 85% reduction in GHG output and a 50% reduction in fossil fuel based energy requirements for PLA production in 2006 compared to PLA manufacture in 2003.

In 2006 an LCA of PLA packaging was published by IFEU GmbH on behalf of NatureWorks LLC {89}. In this cradle to grave analysis PLA clamshell packaging was compared to equivalent products made from polymers such as PP, PS and PET. The LCA stages considered were: 1) the land use for growing maize; 2) the manufacture and transportation of PLA granules; 3) the manufacture of clamshells; 4) the transportation and disposal of post-consumer clamshells by recycling or incineration. The results indicated that PLA clamshell manufacture, use and disposal uses less fossil fuel resources (e.g. around 75% less comparing PLA with PET) and produces less GHG emissions than producing, using and disposing of PP, PS or PET clamshells (e.g. around 50% reduction comparing PLA with PET) {89}.

In September 2008 the NNFCC published an LCA study of bioplastic and petroplastic carrier bags {84}. In this LCA study both degradable and non-degradable HDPE bags were compared to starch based Mater-Bi bags and PLA/petroplastic mix bags (produced by Octopus polymers UK). The system boundaries incorporated raw material and carrier bag production, distribution, use and end-of-life options such as landfill, incineration, recycling and industrial composting. A comparison between the four bag types tested showed that the least environmental impact was obtained by using and recycling HDPE bags. The Mater-Bi bags disposed of by incineration were shown to be second best with only a slightly higher impact than using and recycling HDPE {84}. Important conclusions from this study were: 1) that the major source of environmental impact was the extraction and production of materials for all four bag types; 2) that there was no evidence of energy savings in the production of bioplastic bags; 3) that **waste management options greatly influence the outcome of an LCA**; 4) EfW is the best option for the disposal of bioplastic bags; 5) landfill of bioplastic bags results in the least global warming potential due to slow breakdown of the bags; 6) composting is not a clear winner for the disposal of bioplastic bags {84}. However, it must be highlighted that bioplastic bags are sustainable and are made using renewable raw materials that are biodegradable and can help reduce waste sent to landfill. Future improvements in energy efficiency in bioplastic resin manufacture will help reduce the environmental impacts observed in the above study.

A recent simulated ‘cradle to gate’ LCA study of the manufacture of polyhydroxyalkanoates (PHAs, see appendix section 11.1) from the ‘black syrup’ by-product of biomass-based bioethanol production has shown that it is theoretically feasible to produce PHAs on a commercial scale with a significant reduction in global warming potential (80%) when compared to the manufacture of conventional petroplastics {90}.

In summary, LCAs provide an indication of the environmental impact bioplastics may have and are useful if there is a comparison to current manufacturing methods and products. However, LCAs do not have a standard methodology or standard boundary specifications which can make comparisons between different materials complicated. In addition, if different LCA methods and boundaries are used to update a previous material study then comparisons between old and new LCAs can also be complicated. LCA is still a relatively new technique, requires standardisation and is an evolving science. It is clear from the collection of LCAs described above that studies performed on similar materials can give divergent results. This is probably due to the use of different LCA protocols and improvements in plant/process efficiency between studies. It is noteworthy that PAS 2050 is a UK initiative to try and standardise LCA studies for goods and services in the UK that will be implemented in the next few years (see section 2.0.5) {34}.

Ultimately LCAs are a driver for bioplastic use at the level of packaging conversion (use of the granulated bioplastic) if they show reduced environmental impacts of the materials, but they are also a barrier at the level of resin manufacture due to the costs incurred in both time and money. If an LCA indicates little improvement over other rival materials then this provides a driver for companies to improve process efficiency. This, in turn, improves results in further LCA studies performed.

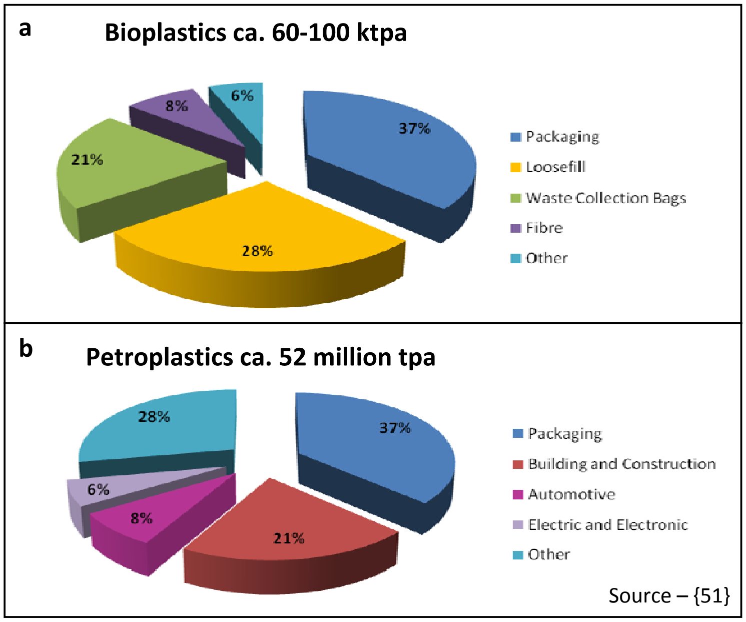
7.0 The current bioplastic market

7.0.1 The current world bioplastic market

The world produces over 260 million tonnes per annum (tpa) of plastics. Europe consumes approximately 53 million tpa and, specifically, the UK processes around five million tpa of plastics {3;4}. At the moment bioplastics make up only approximately 0.1-0.2% of European plastics consumption (at around 60-100 ktpa). Worldwide bioplastic production is approximately 300 thousand tpa (ktpa) which equates to about 0.1% of world plastic production capacity. European Bioplastics predict that the worldwide bioplastics market will exhibit a six-fold expansion by 2011 {51}.

In the EU, bioplastics are used mainly in packaging, loosefill packaging and waste collection bags with 37%, 28% and 21% bioplastic market share, respectively (see figure 7.01a). In comparison, petroplastic usage covers packaging, but also other applications including building and construction, automotive components and electronics with 37%, 21%, 8% and 6% petroplastic market share, respectively (see figure 7.01b) {51}.

Figure 7.01 Uses of Bio- and Petroplastics in Europe



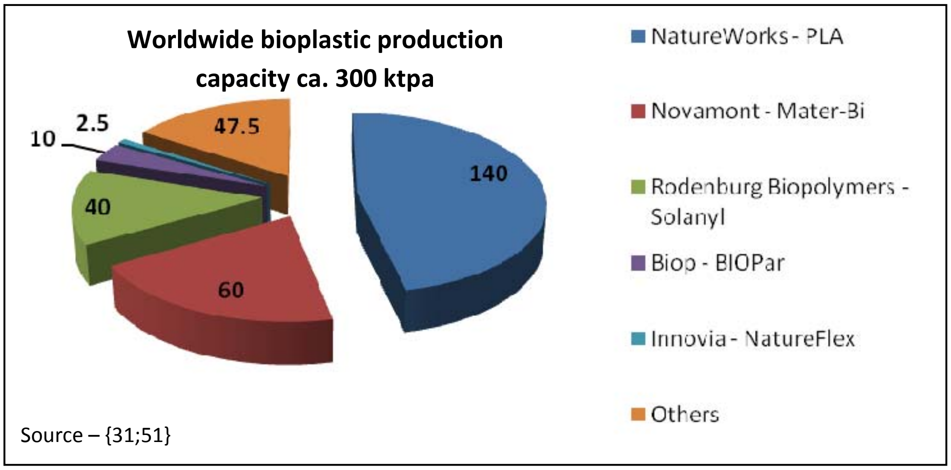
Source – {51}

Currently, thermoplastic starch (TPS, see appendix section 11.1), extruded starch and starch blends make up about 60% of the European bioplastics market and most of this starch is derived from maize (and to a lesser extent potatoes) {51}. However, other high starch crops such as wheat could be used as feedstock to manufacture bioplastics.

Globally, there are more than 80 different companies involved in the manufacture of starch bioplastic resin and bioplastic products containing or derived from starch including NatureWorks LLC (USA), Novamont (Italy), Rodenburg Biopolymers (Netherlands) and BIOP Biopolymer Technologies (Germany) (see figure 7.02 for publicised production capacities) {91;92;93;94}. One of the largest companies involved is NatureWorks LLC which has a manufacturing capacity of around 140 ktpa of PLA and distributes its product roughly evenly between Europe, Asia and the US {91}. Currently, PLA pricing, when compared to other bioplastics, is closer to conventional plastics (such as food grade PET) making it more competitive in the marketplace {91;55}. Other companies are also pursuing PLA resin/bioplastic production including Durect Corp. (USA), FKuR Kunststoff GmbH (Germany), Hycail (Netherlands), R. O. J. Jongboom Holding B. V. (Netherlands), Mitsui chemicals (Japan), Purac (Netherlands), Pyramid Bioplastics Guben GmbH (Germany), Synbra Technology B. V. (Netherlands), Toray Industries Inc. (Japan), Toyota Motor Corp. (Japan) and Hitachi (Japan) {95;96;97;98;99;100;101;102;103;104}.

