Plastics in the Bioeconomy

Report for the Biomass Biorefinery Network
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Executive summary

Plastic is a material that has revolutionised our modern world. That said, society is increasingly understanding the environmental impact of this ubiquitous material, particularly when it is not treated or managed carefully. According to the Ellen MacArthur Foundation, most plastic packaging is used only once (single use items) and 95% of the value of the material is lost to the economy annually, totalling US$80-120 billion globally.

In response to the environmental harm caused by plastic pollution, the UK government is now taking a fundamental look at its regulations and policies relating to plastic packaging as part of a revised Waste and Resources Strategy. In addition, the UK Plastics Pact, a collaboration across the entire packaging supply chain, is an example of a new voluntary agreement designed specifically to tackle the issue of plastic waste. The UK Plastics Pact contains targets which are directly relevant to this study, specifically that 100% of packaging is to be recyclable, reusable or compostable, with a target of 70% to be effectively recycled or composted by 2025. Also contained within the UK Plastics Pact is a commitment to eliminate unnecessary or problematic single-use packaging.

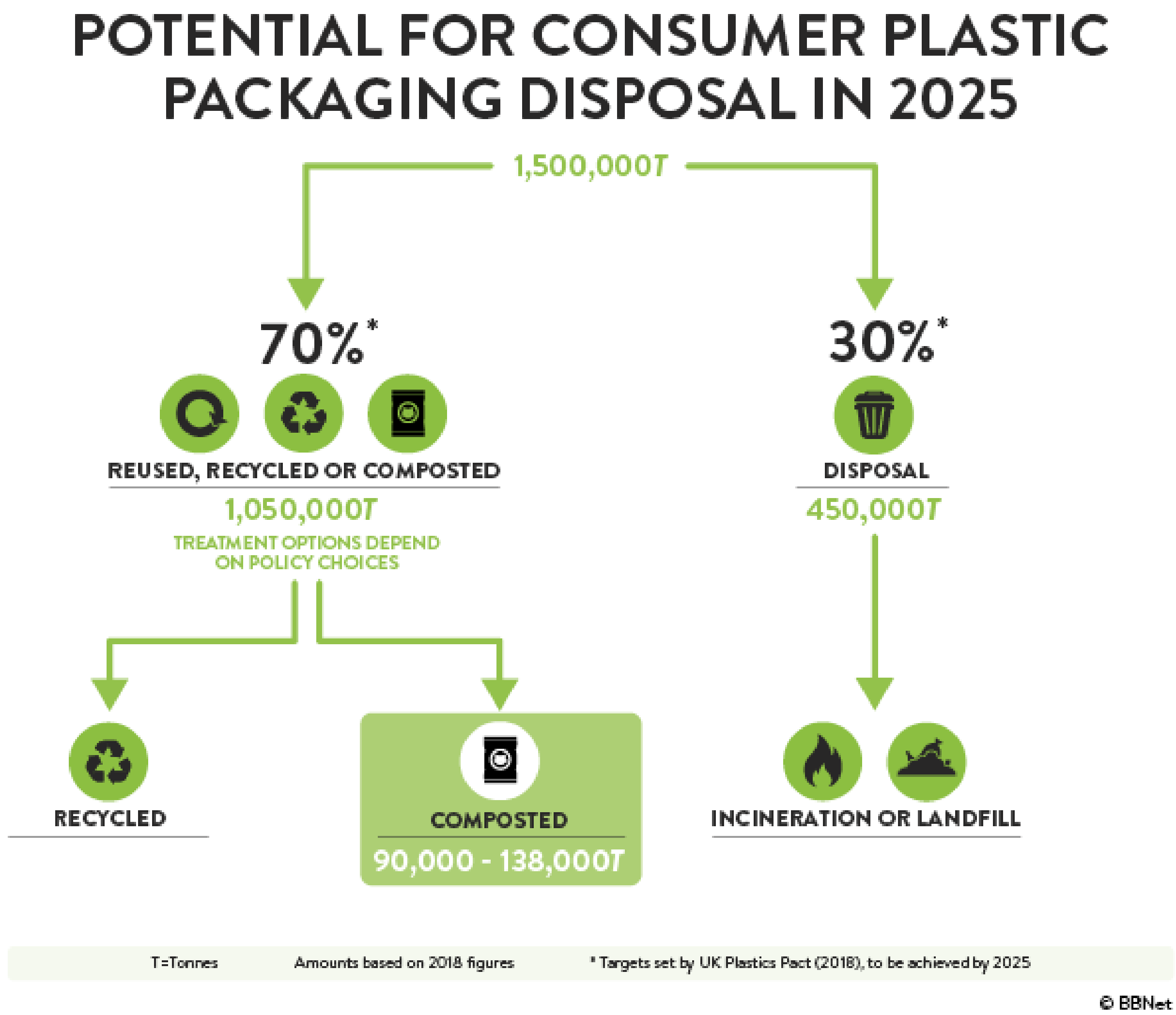
To achieve these targets, significant changes will be required. We need to understand and assess our use of plastic, increase the rate of plastic recycling and treatment capability in the UK and, most importantly, look for alternatives for hard to recycle, single use plastics. This report examines how compostable packaging can play an important part in helping this transition over the next five years.
Compostable bio-based plastics can provide a sustainable alternative to petroleum-based persistent plastics in some applications. This report, commissioned by the Lignocellulosic Biorefinery Network, summarises research in the UK regarding:

