Industrial uses for crops: Bioplastics

HGCA

A *polymer* is a substance with a structure formed of many identical small organic molecules bonded together.
A *plastic* is a synthetic material made from a wide range of organic polymers.
A *bioplastic* is a plastic made using renewable biomass.
A *mixed bioplastic* is a plastic derived from both renewable biomass and fossil fuels.

Bioplastics are manufactured using biopolymers which offer a renewable and sustainable alternative to oil-based plastics (petroplastics). Other advantages of bioplastics include novel functional properties and relatively low greenhouse gas (GHG) emissions during manufacture (see table).

Bioplastics can be produced from plant starch, cellulose, lignin (wood), oils and proteins. Like petroplastics, bioplastics are compounds constructed of linked molecules that form long polymer chains (biopolymers).

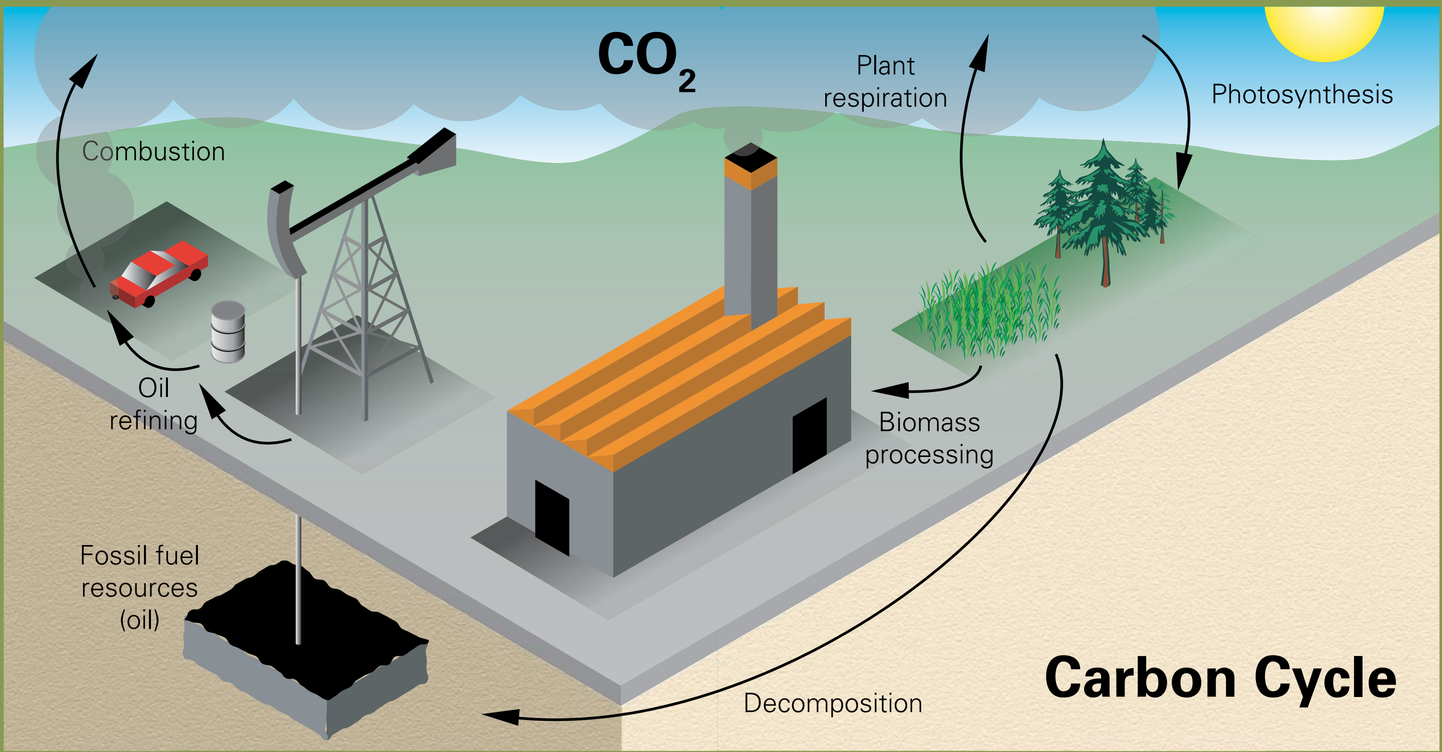
Bioplastics Vs Petroplastics

	Bioplastics	**Petroplastics**
Renewable	Yes or partially	No
Sustainable	Yes	No
Break down in the environment	Biodegradable and/or or compostable	Some degradable by polymer oxidation
Polymer range	Limited but growing	Extensive
GHG emissions	Usually low	Relatively high
Fossil fuel usage	Usually low	Relatively high
Arable land use	Currently low	None