There are also more than 20 companies worldwide involved in the production of bioplastic resins/products made from PHAs and cellulose/cellulose acetate (see appendix section 11.1). Metabolix (USA) is the major company in the PHA field with plans for a 50 ktpa polyhydroxybutyrate (PHB) plant operational in 2009 (see appendix section 11.1) {105}. Innovia Films (UK) is a major manufacturer of cellulose acetate films (see figure 7.02) {31}. There are a few other companies that use castor oil, vegetable oils and sugar cane to produce conventional plastics such as polyamides (PA), PE and polyurethane (PU) (see appendix section 11.1). Interestingly, a couple of companies concentrate on making bioplastics from novel raw materials such as lignin (a paper industry by-product) and plant globulin protein (see appendix section 11.1) {106;107}.

Figure 7.02 Current Worldwide Bioplastic Production Capacity [ktpa]

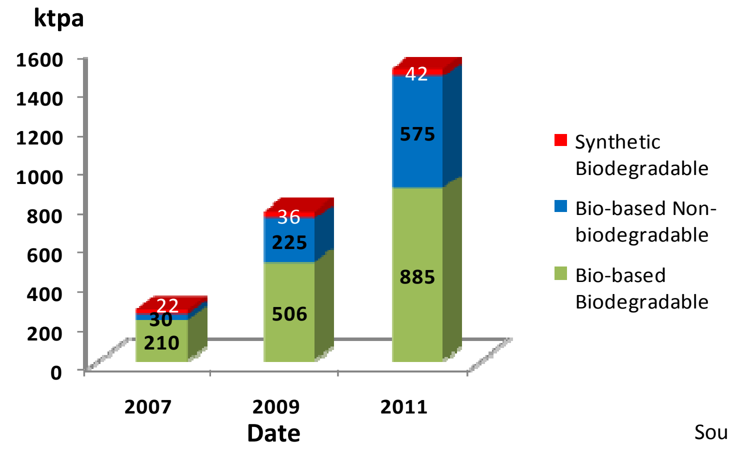


Source – {31;51}

7.0.2 Predicted worldwide bioplastics market growth

European Bioplastics predict that the worldwide bioplastics market will exhibit nearly six-fold growth from 300 ktpa in 2007 to more than 1500 ktpa in 2011 {51}. Bio-based (renewable feedstock) non-biodegradable bioplastics are predicted to expand their market share from 12% in 2007 to approximately 38% in 2011 showing a production increase from 30 ktpa in 2007 to 575 ktpa in 2011. Bio-based biodegradable bioplastic production is forecast to reduce its market share from 80% in 2007 to 59% in 2011 with an increase in production from approximately 210 ktpa in 2007 to 885 ktpa in 2011. Crude oil-based (synthetic) biodegradable plastics are also predicted to increase their market share from 8% in 2007 to 28% in 2011 with an increase in production from 22 ktpa in 2007 to 42 ktpa in 2011 (see figure 7.03).

Figure 7.03 Predicted Worldwide Bioplastic Market Growth [ktpa]



Source – {51}

7.0.3 The current UK bioplastic market

The bioplastics industry in the UK is currently in its infancy and, as such, there is little reliable data available on production and consumption volumes. Some sources quote that current use is about 15 ktpa of bioplastics, compared to a total plastics packaging volume of around two million tpa [49]. In the UK there are around 15 manufacturers/converters of starch-based bioplastic packaging products including Avanti Blue Ltd., BioBag UK Ltd., Biopac UK Ltd, Marchant Manufacturing Co. and Potatopak UK Ltd [108;109;110;111;112]. There is also one factory that makes bioplastic labels with a proprietary renewable and biodegradable adhesive (Berkshire Labels Ltd.) and two production facilities that manufacture renewable cellulose acetate (Innovia Films Ltd. and Clarifoil) [31;113;114]. In addition, there are several other companies that distribute bioplastic products throughout the UK from numerous worldwide sources.

It is worthy of note that the raw materials used for bioplastic packaging products supplied by most UK companies are mainly maize and potato starch, sugar cane bagasse and wood pulp. At the moment there is no evidence that wheat or other UK grain starch sources are being used for bioplastics in the UK. In addition, the renewable polymers used to make bioplastic products distributed in the UK are mainly sourced from continental Europe and the US with the exception of cellulose acetate films (Innovia Films and Clarifoil) [31;114]. However, it must be noted that it is not just the bioplastic resin or final packaging product that has to be transported long distances. For instance; wood for cellulose acetate production is in relatively short supply in the UK and has to be shipped in from managed forests in Europe and the USA [31].

8.0 The future of UK home-grown cereal and oilseed feedstocks in the production of bioplastics

The bioplastics market is predicted to grow six-fold by 2011 according to European Bioplastics {51}. This market potential may provide another opportunity for the industrial use of home-grown cereals and oilseeds in the UK. Wheat is currently the most favourable feedstock for starch-derived bioplastic manufacture in the UK. However, using wheat starch presents a challenge bec ause there are only a few companies able to currently extract starch and sugars for industrial use in the UK. Currently, Roquette (a French company) based in Corby and National Starch (Manchester, now owned by AkzoNobel, a German company) can supply dried starch for bioplastic manufacture. Most UK milling facilities accept grain from UK farmers including Cerestar/Cargill (Manchester), Roquette, Syral (formerly Tate and Lyle, Greenwich) and William Grant and Sons (Grangeston, Scotland). However, most of these facilities are currently focused on sugar or spirit manufacture for the food and drink industries. Since we do not have commercial scale starch bioplastic resin manufacturing capability in the UK yet, there is little driving force to convince grain milling companies to invest further in starch drying facilities. However, this may change if the bioplastics industry expands in the UK.

Alternatively, bioplastic manufacture in the UK could 'piggy-back' on the bioethanol industry. For instance; starch could be bought from bioethanol manufacturers to make starch-based bioplastics. Bioethanol itself could also be used to make polyolefin resins such as PE {115}. In addition, a recent theoretical study has shown that it is possible to manufacture PHAs from the 'black syrup' by-product of biomass-based bioethanol production on a commercial scale {90}.

8.1 Ideal starch feedstock properties for bioplastic manufacture

8.1.1 Starch types for bioplastics

Currently, approximately 80% of bioplastics are manufactured or derived from starch. Some bioplastics are constructed containing starch (TPS) and others are made by starch sugar fermentation (PLA, PHAs, see appendix section 11.1). It is therefore important to find a low cost, high starch content feedstock from which starch can be easily extracted. Common starch sources include maize, wheat, cassava and potatoes. Other potential starch sources include arrowroot, barley, some varieties of liana, millet, oats, rice, sago, sorghum, sweet potato and taro {116}.

The content, physical and chemical structure of starch differs depending on the source (see glossary). Starches also differ in the natural components present. For example; cereal starches contain lipids (fats) and proteins whereas potato starch has lower protein levels, no lipids and different mineral levels. It is noteworthy that salts, lipids and proteins present in starch may have an effect on its processing for bioplastic production.

Wheat produces a highly versatile starch similar to that of maize (see glossary). However, wheat is more attractive because it can be sourced in the UK when compared to maize which is usually imported from Europe (typically from France). Wheat milling is also attractive due to the production of high-value co-products such as gluten for the food and animal feed industries. Maize milling does produce co-products, but they, besides corn oil, are usually only sold into the animal feed market {117}. Interestingly, both maize and wheat are currently (or planned to be) milled for bioethanol production with the dried distillers grains and solubles (DDGS) co-product sold for animal feed {118}. Decades of maize breeding and genetic manipulation have led to the availability of a wide range of maize varieties with different properties suitable for food or industrial uses. However, wheat breeding has produced wheat varieties that are equally useful. In addition, production of starch from UK wheat may be a more sustainable approach than relying on starch imports that may not have been produced in the most environmentally-friendly way.

Potato starch has novel properties compared to other starches. For example; potato starch has a relatively open structure and absorbs more water than cereal starches {119}. It also contains more phosphorous than cereal starches and, as a result, has a higher viscosity (thickness) when mixed with water or a plasticizer (e.g. glycerol). It is also slightly harder to process by extrusion. However, there is evidence to suggest that starches containing high levels of phosphorous are more susceptible to biodegradation when they are made into plastic products {120}. Currently, there is no potato starch extraction industry in the UK and the economics of potato starch production are poor due to the lack of high-value co-products. Other factors that preclude UK potato starch production include the lack of European support payments to growers and manufacturers and the transport and processing costs due to the high water content of potatoes {117}.