- The current scale and types of compostable plastics in the market;
- How the market for compostable plastics could grow in the medium term and the economic benefits of this growth;
- Identification and quantification of suitable biomass resources that could be used as feedstocks; and
- the potential contribution of compostable plastics to the 2025 targets for plastic packaging as set out by the UK Plastics Pact and a strategy for how this could be achieved.

While the bio-plastics market is growing, little information is available regarding the total compostable plastics market in the UK. This study has produced a first systematic analysis of the UK market, taking a look at the estimated market size for compostable bio-plastics by material and exploring how this market is likely to grow based on its capability to substitute conventional plastic packaging in specific, often difficult to recycle, applications.

Headline findings

The benefits of increasing the amount of compostable plastics used for packaging are significant. The study has found that there could be a tenfold increase in the compostable packaging market from 10,000 tonnes to over 100,000 tonnes (range from 90,000 – 138,000) depending on the degree of market uptake. There is a demonstrable need for compostable packaging, especially when the packaging can be used to capture food waste that would otherwise end up in the residual stream. Significant bioeconomy benefits would be achieved through valorising available bioresources, underutilised agricultural crop residues to produce the required biopolymers. Utilising bioresources will also contribute to the strong sustainable performance of compostable packaging when compared to conventional oil-derived plastic.



Increased uptake of compostable packaging

The focus of this study is on consumer packaging. This includes all consumer-facing grocery and non-grocery packaging placed on the market. Of the 2.361 million tonnes (Mt) of total plastic packaging placed on the UK market in 2017, nearly 65% (1.5Mt) is classed as consumer/retail packaging.

To understand the UK market opportunity for compostable packaging we needed to understand the packaging it could most readily replace – its substitution potential. Our assessment concluded that the materials most readily substituted at present can largely be categorised as food product packaging, short lived single-use items and predominantly flexible consumer plastic packaging.

Our analysis of the market estimates the UK could significantly increase the uptake of compostable packaging to between 90,100 and 138,000 tonnes per annum from approximately 8,000 tonnes (+/-1,000t) placed on the market in 2018.:

- Potential Flexibles market 53,000 - 77,000 tonnes per annum
- Potential Rigid market 9,000 – 11,000 tonnes per annum
- Carrier Bag potential 28,100 – 50,000 tonnes per annum

Complementing conventional plastics

It is important to highlight that the adoption of compostable packaging is not a solution in itself. The plastic packaging system also needs a higher recycling rate. The effective plastics system of the future will have different polymers playing different roles, while the adoption of compostable or conventional plastic needs to take a whole-system approach which considers both the role of the packaging and its end of life.