Most, but not all, bioplastics can be broken down in the environment by micro-organisms (as part of the 'carbon cycle' – see below) in a process called 'biodegradation'. This process produces carbon dioxide (CO_2) and water (H_2O) under aerobic conditions or methane (CH_4) under anaerobic conditions (in the absence of air) such as in landfill.

Mixed bioplastics are usually biodegradable, but some are not and can be either recycled or processed for energy recovery.

Note that items labelled as 'biodegradable' should not be confused with those marked as 'degradable'. The latter materials break down in the environment by chemical rather than biological means.



What are biodegradable bioplastics made of?

Biodegradable bioplastic – a plastic derived from renewable biomass that can be broken down in the environment by micro-organisms.

Starch-based bioplastics can be manufactured from either raw or modified starch (e.g. thermoplastic starch or TPS) or from the fermentation of starch-derived sugars (e.g. polylactic acid or PLA). Common starch sources include maize, wheat, potatoes and cassava.

Cellulose-based bioplastics are typically chemically-modified plant cellulose materials such as cellulose acetate (CA). Common cellulose sources include wood pulp, hemp and cotton.

Lignin-based bioplastics contain wood (or lignocellulosic plant material) produced as a by-product of the paper milling industry.

Plant proteins such as maize 'zein' can also be used to manufacture bioplastics.

What are non-biodegradable bioplastics made of?

Non-biodegradable bioplastic – a plastic derived from renewable biomass that cannot be easily broken down in the environment by micro-organisms.

Conventional plastic resins can be made from plant oils and are manufactured using compounds extracted from castor, soya bean or oilseed rape oil. Examples include polyurethane (PU) manufactured from soya bean oil and nylon (polyamides or PAs) made using castor bean oil.

Conventional polyethylene (PE) can be manufactured from bioethanol.

Mixed bioplastics

Mixed bioplastics can be both biodegradable and non-biodegradable depending on the polymers used to manufacture them. For example, a mixed bioplastic containing starch and polycaprolactone (PCL) is biodegradable, whereas a plastic containing a 1:1 mix of biomass and oil-derived polypropylene (PP) is not.

What are bioplastics currently used for?

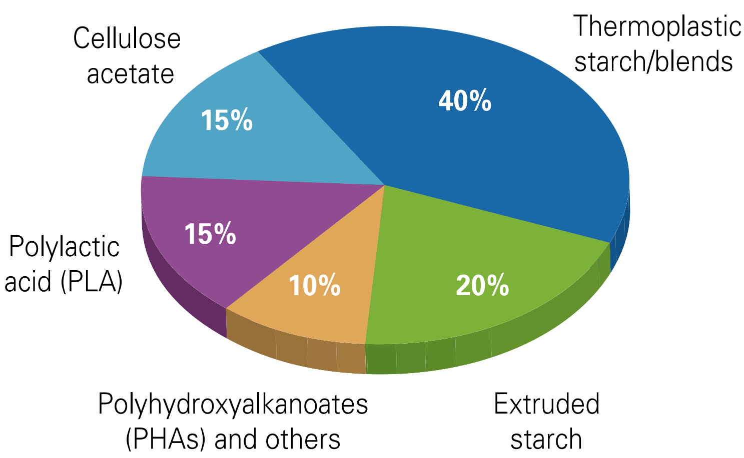
The majority of bioplastics are currently used in packaging applications such as bottles, film, clamshell cartons and loosefill. Bioplastics are also used in waste collection bags, carrier bags, mulch-film and food serviceware such as cutlery. Current niche markets include minor automotive parts and electronics housings.

Typically, starch-based bioplastics (such as TPS) are used to manufacture food serviceware. Starch mixed with crude oil-based polymers is used for carrier bags. Extruded starch can substitute for expanded polystyrene loosefill packaging.