Cassava and sweet potato starches have lower lipid levels and relatively high phosphorous content when compared to cereal starches. However, cassava and sweet potato starches contain fewer phosphorous compounds than potato starch. Cassava starch exhibits a viscosity between cereal and potato starches and is highly soluble when compared to other tuber and cereal starches making it relatively easy to manipulate for bioplastic production. Plasticized cassava starch also has a higher clarity than cereal starches {121}. Whilst these properties may be advantageous to the bioplastic industry, both cassava and sweet potatoes are not grown in Europe and have to be processed locally in Africa, Asia, Central or South America because they do not keep or travel well {122}. Starch from these sources may be relatively inexpensive, but the quality may vary considerably depending on the growth region, the age of the crop, the handling and storage of the raw material and the processing technique. For instance; in Viet Nam small starch production operations (typically of less than one tonne per day), with no uniform method of extraction, were responsible for about 70% of the total national output of cassava starch for 2005 {123}. It is important to note that starch manufactured in this way may result in environmental pollution because the waste water produced is rich in nutrients that may cause eutrophication of nearby streams and rivers. However, it must be noted that there are initiatives to reduce pollution from cassava starch manufacture {124}.

Starches from certain varieties of liana and taro exhibit very small starch granules when compared to other starches (such as potato starch) making them ideal for fillers in bioplastics. However, starch extraction is difficult and may require harsh chemical treatments which can lead to environmental pollution {121}.

8.1.2 Starch extraction

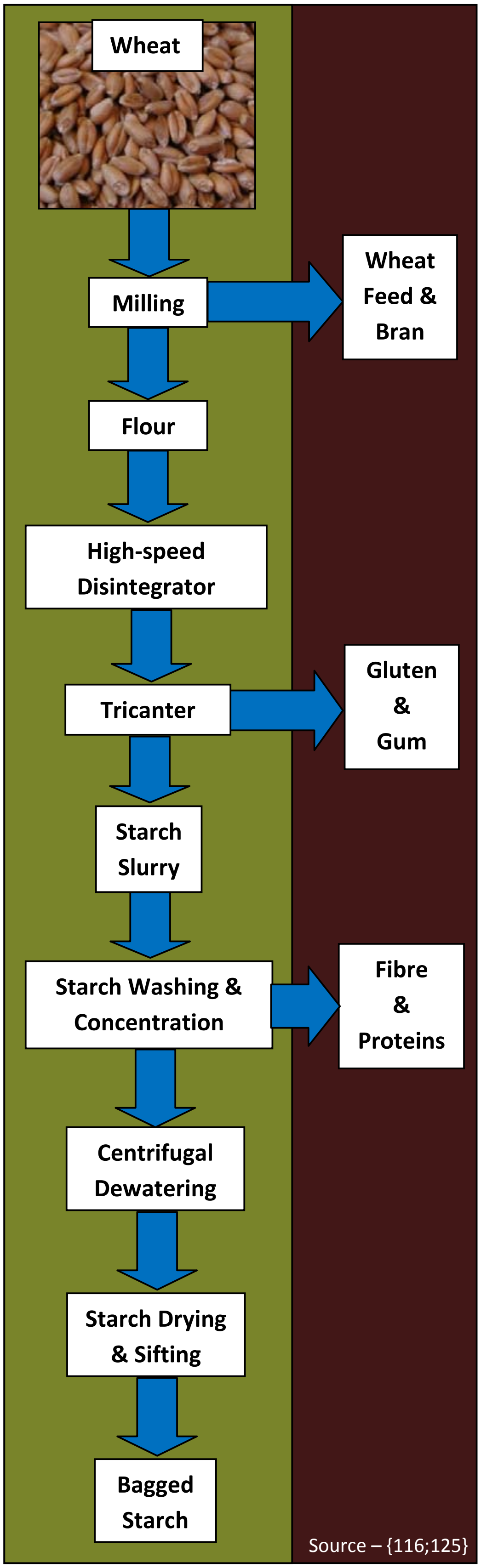
Starch extraction and purification from maize and wheat is usually performed by wet and dry milling, respectively. For potatoes and other root and tuber starches the process is very different in the primary stages, but starch purification is very similar for grain, roots and tubers.

For maize the first step involves cleaning to remove chaff and dust, the grain is then steeped in hot water to swell the grain, release soluble components (e.g. pentosans) and loosen the protein matrix. The steeped grain is then treated with sulphur dioxide. The steep water is then evaporated, the germ separated and the remaining endosperms are milled with water (wet milling). The starch, gluten and fibre are then separated through washing, screening and centrifugation. The starch is then purified by hydrocyclone (see glossary) removing more fibre and proteins. The starch is then dewatered and dried before packaging {116}.

For wheat the grain is initially dry milled to produce flour which is then treated in a wet separation process to extract starch. Flour is typically mixed with warm water in a high speed disintegrator. The starch, gluten and gum (pentosan) fractions are then separated by a three-phase decanter (tricanter). The gum fraction is usually used to make animal feed and the gluten fraction is treated, purified and sold as ‘vital gluten’. Some starch is also recovered during gluten purification. The starch slurries produced are purified further to remove fibre and soluble proteins by washing and hydrocyclone treatment. The purified starch is then dewatered by centrifugation, air-dried and screened before bagging for sale (see figure 8.01) {116}.

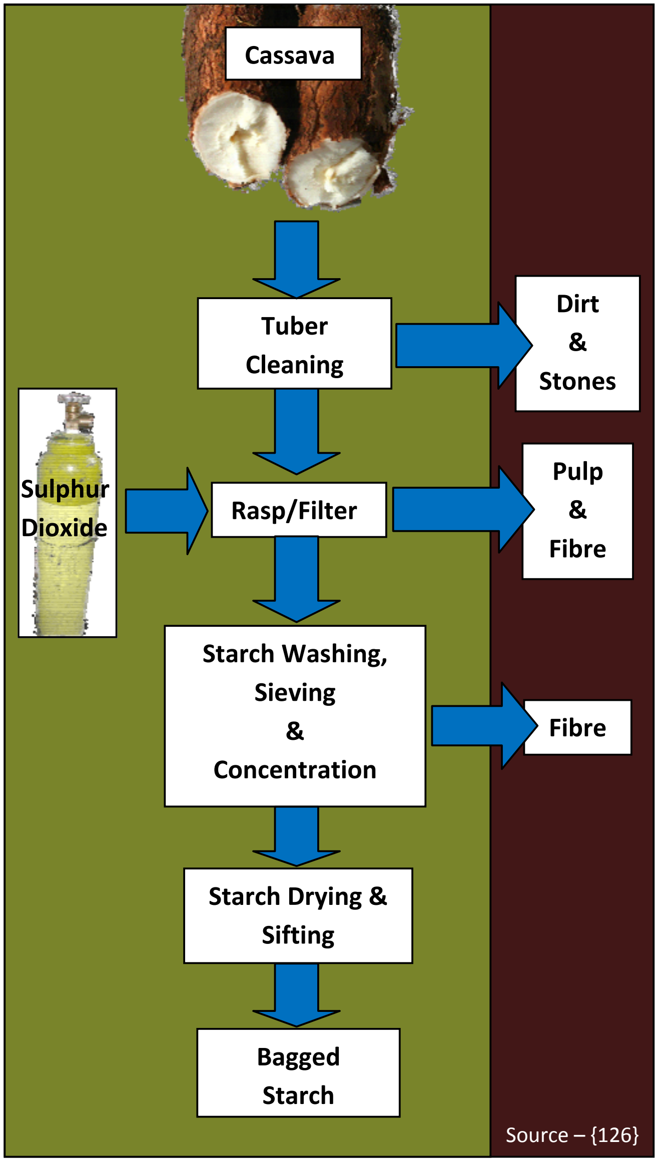
Starch extraction from both potatoes and cassava is similar, but differs from starch preparation from grain. Unlike dried wheat, potatoes and cassava are very susceptible to rapid deterioration through damage and lengthy storage {116}. Under ideal circumstances tuber/root starch crops should be processed as soon as possible after harvest to avoid starch breakdown and poor starch yields. The first step involves cleaning (and stalk removal for cassava) to remove dirt and stones. This step is vital for the quality and purity of the starch produced. The tubers/roots are then broken down into small pieces using a ‘rasper’ which also breaks open cells to help release the starch. Sulphur dioxide is then applied to prevent the browning of the pulverised mixture and the starch is flushed away from the pulp by washing and sieving. The pulp is processed further for cattle feed. The starch suspension is then concentrated by hydrocyclone and purified by repeated washing and concentration by hydrocyclone. The starch is then dried and sifted before packaging (see figure 8.02) {126}.