Significant economic benefits

Our analysis found that the transition to a greater adoption of compostable packaging could, by 2025, provide an economic benefit to the UK's bioeconomy in excess of **£267m** per annum, simply through sales of the biopolymers required for compostable packaging. A wider economic benefit could also be achieved through cost reductions in collections and processing costs for those hard to recycle plastics, such as those heavily contaminated with food waste or multilayer plastics. At end of life, our analysis estimates a 12% lower net cost associated with recovery systems for biopolymer materials (£100/tonne) compared to virgin material recovery (£112/tonne).

Materials capture

Plastic waste is often too contaminated with food waste to be suitable for recycling and is ultimately sent for incineration or to landfill. This presents an opportunity for the compostable packaging market. If the focus for compostable packaging is packaging that often becomes contaminated, a double benefit could be achieved. Not only would landfill and incineration be avoided but the compost produced would return organic matter to the soil.

Abundant feedstocks

Supporting this transition is the availability of bioresource feedstocks. To understand the feedstocks that could be available for bio-plastics production, we examined agricultural production in the UK and mapped this against several key biopolymers. The research confirmed that the UK has an abundance of renewable bioresources to supply the biochemicals needed to produce the biopolymers for the potential compostable packaging market.

Our findings identified over **eight million tonnes** of suitable bioresources from key agricultural residues alone, with a further **five million tonnes** available from other, non-target bioresources. When compared to the proposed growth of compostable packaging of between 90kt to 138kt there is approximately 100 times more bioresources available.

A sustainable alternative

A life-cycle assessment (LCA) was conducted to understand the sustainability implications of producing and using low-density polyethylene (LDPE), a petroleum based-material, compared with the exemplar compostable bio-plastic polylactic acid (PLA), a bio-based material[1]. Our LCA analysis showed that PLA has the potential to have a lower environmental impact (in terms of global warming potential) than LDPE.

Sensitivity analysis was undertaken into the end of life considerations of these two plastics. The analysis found that LDPE did not perform well relative to PLA when contaminated with food waste. Our analysis showed that, the CO2e emitted by PLA compostable packaging is more than 50% lower than that emitted by traditional LDPE when it is contaminated with food and cannot be recycled.

Facilitating the transition

The huge environmental impacts of food waste have created a consensus across the UK that household food waste collections are required. If collections were rolled out across England, as intended within the Waste and Resources Strategy, then the UK could have a collection and processing infrastructure capable of supporting compostable packaging. This removes one of the biggest barriers to the widespread adoption of compostable packaging. The amount of food waste generated in the UK is estimated at 10 million tonnes per annum[2], so an estimated market of approximately 100k of compostable plastics is just 1% of this volume. However, segregation, collection and the composting vs anaerobic digestion all need careful planning to ensure maximum capture of compostable packaging and to allow successful growth of the bio-plastics market. To ensure non-compostable packaging does not contaminate the system, clear labelling will be required to help consumers dispose of the packaging appropriately.

The question is – what proportion of the plastic packaging placed on the market could be reused, recycled or composted by 2025? The answer will be shaped by government policy and needs to be informed through evidence and engagement with stakeholders.

Next steps

The UK Plastics Pact sets out strong, ambitious targets to create a circular economy for plastics and to support the drive for compostable bio-plastics. This report helps to set out the challenges of achieving a 70% recycled or composted target and explores how compostables can address the challenges that cannot be resolved through recycling.

A transition towards compostable packaging provides significant economic and environmental opportunities yet requires whole system support. To facilitate this transition, investment will be required from industry to take forward research and development innovation around bio-plastics, retailers and consumers will need to ‘buy compostable’, the waste and resource recovery industry and local authorities will need to restructure existing collection and treatment models to accommodate compostable materials and, most importantly, the UK government will need to provide policy and regulatory support to drive change. Ultimately it will involve investment in infrastructure and collections, public education and behavioural change.