Starch sugar fermentation products such as polylactic acid (PLA) are used in cold drinks cups and bottles, food packaging film and containers, carpets and clothing. PLA can also be used to manufacture CDs and electronics casings.

Cellulose acetate (CA) films are used in food and consumer goods packaging. Lignin-based bioplastics are used (to a small extent) in electronics housings and golf tees. Plant oil-based nylon bioplastics are currently used in electrical cable sheathing and automotive tubing. Plant oil-based polyurethane and polyesters are currently used in carpet backing and door panels of agricultural machinery, respectively.

Bioplastics market share



The bioplastics market

The world currently utilises approximately 260 million tonnes of plastics each year. Europe uses approximately 53 million tonnes of plastics and the UK utilises approximately five million tonnes of plastics a year. Bioplastics make up about 0.1% of the global market at an approximate consumption volume of 300,000 tonnes per year and experts predict that this market will grow six-fold by 2011 reaching over 1.5 million tonnes per year. In Europe, bioplastic consumption is approximately 60-100,000 tonnes per year and the UK utilises an estimated 15,000 tonnes per year. Forecast market growth is predicted to be greatest in non-biodegradable bioplastics.

In future, bioplastics may be more widely used for general food packaging and may also form major components in electronics housings and vehicles. Bioplastics could also be used in more sophisticated applications such as medicine delivery systems and chemical micro-encapsulation. They may also replace petro-chemical-based adhesives and polymer coatings. However, the plastics market is complex, highly refined and manufacturers are very selective with regard to the specific functionality and cost of plastic resins. For bioplastics to make market ground they will need to be more cost-competitive and provide functional properties that manufacturers require.

Bioplastic labelling

Currently there are a number of labelling systems designed to help consumers identify petroplastic and bioplastic types. In Europe and the USA, bioplastics are usually marked with a triangular symbol surrounding the number 7 with 'other' printed below. However, this label has drawbacks as it: 1) does not specify the polymer type; 2) does not indicate polymer recyclability or biodegradability; 3) can be used to identify 'other' or mixed petroplastics.

Most bioplastics are labelled as compostable (meaning under industrial composting conditions). At the moment there are two European labelling systems in use:

1) The European Bioplastics 'seedling logo' is used on packaging that conforms to the EN13432 European industrial composting standard. EN13432 certification requires a bioplastic to disintegrate and biodegrade by 90% in less than six months under industrial composting conditions (approx. 60°C).

2) The Vinçotte 'OK compost home' and 'OK biodegradable' labelling systems are used to identify bioplastics that are home compostable and biodegradable (in water, soil etc.), respectively.

Bioplastic labels currently in use.

End of use disposal

One of the most important factors governing the uptake of bioplastics into the plastics market is what to do with the materials after use. Since bioplastics are made from renewable resources, and are mostly biodegradable, it is important to dispose of them in the correct manner to gain maximum environmental benefit.

Once a bioplastic product comes to the end of its useful life there are a number of disposal options available. These include composting, recycling, energy from waste options (e.g. anaerobic digestion and incineration) and landfill. Industrial composting is the current preferred route for bioplastic disposal. It must be noted that home composting may not reach a high enough temperature to allow biodegradation of bioplastics. In future, incineration of bioplastics with other biomass combined with heat and power generation may be an alternative. Landfill is not a desirable route since bioplastic anaerobic breakdown produces methane (a greenhouse gas 23 times as damaging as carbon dioxide).