Figure 8.01 Wheat Starch Extraction



Source – {116;125}

Figure 8.02 Cassava Starch Extraction



Source – {126}

8.1.3 Choosing starch for bioplastic manufacture

It is currently possible to adapt the properties of a bioplastic material containing starch (see appendix section 11.1 and glossary) by adding other polymers if the starch used does not have all the characteristics required. However, adding crude-oil based polymers to starch during bioplastic manufacture reduces the sustainability and increases the GHG output associated with said bioplastic. In future, renewable additives will be required in order to reduce the environmental impact of starch bioplastics whilst maintaining functionality. For example; the addition of maize zein protein to thermoplastic starch (TPS, see appendix section 11.1) enhances its mechanical strength, lifespan and resistance to water {127}. Alternatively, choosing a ‘bespoke’ starch for a particular purpose may negate or reduce the requirement for bioplastic additives or reinforcements. For instance; starches with a high phosphorous content may be preferred for the production of bioplastics that require fast biodegradation thereby reducing the need for the addition of degradation catalysts {120}. Small granule starches, such as those extracted from varieties of liana and taro, may be chosen for bioplastic fillers in preference to potato starch which has large starch granules {121;128}.

For the production of bioplastics derived from starch-sugar fermentation products such as (PLA, see appendix section 11.1) the most important factor, other than raw material cost, is how easily a starch can be converted into sugars (saccharification) for subsequent fermentation. Generally, starches containing high levels of phosphorous compounds are more resistant to saccharification {120}. However, sweet potato and cassava starches (that contain phosphorous compounds) are converted to sugars relatively easily whereas potato starch (which also contains phosphorous compounds) is slightly more resistant when compared to maize starch {121}. Other authors have found that the order of enzyme digestibility of starches (to sugars) from fastest to slowest is as follows: wheat, maize, cassava, sweet potato and potato {129}. This indicates sugars may be sourced efficiently from wheat starch for the production of bioplastics such as PLA or PHAs (see appendix section 11.1).

8.2 The feasibility of polylactic acid manufacture in the UK

The UK uses bioplastics to a limited extent at the moment and there are more than 25 UK packaging converters and bag manufacturers that are willing to use such materials. However, we rely upon three bioplastic resin manufacturing hubs in North America, continental Europe and Asia to supply us with bioplastics (excluding cellulose acetate, see appendix section 11.1). This clearly shows that the bioplastics we currently use in the UK, with the exception of cellulose acetate, have to be imported. The UK can grow cereals and oilseeds for bioplastic production, but there are issues to contend with such as the land for food or industrial use debate. At the moment **NatureWorks LLC (in the USA) has the largest bioplastic manufacturing capacity of around 140 ktpa** {91}. **To produce this quantity of polylactic acid (PLA, see appendix section 11.1) only around 0.1% of the total US maize cropland would be required. Clearly, land use for bioplastic manufacture at the current stage in bioplastic industry development is relatively minor and will not significantly impact food supply.**

Currently, the largest manufacturer of PLA is NatureWorks LLC based (in the USA) far from the European cereal growing region. This means if Europe is to utilise its grain for sustainable PLA bioplastic manufacture it requires manufacturing facilities in Europe. If UK companies are to venture into bioplastic resin manufacture careful planning and piloting must be undertaken. To this end, in 2007-2008 DEFRA funded a National Non-Food Crops Centre (NNFCC) managed assessment of the potential for a PLA manufacturing plant in the UK {55}. In this report, produced by Peter Reineck Associates, there is an estimate that around **490 ktpa of feed-grade wheat could be used to produce around 200 ktpa of lactic acid for PLA manufacture. The feasibility study suggests that the market for PLA in the EU is currently 25 ktpa with estimated expansion to approximately 180 ktpa in 2015 and approximately 650 ktpa in 2025** {55}**.** According to the report, a cautious approach is warranted with initial consumption of approximately 34 ktpa of imported lactide intermediate feedstock to produce PLA. The next step would be to build a lactic acid plant with a view to begin operations in 2016, doubling the lactide capacity of the plant {55}. The final step would be to build a dedicated starch mill to dry-mill approximately 490 ktpa of wheat generating around 228 ktpa of native starch. This starch would then be converted to approximately 200 ktpa of lactic acid for the manufacture of about 132 ktpa of PLA. In addition, the plant would be capable of accepting around 320 ktpa of high dextrose (glucose) syrup from various suppliers as a backup feedstock {55}.

Another important factor is the location of a PLA manufacturing plant in the UK. The report suggests that PLA plant construction should be on a site close to existing UK starch and high dextrose syrup extraction businesses. In Europe, Roquette has collaborated with a number of large industrial companies such as Solvay and Arkema (involved in polymer manufacture) to form a French consortium called the 'Biohub®' program supported by the French industrial innovation agency (FIIA). Its aims are to bring together 'white' biotechnology companies for the production of renewable and sustainable chemical products {130}.

8.2.1 Land use and feedstock options for UK PLA manufacture

If a PLA plant utilising 228 ktpa of starch is to be built in the UK the issue of feedstock supply security is important {55}. As mentioned above, high dextrose syrups could be bought from companies already producing sugars in the UK. However, dedicated starch milling facilities will be required. **NatureWorks LLC quotes that about 2.5 kg of US maize grown on approximately 2.5 square metres of land is required to make 1 kg of PLA {91}. In 2007 more than 36 million hectares of maize was planted in the US with about 34 thousand hectares theoretically required for NatureWorks PLA production (at full capacity) {91;131}. This is approximately 0.1% of the total land used for growing US maize.**

For the UK there are several potential starch and sugar feedstock options including potatoes, sugar beet, feed barley, grain maize and feed wheat. However, not all would be economically viable. For example; potatoes have a high water content of around 80% wet mass and only around 18% starch making them expensive to transport and process to remove the water {116}. A more likely UK feedstock is wheat (with around 65% starch, 15% water and two million hectares in 2007) {116;131}. In March 2008 feed wheat was priced at around £180 per tonne, but dropped to around £100 per tonne in September 2008 (see figure 2.03) {38}. This type of price volatility is a problem when choosing renewable UK feedstocks for bioplastic manufacture. **In the UK the average yield of grain per hectare of wheat is approximately 7.6 tonnes (based on an average of UK wheat yields 2003-2007) {38}. This means that 490 thousand tonnes of wheat will require about 64,500 hectares of farmland equating to around 3.2% of the wheat growing area {131}. Between 2003 and 2006 the UK exported around 2-3 million tonnes of wheat per annum {132}. If the UK were to mill this quantity of exported wheat for industrial uses it would cover the amount required for PLA bioplastic manufacture (assuming only one PLA plant and no other starch bioplastic plants) and a portion of that needed for proposed bioethanol production (estimated wheat requirement of 3,300 ktpa) {55}.** However, it must be noted that this is only one possible option that does not incorporate an increase in wheat planting due to greater demand. **In theory the UK could utilise more of the 559 thousand hectares of former set-aside land for growing wheat to cover the new demand imposed by bioplastics and biofuels {133}. According to Defra around 270 thousand hectares of extra wheat could be grown on set-aside land producing approximately 2.1 million tpa in the immediate future. In the long-term future conversion of temporary grassland may provide 58,800 hectares of land with the potential to produce around 470 ktpa of wheat. Higher intensity crop rotation may also provide a further 247 thousand hectares of wheat equating to approximately 2 million tpa of wheat. A combination of the above may yield an extra 4.5 million tpa of wheat for food and industrial uses {134}.** However, a clear land use strategy will be required to try and minimise the environmental effects of more intensive farming practices eventually needed to supply extra crops for industrial uses. This issue links with the indirect land use concerns raised in the 'Gallagher' report on biofuel production and requires further work {135}.

8.3 The HGCA industrial uses programme

HGCA has a long-term interest in promoting the use of home-grown cereals and oilseeds for industrial uses such as biofuels, eco-composites and biopolymers. Since its conception in 1995, the HGCA Enterprise Award Scheme has helped provide funding to over 160 different businesses for the development of a number of food and non-food uses for grain and grain by-products. Industrial uses projects over the years have included (amongst many others) the production of: 1) fuel pellets from miscanthus and grain; 2) paper from wheat straw; 3) renewable fuels from grain; 4) bio-resins from oil seed rape oil; 5) mulch mats using linseed and wheat straw; 6) eco-packaging foam from extruded wheat (see www.hgca.com/enterprise for details).