[1] PLA was selected as a suitable option to represent biodegradable bio-plastics
[2] http://www.wrap.org.uk/sites/files/wrap/Estimates_%20in_the_UK_Jan17.pdf

Glossary

- **AA** – Adipic Acid
- **Anaerobic Digestion** - Anaerobic digestion (AD) is the breakdown of organic material by micro-organisms in the absence of oxygen. AD produces biogas, a methane-rich gas that can be used as a fuel, and digestate, a source of nutrients that can be used as a fertiliser.[3]
- **Bio-based Plastics** – Bio-based plastics are made either partially or in whole by renewable biological resources (i.e. corn, sugarcane or cellulose). They are often a combination of plant or animal organic matter and fossil derived matter.
- **Biodegradable** – Biodegradable plastics are plastics that can be broken down completely by microorganisms under the right conditions into water, naturally occurring gases (e.g. carbon dioxide or methane) and biomass. The biodegradability of a material is strongly dependent on conditions such as temperature and the presence of oxygen, water and microorganisms.[4]
- **Bio-plastics** - The term bio-plastics covers a range of often biological-based materials with different properties and applications. A material is categorised as bio-plastic if it is either bio-based, biodegradable, or both[5]. These definitions are explained in turn above.
- **Compostable**- Industrial compostable materials will break down in industrial composting environments such as anaerobic digestion or in-vessel composting. They are broken down by microorganisms in the same way and at the same rate as food & garden waste. It leaves no toxic residue and produces less methane. Home compostable materials may be composted in home composting systems should they meet the appropriate standard.
- **Consumer Packaging** – Consumer packaging is classified as the item that you see at the point of purchase. (i.e. cereal box, shampoo bottle, ice cream tub).
- **Degradable Plastic** – Degradable plastic will break down over time into small fragments or powders through the action of natural daylight, as a result of oxidation, or through hydrolysis. This does not necessarily mean that the material will return to nature i.e. microplastics are degraded plastic products.
- **Drop-in bio-based plastics** - plastics within this group have the same chemical structure and characteristics as their fossil-based counterparts and are recyclable but are made from biogenic materials. However, they are not bio-degradable. They include bio-based PET, PE, PA and PTT.
- **Energy from Waste (EfW)** – The process of generating electricity and/or heat energy through the treatment of residual waste via combustion. EfW facilities use the heat from the combustion process to create steam which is then in turn used to generate electricity. Facilities can operate as combined heat and power plants (CHP) if heat is also produced and utilised.
- **EVOH** - Ethylene Vinyl Alcohol.
- **Extended Producer Responsibility (EPR)** – a strategy whereby the total environmental costs associated with a product or service throughout its lifecycle are attributed to the producer. This includes placing responsibility on businesses for the environmental impact of their products and for the full net costs of managing products at end of life. EPR thus incentivises producers to manage resources more efficiently, promoting re-design and re-manufacturing initiatives to decrease the environmental impact of products and often includes take-back schemes, placing taxes on products that cannot easily be reused or recycled (e.g. 5p carrier bag charge) or by promoting reuse initiatives.

[3] NNFCC (2009) The Official Information Portal on Anaerobic Digestion
[4] WRAP (2018) Understanding plastic packaging
[5] European Bio-plastics

- **Flexible Packaging** – Any package with a non-rigid form. Typically used for bags, pouches, liners or overwrap. Can be made from plastic, film, paper or aluminium foil (or a combination of these, usually in a layered format).
- **HDPE** – High Density Polyethylene (e.g. used for milk bottles, bleach, cleaning products and most shampoo bottles).
- **In-vessel composting (IVC)** – In-vessel composting (IVC) composts organic material including food waste and garden waste through a process of mixing under strictly controlled environmental conditions within a sealed, fully enclosed container. The output is nutrient-rich compost suitable for the farming and agriculture industry as a soil improver.[6]
- **LDPE** – Low Density Polyethylene (carrier bags, bin liners and packaging films).
- **Mechanical Biological Treatment (MBT)** – a form of waste processing that combines a mechanical sorting facility (to recover recyclables, refuse-derived fuel and sort rejects to landfill) with a form of biological treatment such as composting or anaerobic digestion.
- **PA** – Polyamides
- **PBAT -** Polybutylene Adipate Terephthalate. A biodegradable polymer with applications including plastic films and bottles, coating and foam. Resembles LDPE in its properties.
- **PBS –** Polybutylene Succinate. Comparable to PP in terms of properties.
- **PE –** Polyethylene.
- **PET** – Polyethylene Terephthalate (Fizzy drink and water bottles, salad trays).
- **PHA** – Polyhydroxyalkanoate – polyesters produced in nature through the bacterial fermentation of sugar or lipids.
- **PLA** – Polylactic Acid is a non-toxic, compostable bio-based material typically derived from lactic acid produced from the sugars and/or starch from foods such as potato, wheat and corn starch.
- **PP** – Polypropylene (Margarine tubs, microwaveable meal trays, also produced as fibres and filaments for carpets, wall coverings and vehicle upholstery).
- **PTT** – Pots, tubs and trays.
- **PS** – Polystyrene (Yoghurt pots, foam hamburger boxes and egg cartons, plastic cutlery, protective packaging for electronic goods and toys. Insulating material in the building and construction industry).
- **PTT** - Polytrimethylene terephthalate
- **PVC** - Polyvinyl Chloride (Pipes, fittings, window and door frames (rigid PVC) thermal insulation (PVC foam), and automotive parts).
- **PVdC** - Polyvinylidene Chloride.
- **SA** - succinic acid.
- **Starch blends** – Bio-based plastic using starch as a feedstock. The most common sources of starch include potatoes, maize and cassava.