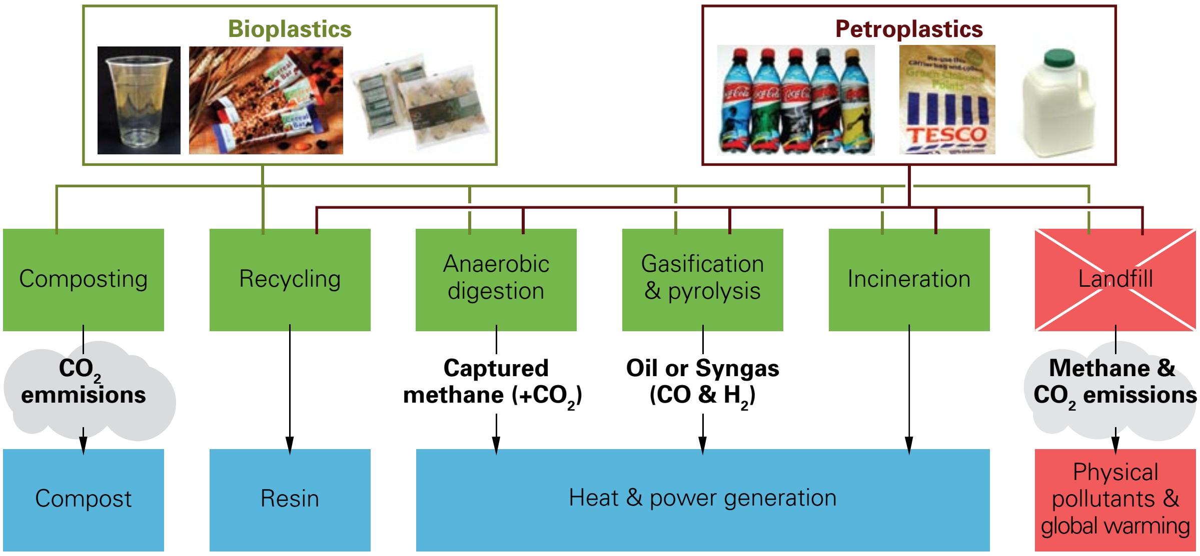
Some bioplastics, such as PLA, can be recycled. However, they present a challenge to petroplastic recycling streams, for example, PLA can contaminate recycled polyethylene terephthalate (rPET, a drinks bottle plastic) making it unusable. The EU plastic recovery target for 2008 was 22.5% and the 2009 EU plastics recycling target for obligated businesses is 27%. Using recyclable bioplastics may help meet current and future recycling/recovery targets.

Anaerobic digestion (AD), the biodegradation of organic materials in the absence of air, offers an alternative to composting biodegradable bioplastics. The process produces both digestate and methane, but unlike landfill, the methane is captured and burnt to generate heat and power. Currently, there is no official standard for the digestate produced. However, the Environment Agency and the Waste and Resources Action Programme (WRAP) are developing a quality protocol for digestate (Publicly Available Specification PAS 110) to allow its use.

Bioplastics can be disposed of by incineration to generate heat and power. However, careful selection of the best materials to be burnt with bioplastics (e.g. biomass) and the furnace conditions, is required to minimise their environmental impact. Other novel energy from waste (EfW) technologies suitable for bioplastic disposal include pyrolysis and gasification. Pyrolysis is the chemical decomposition of organic materials by heating in the absence of air to produce a mixture of carbon monoxide (CO) and hydrogen (H_2), or 'syngas' which is then converted to form an oil that can be burnt. Gasification is a similar technology, but the 'syngas' produced is burnt directly.

Landfill is the least favourable option for disposal of biodegradable bioplastics because methane is uncontrollably released during anaerobic decomposition. The EU Landfill Directive aims to reduce the amount of biodegradable organic materials sent to landfill in an attempt to abate GHG emissions. This directive specifies a 2010 target for reducing landfilled organic material by 25% from 1995 levels. In addition there are currently disincentives for using landfill including Landfill Tax (LAX, currently £40/tonne in April 2009 and rising) and the Landfill Allowance Trading Scheme (LATS) which restricts the amount of biodegradable waste a local authority can landfill.

End of life options for plastics



Measuring the environmental impact of bioplastics

The net environmental impact of bioplastics can be assessed using a methodology called life cycle analysis (LCA). LCA uses input and output data from each step in the manufacture of a product to quantify the overall environmental impact (often referred as 'cradle-to-grave'). LCA would assess parameters such as GHG emissions through raw material production, processing, product manufacture and disposal. Currently there is no unified LCA standard which makes it difficult to compare the same products made from different polymers. A publicly available specification (PAS) 2050 has been recently developed to provide a common LCA methodology for UK products and services.

Challenges for the bioplastics industry

Bioplastics offer several environmental and functional benefits over petroplastics, but, as with any new industry, there are challenges to be surmounted to increase their market share. One of the biggest challenges is cost. Currently bioplastic resins cost at least twice as much as petroplastic resins which is not helped by low crude oil (and, therefore, petroplastic) prices at the moment (March 2009). Clearly economies of scale will help improve the price differential if more bioplastic resin manufacturing capacity comes on-line in future. In addition, an obligation scheme to use renewable and biodegradable materials in packaging would provide a driver for development of the bioplastic industry in the UK. This scheme could be analogous to the Renewable Transport Fuel Obligation (RTFO) introduced for biofuels.