Recently, Cambridge Biopolymers (Duxford, UK), a 2005 HGCA Enterprise Award winner, has developed a bio-resin system using oil seed rape oil. This renewable alternative to petrochemical based resins has several potential applications including: 1) eco-friendly mannequin manufacture; 2) model and sculpture casting (see figure 8.03); 3) oriented strand construction board (OSB) production; 4) chemical micro-encapsulation; 5) coatings and adhesives; 6) eco-friendly coffin manufacture.

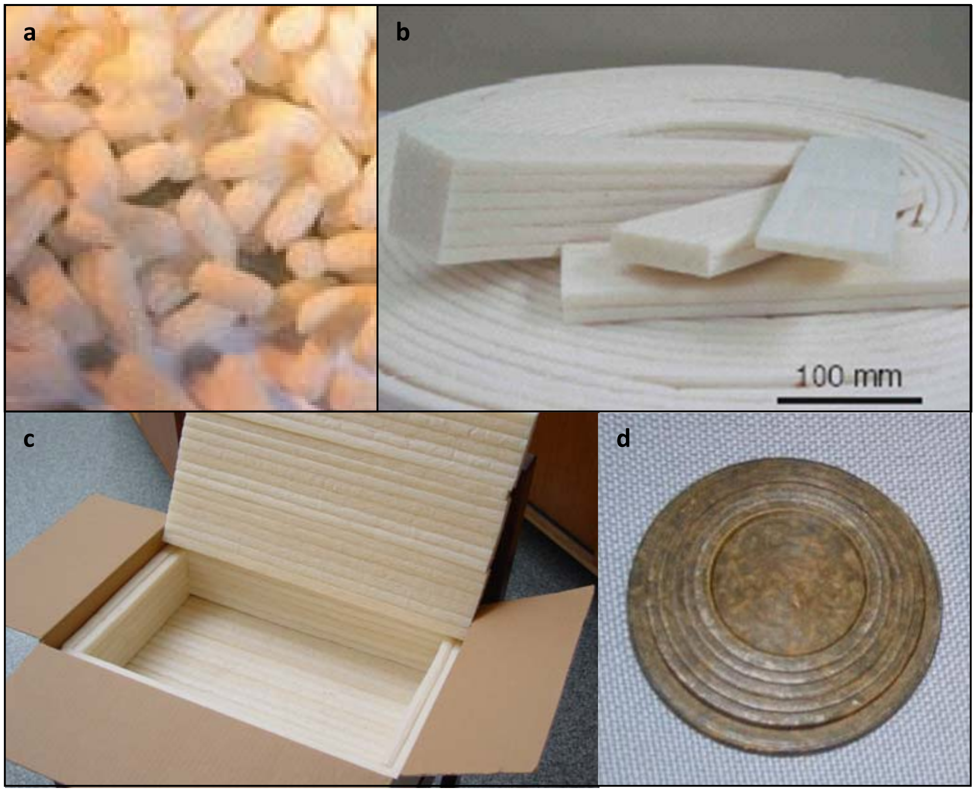
Figure 8.03 Oilseed Rape Oil-Based Bioresin Casting and Moulding

Source – Cambridge Biopolymers (lead scientists: Fitchett, C. and Chappell, C., Duxford, UK)

Eco-mats (Ely, UK), a 2008 HGCA Enterprise Award winner, has developed a 100% biodegradable plant-based mulch mat material from linseed and wheat straws. The mats are constructed using fibres bonded together with a PLA binder and are designed to help control weed growth, soil moisture retention and erosion.

HGCA has also helped fund research and development into the use of wheat flour, starch and straw in the manufacture of eco-composite materials. Some of the potential applications of expanded wheat flour and starch include: 1) loosefill packaging (a replacement for expanded PS, see figure 8.04a); 2) regular packing and stacking (RPS) foams (see figure 8.04b); 3) compression bonded loosefill (CBL) boards; 4) void makers in concrete for cables and piping; 5) coolboxes (see figure 8.04c and www.hgca.com for details). Other applications for wheat starch and straw composites include: 1) 'straw pigeons' (a replacement for clay pigeons, see figure 8.04d); 2) road barriers; 3) tree shelters.

Figure 8.04 Wheat Starch and Straw Products



Source – RM DEFRA LINK RM046/DTI APPS2B project s (lead scientists: Song, J. and Tarverdi, K., Brunel University, UK).

8.3.1 Plans for the HGCA industrial uses programme

HGCA has devised a strategy to help develop the UK market for bioplastics manufactured from home-grown cereals and oilseeds. Over the coming months (Jan 2009 onwards) HGCA aims to: 1) increase awareness of bioplastics through publications, talks and articles; 2) develop contacts with each segment of the plastic packaging supply chain; 3) assist the plastic packaging supply chain with information and ideas.

Marketing activities will include:

- Continued support for companies to develop novel bioplastic uses
- Work with manufacturers and retailers to develop supply chains
- Participation in a UK PLA manufacturing thematic working group
- A supply chain symposium with speakers from each industry sector
- Presentations to the farming community
- A bioplastics stand at Cereals 2009

HGCA will also contribute to:

- Trials for the disposal routes of mixed bioplastics
- A supermarket survey of bioplastic usage
- A Non-Governmental Organisation attitude survey on biopolymers
- A survey of Local Authority and service company attitudes to biopolymers

Research and development activities will include:

- Ongoing support of Defra LINK renewable materials projects
- A report on the disposal best practices for bioplastics

9.0 Glossary

Anaerobic digestion or AD is a form of controlled biodegradation of organic matter by micro-organisms such as bacteria in the absence of air. AD feedstocks are typically waste water sludges, animal by-products, food and other organic wastes. The system usually consists of one or more enclosed vessels where temperature and feedstock composition are carefully controlled. The gaseous end products of digestion are predominantly methane (CH_4) and carbon dioxide (CO_2) at around 60% and 40% by volume, respectively {164}. The methane produced is usually captured and burnt for heat and power generation. Other products include compost or liquid fertiliser 'liqour' that can be used to rejuvenate farmland. Note that there is a standard under development for compost and 'liquor' produced by AD termed PAS 110 {82}.

Biodegradable plastics can be crude oil-based plastics or bioplastics. They are defined as plastics that can be completely broken down by micro-organisms in the environment to form non-toxic compounds. Under aerobic conditions these compounds are typically carbon dioxide (CO_2) and water (H_2O). Whereas, under anaerobic conditions (such as in landfill) methane (CH_4) is released. **Biobased biodegradable** bioplastics are plastics manufactured from renewable resources that are also biodegradable. **Biobased non-biodegradable** bioplastics are plastics manufactured from renewable materials that cannot be easily broken down by micro-organisms (e.g. PP or PE derived from bioethanol).

Biodrying is a partial composting treatment of the organic waste fraction of municipal or industrial waste by micro-organisms to 'stabilise' the material for burning or secondary processing. If the material produced is to be burnt it is normally termed refuse-derived fuel or RDF.

Bioplastics are typically plastics containing **biopolymers** made using renewable materials (such as starch, sugars and oils) extracted from plants. Bioplastics can be made using naturally occurring native plant polymers such as starch, cellulose and lignin (see appendix section 11.1). They can also be made using plant-derived sugars in microbial fermentation processes. Alternatively, bioplastics can be manufactured from plant oils using conventional (or modified) polymer chemistry methods. Some biodegradable bioplastics contain a mixture of biopolymers and crude oil-based polymers. Note: bioplastic should not be confused with biodegradable plastic (see **biodegradable plastics**).

Carbon footprinting is a method of measuring the amount of carbon dioxide (CO_2) and other global warming greenhouse gasses (GHGs), such as methane (CH_4), emitted into the atmosphere by human activity. A neutral carbon footprint indicates that the process or product in question does not produce a net increase in GHG emissions. Note that some GHGs are worse than others: CH_4 and nitrous oxide (N_2O) are 23 and 296 times more potent than CO_2, respectively {17}.

Compostable is a common term used to describe a disposal option for certain bioplastics. Currently, 'compostable' is often mistaken to mean 'home compostable'. However, not all compostable plastics will break down under home composting conditions. Some plastics may require higher temperatures than others to break down. These temperatures may only be achieved under controlled industrial composting conditions. The EN 13432 European Standard defines that a 'compostable' plastic must totally biodegrade in six months {11}. Some biodegradable plastics may not degrade quickly enough and therefore cannot be classed as 'compostable'.

Degradable plastics are usually petroplastics containing catalysts that breakdown the polymer structure under ultraviolet (UV) light, heat or mechanical stress. The term 'oxodegradable' is sometimes used for this type of oxidative plastic degradation process. The majority of the breakdown process to CO_2 and water is usually not reliant upon micro-organisms. However, latter stages may employ micro-organisms such as bacteria that can assimilate some of the carbon into biomass {137}. Note: degradable should not be mistaken for biodegradable.