[6] Biogen (2019) http://www.biogen.co.uk/Composting/In-Vessel-Composting

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Appendices

1 Introduction

1.1 Context

This report has been commissioned by the Lignocellulosic Biorefinery Network, LBNet, a Biotechnology and Biological Science Research Council Phase I Network in Industrial Biotechnology and Bioenergy (BBSRC NIBB). The work generated in this report will be maintained and supported by the Biomass Biorefinery Network, BBNet, a Phase II BBSRC NIBB[7]. These networks enable industrial and academic co-operation on the development of novel materials, chemicals and fuel using biomass as an alternative to petroleum-derived inputs.

The network wishes to produce a report summarising:

- the current status of compostable plastics;
- how the market for compostable plastics could grow;
- what the most suitable biomass resources are that could be used as feedstock; and
- how bio-plastics could contribute to targets for plastic packaging as set out by the UK Plastic Pact for 2025 along with a strategy for how this could be achieved.

At present, the majority of plastics are derived from petrochemicals. This dominance of petrochemicals is due to the (comparatively) low cost of oil and the difficulty of competing with the well-established oil refineries not just in the UK but also globally. However, research and experience (including previous work commissioned by LBNet) demonstrates that many of the chemicals involved in industrial processes to produce these products can be replaced by bio-based sources. A previous report by LBNet[8] highlighted that the UK is well positioned to benefit from growth opportunities for bio-based polymers due to a strong academic and industry research base. Significant R&D within this area is a key part of the UK chemical industry as new alternatives to conventional plastics grow. This report examines the substitution potential for biodegradable packaging, more specifically compostable packaging, to replace conventional packaging made from oil-based polymers.

The focus of this study is on consumer-based single-use packaging. This includes all consumer-facing grocery and non-grocery packaging placed on the market. Of the 2.361Mt of plastic packaging placed on the market in 2017, nearly 65% (1.5Mt) is classed as consumer / retail packaging[9].

An introduction to bio-plastics is provided in Section 3, however this study will assess the packaging substitution potential for compostable plastics (a subset of bio-plastics). Please see the glossary of terms for further distinction.

This report is commissioned by the LBNet with the input of a steering group comprising academic and industry experts to help inform data gathering assumptions and industry insights.

1.2 Drivers for change

The following section summarises the strategic context for the study and helps illustrate the major external drivers that will impact and shape the packaging market over the next six years to 2025. These

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[7] The Biomass Biorefinery Network, BBNet, a Phase II Biotechnology and Biological Science Research Council Phase I Network in Industrial Biotechnology and Bioenergy (BBSRC NIBB) is a successor to the Lignocellulosic Biorefinery Network, LBNet,a phase I BBSRC NIBB
[8] E4tech (2016), An initial feasibility study of the potential for the establishment of lignocellulosic biorefineries in the UK
[9] Valpak PlasticFlow 2025 data

are summarised in Table 1 and highlighted where reference has been made to plastic packaging, bio-based, and compostable packaging.