Currently, bioplastic materials are mainly aimed at the plastic packaging market which has stringent material specifications (e.g. moisture and gas permeability). Exacting specifications are also required for other plastic applications (e.g. electronics housings). If bioplastics are to make any market ground they must provide similar or better properties to petroplastics.

Coupled with this is the shortfall in waste processing infrastructure in the UK for most of the disposal options described above. The two most developed disposal options in the UK are composting facilities and landfill sites. However, the latter is the least environmentally desirable option and the UK is running out of landfill space and must explore other waste disposal options.

Recycling is a challenge for disposal of both bioplastics and petroplastics. The current UK system (The Producer Responsibility Obligations Regulations) obliges companies to help meet European recycling targets. Businesses with a turnover of more than £2 million and 50 tonnes per year of packaging must help pay for the recycling of at least 92% of the packaging waste they generate. Companies meet their packaging recycling obligations through: 1) contracting recycling companies to process their allocated quantity of packaging waste; 2) recycling their own packaging waste; 3) purchasing Packaging Recovery Notes (PRNs). Currently, companies earn or buy PRNs to meet their recycling obligations. There are several PRN types available depending on the packaging waste type produced (e.g. 'paper' or 'plastic').

Bioplastics do not have a specific PRN allocation. However, if the major bioplastic component is starch or cellulose it is classed in the 'paper' category. If a bioplastic contains predominantly oil-based polymers it is classed in the more expensive 'plastic' category.

In Europe, the 'Green Dot System' obliges companies that produce or use packaging to contribute to the cost of recycling packaging waste. In Germany, bioplastics are exempt from 'Green Dot System' fees to encourage their use. However, this mechanism does not provide funding for bioplastic disposal. In the UK, low PRN fees or fee exemption for bioplastics may help their uptake into the market. However, it may also be necessary to introduce mandatory targets for incorporation of bioplastics into packaging products.

The green dot system for recycling

Another challenge for the emerging bioplastics industry in the UK is the need for development of a unified national local authority approved method for collection and sorting of waste in order to maximise recovery of materials with minimal environmental impact.

Starch

Food Serviceware

Packaging loosefill

Plant oils

Insulation

Machine parts

Cellulose

Packaging film

Food packaging

Future of the UK bioplastics industry

a) Manufacturing capability

The UK has a mature grain milling and sugar manufacturing infrastructure supplying the food and drink industry. These facilities could provide feedstocks for bioplastic manufacture in the UK. There are several potential manufacturing avenues including: 1) PLA; 2) starch bioplastics; 3) polyethylene from bioethanol.

1 A feasibility study (a Defra-funded project undertaken on behalf of the National Non-Food Crop Centre) on the potential for PLA manufacture in the UK suggests that 490,000 tonnes of wheat could be used to manufacture 132,000 tonnes of PLA per year by 2025.

2 Starch bioplastics, currently imported, could be manufactured using wheat starch from UK grain.

3 The emerging UK bioethanol industry may provide feedstock for polyethylene and polypropylene manufacture.

b) Land availability

A key issue for the production of crops for bioplastic manufacture is land availability. Currently, the bioplastics industry is in its infancy and, as a result, does not require a significant proportion of land for feedstock supply. By way of example, figures below indicate the land area that is currently required for PLA manufacture in the USA (NatureWorks model).

The US NatureWorks model:

Approximately 2.5 kg of US maize produced on 2.5 square metres of land is required to produce 1 kg of PLA. In the USA around 36 million hectares of maize is grown annually and around 34 thousand hectares is required to produce 140 thousand tonnes of PLA (the full capacity of NatureWorks). This land use equates to 0.1% of the total US maize land area.

In the UK the most likely crop feedstock for bioplastic manufacture is wheat. A plant producing 132,000 tonnes of PLA per annum would only require a small percentage of the wheat produced in the UK. This slight increase in demand could be met through use of some of our exported wheat (currently 3.9 million tonnes per annum), through improved crop yields and more efficient use of farmland.