Energy from waste (EfW) options are processes such as gasification, incineration and pyrolysis that result in the production of heat and power from municipal and industrial waste.

Gasification is the partial burning of waste in the presence of oxygen and steam. A mixture of carbon monoxide (CO) and hydrogen (H_2) termed synthesis gas or 'syngas' is generated which is then burnt to produce heat and power.

Hydrocyclone – A piece of equipment that allows the separation of particles in suspension (e.g. starch and fibre) by the natural spin of the suspension fed into a conical column from one side. Dense particles leave the narrow bottom of the cone whereas less dense particles leave in the liquid extracted from the top of the cone. There are several designs available depending on the densities of the materials to be separated.

Incineration is a disposal route for combustible waste materials such as plastics and organic materials. Combustible materials (e.g. RDF) are typically shredded and blended to create a relatively uniform feedstock. The material is then usually fed into the incinerator via a moving grate and is burnt under the specifications of the Waste Incineration Directive (WID, 2000/76/EC) in order to reduce the output of harmful dioxin and furan compounds {64}. Flue gas is normally recycled to ensure complete combustion of the gas and is eventually filtered and cleaned to remove particulate material and other gasses before release into the atmosphere. Bottom ash and fly ash (from chimneys) are both produced as a waste which is usually sent for landfill. The heat generated during combustion is normally used to generate power and provide industrial (and domestic) heating.

Life cycle analysis (LCA) is an environmental impact auditing methodology that can be applied to procedures, processes or manufactured products and is a detailed examination of, for example: 1) the source of raw materials; 2) product manufacturing; 3) product use and reuse; 4) product recycling and disposal. LCAs are useful because they quantify environmental impacts such as the energy used, and GHG emissions produced, during the life of a product.

A Publicly Available Specification (PAS 2050) is under development by the British Standards Institution (BSI) funded by the Carbon Trust and Defra. This legislation aims to provide a standard method for life cycle analysis of goods and services in the UK (see section 2.0.5) {34}.

Mechanical biological treatment of waste (MBT) is the treatment of mixed waste (municipal or industrial) at a plant that can initially sort recyclable materials from the waste and then compost, anaerobically digest or dry the organic materials to a stable form that can be either utilised or processed further. A typical facility has a 'front-end' mechanical sorting plant (MRF) coupled to a composting or AD process. However, a number of permutations in plant design are possible with current methods and technologies. Typical outputs include a recyclable fraction, a non-recyclable non-compostable fraction (which is usually sent to landfill) and an organic fraction (which is composted, treated by AD or dried). Various gasses are also produced during the 'stabilisation' of the organic matter fraction depending on whether it is composted or treated by AD. Composting produces mostly carbon dioxide (CO_2). AD produces both CO_2 and methane (CH_4). Some MBT plants partially microbially treat waste to produce dry material in a process termed **bio-drying**. The material produced is usually termed refuse derived fuel (RDF) which is then burnt to produce heat and power. A variant of MBT is **biological mechanical waste treatment (BMT)** which entails a reversal of the waste processing steps of MBT so that treatment of the organic matter occurs first with the removal of recyclable and non-recyclable materials afterwards.

Petroplastics are plastics made using chemicals (e.g. naphtha) derived from crude oil.

Polyolefin is a general chemical term given to polymers made from simple 'olefin' molecules such as ethylene (used to make polyethylene or PE).

Pyrolysis is the chemical decomposition of organic materials by heating in the absence of oxygen to produce a mixture of carbon monoxide (CO) and hydrogen (H_2) termed synthesis gas or 'syngas' which is then condensed to form an oil that can be used as a fuel.

Renewable resources are natural resources that can be replenished from the environment on a relatively short timescale.

Saccharification is a process by which sugar polymers such as starch or cellulose are broken down or 'hydrolysed' to their component sugars (i.e. glucose). Typically either acid or enzyme hydrolysis is used. However, enzyme-based methods are preferred because they are more controlled, efficient, economic and environmentally-friendly. Properties that may affect the ease by which starch is converted into sugars include: 1) starch solubility; 2) starch structure; 3) starch grain size; 4) phosphorous compound levels; 5) the presence of contaminants.

Starch is a plant energy storage compound principally made up of two glucose sugar polymer compounds called amylose and amylopectin. Amylose and amylopectin are linear and branched polymers of glucose, respectively. The content of these two polymers varies between different plant starches and provides different structural, functional and processing properties to each starch. Typical sources of starch include maize, wheat, cassava and potatoes. Other potential starch sources include arrowroot, barley, some varieties of liana, millet, oats, rice, sago, sorghum, sweet potato and taro {115}. The starch content of maize, wheat, potatoes and cassava is approximately 62, 65, 18 and 22%, respectively (see appendix). Table 9.01 shows the typical amylose and amylopectin content of several starch sources. When dissolved in water, amylose forms a viscous clear gel whereas amylopectin absorbs water and swells. This affinity of amylopectin for water affects the solubility of starches.

Table 9.01 Starch Amylose and Amylopection Content

Starch Source	Amylose Content [%]	Amylopectin Content [%]
Maize	28	72
Wheat	26	74
Potatoes	20	80
Cassava	17	83
Barley	22	78
Sweet Potato	18	82

Source – {165}

For instance; potato starch will absorb more water than wheat starch and materials made containing high starch amylopectin levels tend to be more sensitive to water {138}. Starches also vary in the level of contaminants present. For example; cereal starches contain lipids (fats) and proteins whereas potato starches contain lower protein levels and no lipids. Different starches also contain different mineral levels.

Starch can be utilised in its native (or chemically modified) form with other additives to create bioplastics or it can be broken down into its sugar units for the production of bioplastics by bacterial fermentation (see appendix section 11.1). Interestingly, extruded starch materials (plastisised with glycerol) made from amylopectin-rich starch (97-98% amylopectin) are soft and flexible, but upon aging they shrink and crack. Materials made using high amylose starch (70% amylose) generally have good strength and stiffness and age better than amylopectin-rich materials {138}.

Sustainable development is the use of resources to meet current demands without jeopardising the ability of future generations to meet their own needs {139}.

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11.0 Appendix

11.1 Current and future bioplastics

Bioplastics are polymers derived from renewable feedstocks including wood, starches, sugars and oils. Bioplastics can be grouped into different types based on their polymer structures and inherent physical properties. Examples of current and future bioplastics can be found in table 11.01.

Table 11.01 Examples of Bioplastics

Primary Feedstock	**Bioplastic Name**	**Trade Name**	**Example of Use**	**Reference**
Starch	Thermoplastic starch (TPS)	TPS	Disposable cutlery	{140}
Starch	Plastarch material (PSM)	PSM	Disposable cutlery	{141}
Starch/ Crude oil	Starch/polycaprolactone (or polyvinyl acetate) mix	Mater-Bi	Plastic bags	{92}
Starch sugars	Polylactic acid (PLA)	Ingeo™	Cold drinks cups	{142}
Starch sugars	Polyhydroxyalkanoates	Mirel™	Cups	{105}
Starch sugars	Polyester made with 1,3 propanediol	Sorona® EP	Glass reinforcement	{143}
Starch sugars	Polyester made with 1,4 butanediol	Polybutylene terephthalate (PBT)	Electrical insulation	{144}
Starch/ crude oil	Polyester/PLA mix	Ecovio®	Carrier bags	{145}
Wood, cotton or hemp cellulose	Cellulose acetate	NatureFlex™	Food packaging film	{31}
Wood (lignin)	Lignin	Arboform®	Electronics housings	{106}
Castor beans	Nylon	Rilsan® PA11	Automotive tubing	{146}
Soya beans	Polyurethane	Polyurethane	Construction insulation	{147}
Starch/ crude oil	Polypropylene	Biopropylene50	Packaging	{148}
Sugarcane-derived bioethanol	Polyethylene	Green polyethylene	Packaging	{149}

11.1.1 Starch-based bioplastics

Starch-based bioplastics can be split into two groups. Those that are formed from starch itself and those manufactured from starch-sugar fermentation products. Both forms can be made from starch extracted from a variety of plants including maize, wheat, cassava and potatoes. Other potential starch sources include arrowroot, barley, millet, oats, rice, sago, sorghum and sweet potato {116}. Typical average yields of the major starch crops (2007) are given in table 11.02.