Key market requirements for the development of a bioplastics industry in the UK

- **Lower bioplastic resin price (greater production capacity)**
- **Legislative and financial incentives for using bioplastics**
- **Improved disposal infrastructure**
- **Greater public awareness of bioplastic materials and how to dispose of them**
- **A bioplastic demonstration plant**

HGCA bioplastic initiatives

HGCA has a role in promoting the use of home-grown cereals and oilseeds for industrial applications such as bioplastics.

The HGCA Enterprise Awards Scheme funds the market development of a number of industrial uses ventures. For example, Cambridge Biopolymers (Duxford), a 2005 Enterprise Award winner, developed a bio-resin system based on oilseed rape oil. This bio-resin has applications in eco-friendly mannequin manufacture, model and sculpture casting, construction products, chemical micro-encapsulation, coatings and adhesives and eco-friendly coffin manufacture. Green Light Products (London), a 2003 Enterprise Awards Scheme winner, developed a wheat starch-based loosefill packaging material intended as a renewable and biodegradable alternative to expanded polystyrene.

HGCA also helps fund a number of research and development projects on the use of wheat flour, starch and straw in the manufacture of eco-composite materials. Expanded wheat flour and starch products are under development for packaging, construction components such as ceiling panels, eco-friendly cool boxes and concrete void-makers for cabling and piping. Eco-friendly wheat straw products such as 'straw pigeons' (a clay pigeon replacement), road barriers and tree guards are also under development.

1. Wheat flour/starch packaging foam

2. Straw pigeon

3. Oilseed rape bioresin cast figure

4. Wheat flour/starch loosefill packaging

Summary

- Bioplastics are renewable and sustainable alternatives to oil-based plastics.
- Currently, the main opportunities for bioplastics are in packaging materials, but in future bioplastics may be used more in higher value applications (electronics and vehicle parts).
- Bioplastics have a 0.1% share of the current global plastics market.
- Land usage for the production of bioplastics is currently small (e.g. 0.1% of US maize area for PLA production).
- The world bioplastics market has potential to grow six-fold by 2011.
- Potential for UK wheat to be used in bioplastic manufacture in the UK.
- Implementation of the correct disposal methods and corresponding infrastructure are vital if the bioplastics industry is to flourish and deliver environmental benefits.

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Related material

This leaflet is based on Project Report 450 available from HGCA entitled:
Industrial uses for crops: markets for bioplastics.

Information

Information on industrial uses projects sponsored or co-funded by HGCA can be found on the HGCA website at www.hgca.com.

Ongoing HGCA projects

Ongoing project 3351: Novel bio-composites based on whole utilisation of wheat straw.
Ongoing project 3368: Inorganic polymer bio-composites.

Useful links

Organisations

Bioplastics Magazine
www.teamburg.de/bioplastics

British Plastics Federation
www.bpf.co.uk

British Standards Institute
www.standardsuk.com

Department for Environment Food and Rural Affairs (Defra)
www.defra.gov.uk

Environment Agency
www.environment-agency.gov.uk

European Bioplastics
www.european-bioplastics.org

European Commission
www.eur-lex.europa.eu

National Non-Food Crops Centre (NNFCC)
www.nnfcc.com

Plastics Information Europe
www.pieweb.com

Society of the Chemical Industry
http://beta.soci.org

Society of the Plastics Industry (SPI)
www.plasticsindustry.org

Sustainable Organic Resources Partnership (SORP)
www.sorp.org

The Association for Organics Recycling
www.organics-recycling.org.uk

Waste and Resources Action Programme (WRAP)
www.wrap.org.uk

Starch manufacturing companies

National Starch (now part of Akzo Nobel N.V.)
www.nationalstarch.com

Roquette
www.roquette.com

Syral (formerly Tate and Lyle)
www.syral.com

Bioplastic manufacturers

Braskem
www.braskem.com.br

Clarifoil films
www.clarifoil.com

Innovia films
www.innoviafilms.com

Mirel
www.mirelplastics.com

NatureWorks
www.natureworksllc.com

Novamont
www.materbi.com

Anaerobic digestion companies

Andigestion
www.andigestion.co.uk

Biogen-Greenfinch
www.biogengreenfinch.co.uk

Composting companies

Eco sustainable solutions Ltd.
www.thisiseco.co.uk

LondonWaste Ltd.
www.londonwaste.co.uk

Recycling companies

Closed Loop Recycling
www.closedlooprecycling.co.uk

Valpak Recycling
www.valpak.co.uk

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