Table 11.02 Starch Crop Yields 2007

Starch Crop	Typical Crop Yield [tonnes per hectare][a]	Typical Starch Yield [tonnes per hectare]	Typical Crop Starch Content [% wet weight][b]
Maize (US)	9.5	5.9	62
Wheat (UK)	7.3	4.7	65
Potatoes (UK)	40.5	7.3	18
Cassava (Nigeria)	11.9	2.6	22

[a] {150}. [b] {116}.

11.1.1.1 Starch bioplastics

Starch is a natural polymer of glucose and can be used to manufacture plastics without disassembly to its sugar units. There are several different formulations and blends (with petroplastics) of biodegradable starch plastics including thermoplastic starch (TPS) and plastarch material (PSM). Starch bioplastics are usually made by heating maize or potato starch with a plasticiser, such as glycerol, under shear force to produce a mouldable plastic {151}. TPS and PSM plastics are pelleted resins that are manufactured by several companies including PSM North America and Cereplast (both US based) {140;141}. Starch bioplastics can effectively replace petroplastics such as polyethylene (PE) and polystyrene (PS) in applications such as disposable cutlery (see figure 11.01), food packaging, plastic bags and mulch film.

Figure 11.01 Thermoplastic Starch Cutlery

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11.1.1.2 Starch sugar-based bioplastics

Sugar, namely glucose, manufactured from starch can be used as a nutrient in bacterial fermentation processes to produce bioplastics or their precursors. There are three main bioplastic/bioplastic precursor groups made in this way:

1) Polylactic acid or PLA
2) Polyhydroxyalkanoates or PHAs
3) 1,3 propanediol or 1,4 butanediol (Bio-PDO and Bio-BDO, respectively), precursors for bioplastic production

11.1.1.2.1 Polylactic acid

Polylactic acid, or PLA, is a biodegradable bioplastic mainly produced by NatureWorks LLC (a Cargill-Teijin venture) situated in the heart of US corn country in Blair, Nebraska. The plant has a production capacity of about 140 thousand tonnes of PLA per year and uses mainly maize starch (but other cereal starches could be used) as a raw material. The starch is initially extracted and broken down (hydrolysed) into glucose which is then fed into fermenters where bacteria convert it into lactic acid. The lactic acid is then converted to 'lactide' and polymerised to form PLA (for production steps see appendix section 11.3) {89}. The finished product takes the form of white pea-sized granules that can be processed further for use in applications such as packaging, cold drinks bottles, CDs, carrier bags and apparel (see figure 11.02). PLA is a suitable substitute in certain applications that normally use petroplastics such as PE, polyethylene terephthalate (PET), polypropylene (PP) and PS.

Figure 11.02 PLA Products

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11.1.1.2.2 Polyhydroxyalkanoates

Polyhydroxyalkanoates (PHAs) are naturally occurring biodegradable polymers made by several bacteria under specific nutrient conditions: plentiful carbon source (typically sugars), but limited nitrogen and phosphorous {153}. To produce PHAs such as poly-(3-hydroxybutyric acid), or PHB, maize (and potentially other cereal) starch sugars are extracted and fed to fermenters where bacteria produce the polymer. The bacteria are then harvested and the minute polymer granules are extracted. There are several companies that make PHAs, but US-based Metabolix is the main producer. Metabolix, in partnership with Archer Daniels Midland (ADM), has plans to produce around 50 ktpa of PHB at their Telles Iowa plant in 2009 under the Mirel™ brand name {105}. The Mirel™ product is a white granulated plastic that can be processed into agricultural mulch film, compostable bags, cups, food and cosmetic packaging. Importantly, PHBs such as Mirel™ are a good substitute for a wide range of petroplastics (including PP) in certain applications. Interestingly, PHB can also be made using maple sap in a similar way to maize sugars {153;154}.

11.1.1.2.3 Plastics made using bio-based 1,3 propanediol and 1,4 butanediol

Bioplastics and non-biodegradable plastics can be made from the chemicals 1,3 propanediol (Bio-PDO) and 1,4 butanediol (Bio-BDO) derived from bacterial fermentation of starch sugars. Bio-PDO is used in combination with other compounds including terephthalic acid or dimethyl terephthalate to produce non-biodegradable polyester plastics such as Sorona® EP made by DuPont. Sorona® EP is currently under development for use as a glass reinforcement plastic {143}. Genomatica, a US biotechnology company, is involved in the development of micro-organisms and fermentation procedures for the production of Bio-BDO for solvents and non-biodegradable plastics such as polybutylene terephthalate (PBT) {143}.

11.1.2 Cellulose-based bioplastics

Cellulose was first used in the production of celluloid plastic in 1870 {155}. Now several companies utilise sustainably sourced wood pulp or cotton-derived cellulose to make biodegradable films. The process involves purifying cellulose fibres from wood pulp followed by chemical modification to produce cellulose acetate (CA) {156}. The resultant plastic has a high translucency and is mainly used in food and cosmetic product packaging. UK companies that manufacture cellulose acetate films from managed and sustainable resources include: 1) Innovia Films who produce about 2,500 tpa under the NatureFlex™ brand name (see figure 11.03) {31}; 2) Clarifoil {114}.

Figure 11.03 Cellulose Acetate Film

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11.1.3 Lignin-based bioplastics

Lignin is a complex polymer of 'lignol' aromatic alcohols produced by plants and, in combination with cellulose, forms the main constituent of wood (lignocellulose) which is used to maintain the structural integrity of plant tissues {157}. Lignin can be used in the formulation of bioplastics as the main structural biopolymer. Tecnaro, a German company, manufactures bioplastic products using lignin derived from paper pulp by-products and fibres obtained from flax, hemp and other plants. Applications include automotive interior parts, toys, electronics housings and construction components (see figure 11.04) {105}.

Figure 11.04 Lignin-Based Speaker Hulls

Source – {106;166}

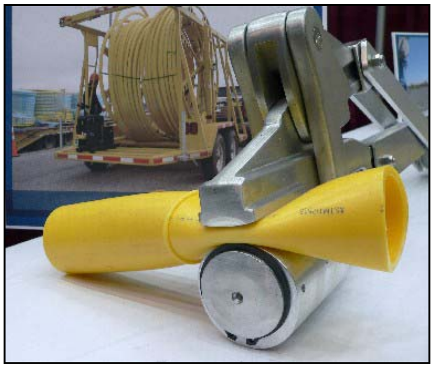
11.1.4 Renewable resins

Another avenue explored by polymer manufacturers is the production of non-biodegradable resins (such as polyethylene) using renewable materials such as cellulose, starch and plant oils. There are several examples available on the market produced by companies such as Arkema (France), Dow Chemical Co. (USA) and DuPont (USA) (see section 11.1.4.1 and 11.1.4.2) {146;147;158}.

11.1.4.1 Plant oil-based conventional plastics

It is possible to produce Nylon (a polyamide or PA) and polyurethane (PU) plastics from renewable oils extracted from castor beans, soya beans and palm kernels. Arkema produces a PA plastic called Rilsan® PA11 from castor oil {146}. Typical applications for Rilsan® PA11 include electrical cable sheathing, automotive tubing and medical devices (see figure 11.05). Dow Chemical Co., a US company,

Figure 11.05 Rilsan PA11 Tubing



Source – {146}

manufactures PU plastic from soya bean oil. PU foams are generally used in packaging, building insulation and carpet backing {147}. In addition, DuPont manufactures PA bioplastics using soya bean and palm oils. Their Selar® VP PA is available in film form for use in covering foods or products that require controlled gas exchange and moisture levels {158}.

11.1.4.2 Cellulose and starch-based conventional plastics

Cellulose, hemicellulose and starch (when broken down to their constituent sugars) can be utilised to produce a plethora of conventional polymers such as PBT used in electrical insulation, and polymethyl methacrylate (PMMA or Plexiglas) used as an alternative to glass. Plant derived sugars can also be utilised for the production of detergents, solvents and a variety of other useful products {159}.

Currently, Cereplast (USA) produces a non-biodegradable PP plastic called Biopropylene 50 made with 50% starch and 50% PP (see figure 11.06) {148}. Interestingly, dehydration of bioethanol produces ethylene which can be used to make PE plastics {115}. Various companies including Braskem (Brazil), Solvay Indupa (Argentina) and Dow Chemical Co./Crystalsev (Brazil) are investing in, or are already producing bio-derived, non-biodegradable ethylene/PE {149;160}. This area of development is particularly interesting due to the current engagement of the global chemical industry in bioethanol production.

Figure 11.06 Biopropylene 50 products

Source – {148}

11.1.5 Bio/petropolymer blends

Compatible biopolymers and petropolymers can be mixed to create blended (or hybrid) bio/petroplastics. The advantage of mixing polymers is that it creates products with characteristics which cannot be replicated by a bioplastic on its own. From an environmental stance, producing a bio/petroplastic hybrid reduces the carbon footprint and increases the sustainability of a product that normally uses solely petroplastic. However, there are some disadvantages to using such hybrids. For instance; they are not completely renewable and require fossil fuel resources for feedstock. They may also cause issues with disposal if the bioplastic components are biodegradable and compostable, but the petroplastic constituents are not. In a composting scenario the remaining petroplastic components would have to be sent to landfill, an EfW/biomass plant or recycled to fully dispose of the plastic. Plastic resin manufacturers realise that the biodegradablility of non-renewable components is imperative. As a result, resin manufacturers design hybrid bio/petroplastics to be fully biodegradable.

Several companies manufacture bio/petroplastic blends including BASF (Germany), DuPont and Novamont (Italy) {145;158;92}. BASF supply a hybrid with 45% renewable content called Ecovio® which contains a biodegradable polyester petroplastic (Ecoflex®, constructed from terephthalic acid, adipic acid and 1,4-butanediol) combined with PLA (see figure 11.07). BASF currently manufactures 14 ktpa of Ecoflex® which in conjunction with PLA can be used to make carrier bags (see figure 11.07) {145}.

Figure 11.07 Ecovio Film

Source – {145}

DuPont makes several bio/petroplastic hybrids such as Hytrel®, Sorona® EP and Selar® VP. Both Hytrel® and Sorona® EP are 20-37% and 25-50% renewable, respectively. Both are made using a product of maize starch fermentation (Bio-PDO) mixed with non-renewable components {143}. Hytrel® is marketed for use in tubing, wiring and film applications, whereas Sorona® EP is under development for use as a glass reinforcement material. Selar® VP PA plastic contains 30% renewable content {158}. Novamont produces a compostable bio/petroplastic hybrid with up to 95% renewable content called Mater-Bi using maize starch and non-renewable ingredients. Mater-Bi is typically marketed for use in plastic bags, food packaging and disposable cutlery (see figure 11.08) {92}.

Figure 11.08 Mater-Bi Bags

Source – {92}

11.1.6 Bioplastic composites

It is possible to improve the functionality of a bioplastic material by combining different polymer types in different layers (laminates) or zones. A good example is packaging for Jordans organic cereals in the UK. The plastic laminate utilises an outer layer of printable NatureFlex™ NE30 (more than 95% renewable) and an inner web of Mater-Bi (up to 95% renewable) to provide a moisture barrier (see figure 11.09) {161}.

Figure 11.09 NatureFlex/Mater-Bi Bags

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Bioplastic composites also include materials containing a biopolymer in conjunction with structural reinforcement materials such as carbon, plant or wood fibre. For example, NEC has developed PLA/carbon fibre and PLA/Kenaf composite bioplastics with enhanced heat conductivity and strength for use in mobile phone and computer casings (see figure 11.10) {162}. Non-fibre additives can also be applied to bioplastics to give them desirable properties such as flame resistance {163}.

Figure 11.10 NEC PLA/Kenaf N701i ECO Cell Phone

Source – {162}

11.2 EU recycling and biodegradable waste reduction targets

Table 11.03 EU Material Recovery Targets 2008 (by weight)

Material	Target [%]
Paper	60
Glass	60
Metals	50
Plastic	22.5
Wood	15

Source - {39}

Table 11.04 Business Material Recycling Targets (by weight)

Material	2008 Target [%]	2009 Target [%]	2010 Target [%]
Paper/Board	67.5	68.5	69.5
Glass	78	80	81
Aluminium	35	38	40
Steel	68	68.5	69
Plastic	26	27	29
Wood	20.5	21	22

Source - {40}

Table 11.05 Landfill Directive Biodegradable Waste Reduction Targets (by weight)

Date	Reduction from 1995 levels [%]
2010	25
2013	50
2020	65

Source - {19}

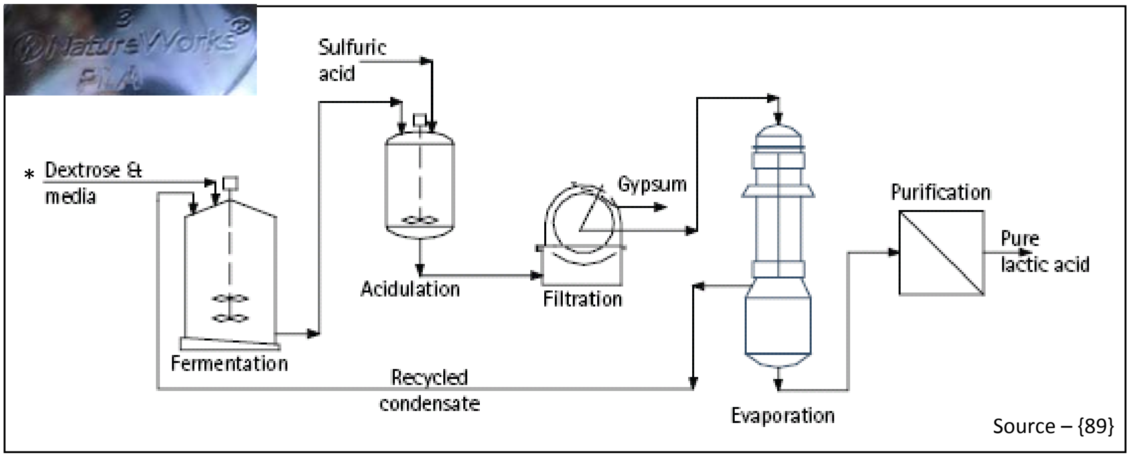
Table 11.06 Packaging Recovery Note (PRN) prices March 2009

Material Category	Price [£ per tonne]
Glass	22-25
Paper	4-7
Aluminium	45-80
Steel	30-50
Plastics	24-28
Mixed – Energy Recovery	3-6
Wood	4-7

Source – {41}

11.3 NatureWorks PLA manufacture

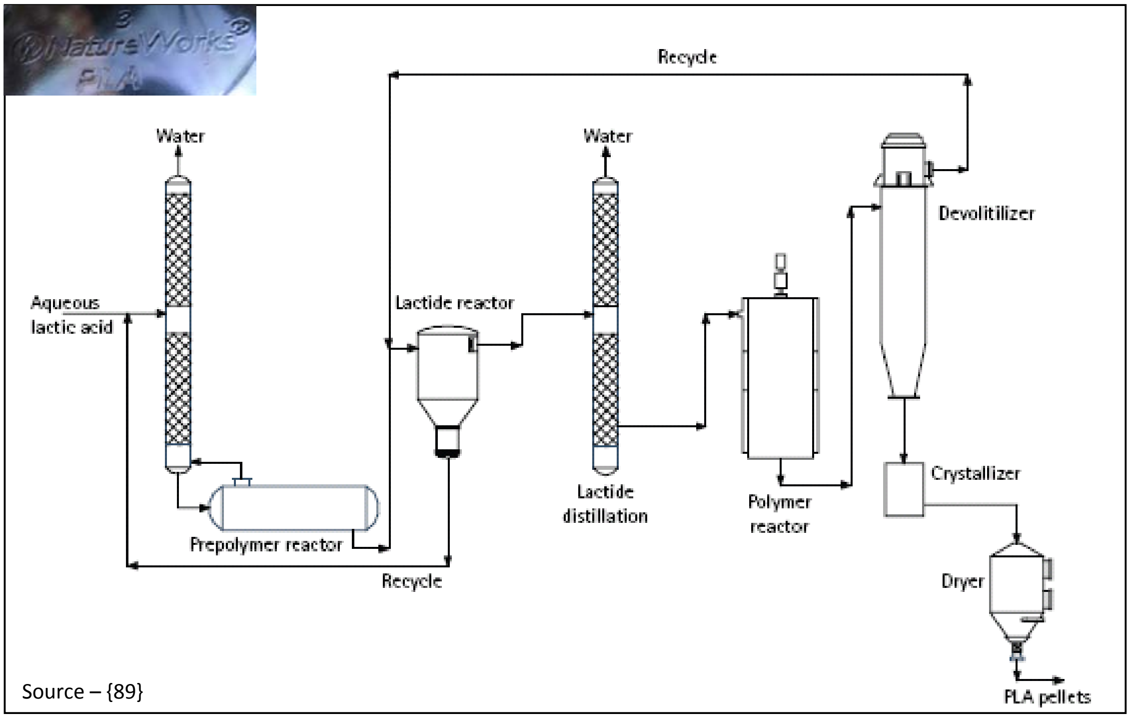
Figure 11.11 Manufacture of Lactic Acid from Maize Dextrose



Source – {89}

* Dextrose and media – Glucose and bacterial nutrients

Figure 11.12 Manufacture of PLA from Lactic Acid



Source – {89}