Table 1 Drivers for change

Policy	Plastic packaging	Bio-based plastics	Compostable plastics
EU Circular Economy Package	✓		
Ellen MacArthur Foundation 'New Plastics Economy'	✓	✓	✓
UK Plastic Pact 2025	✓	✓	✓
European Strategy for Plastics	✓	✓	✓
UK 25-Year Environmental Plan	✓		
UK Waste and Resources Strategy	✓	✓	
EU Single-use Plastics Proposal Directive	✓	✓	✓
UK Deposit Return Scheme	✓		
UK Biodegradable Municipal Waste Landfill Ban	✓		
UK Growing the Bioeconomy	✓	✓	✓

1.2.1 EU CE Package

Background

The Circular Economy Package (CEP)[10] was adopted by the European Commission in December 2015. It includes a range of policy options around waste management but also addresses product lifecycles. As part of the package, the Commission presented an action plan for the circular economy, as well as four legislative proposals amending the Waste Framework Directive, the Landfill Directive, the Packaging Directive and the Directives on end-of-life vehicles, batteries and accumulators, and waste electrical and electronic equipment.

Member States (MS) are required to transpose the directives into national law by 5th July 2020. The UK government signalled that as the CEP has been adopted into formal EU law before the end of the two-year Brexit process, it will be among the environmental legislation brought into UK law via the 'European Union (Withdrawal) Bill'.

Proposed waste management targets within the CEP include:

- Share of all packaging waste prepared for reuse and recycling – 55% by 2025
- Share of municipal waste landfilled – 10% by 2030

[10] European Commission Circular Economy Package. Available here: ec.europa.eu/environment/circular-economy/index_en.htm

Key dates

- July 2014 – Circular Economy package launched
- December 2015 – New circular economy package released with revised targets and actions
- July 2018 - Legislation entered into force
- 5th July 2020 – Member States (MS) are required to transpose the directives into national law

How will this policy affect the bio-plastics industry, including risks and opportunities?

The Circular Economy Package presents several opportunities and potential risks for the bio-plastics industry. For example:

- Ambitious recycling targets that are likely to generate an increase in recycling, either through enhanced infrastructure, remanufacturing products or more successful recycling collection methodologies. This increases avenues for recycling and could therefore restrict the development of alternative solutions such as compostable bio-plastics.
- Mandated food waste requirements.
- The EU Strategy for plastics (see 1.2.4) was developed on the back of the CEP which directs funding toward bio-plastic investment.
- Reductions in waste sent to landfill – this is currently one of the main waste management routes for bio-plastics (alternatively sent for incineration).

1.2.2 The New Plastics Economy, the Ellen MacArthur Foundation

Background

The New Plastics Economy[11] is an initiative led by the Ellen MacArthur Foundation in collaboration with businesses, governments, academics, NGOs and citizens. It provides a vision of a circular economy for plastic, diverting plastic from waste.

The New Plastics Economy report acknowledges that while plastics and plastic packaging are an integral part of the global economy and deliver many benefits, their value chains currently entail significant drawbacks. For example, it is found that most plastic packaging is used only once; 95% of the value of plastic packaging material, worth $80-120 billion annually, is lost to the economy. Additionally, plastic packaging generates negative externalities, valued conservatively by UNEP at $40 billion[12]. There is clearly an opportunity for the plastics value chain to deliver better system-wide economic and environmental outcomes.

Key dates

- The New Plastics Economy launched the Global Commitment in 2018.

The New Plastics Economy envisages a new approach based on creating effective after-use pathways for plastics to achieve the following three objectives:

- Create an effective after-use plastics economy
- Drastically reducing leakage of plastics into natural systems and other negative externalities,
- Decoupling plastics from fossil feedstocks[13].

How will this policy affect the bio-plastics industry, including risks and opportunities?

The New Plastics Economy report (Rethinking The Future Of Plastics)[14] presents the need for the exploration of the role of renewable plastic sources, including the use of bio-based sources. The report

[11] Ellen MacArthur Foundation (2018) The New Plastics Economy - Rethinking The Future Of Plastics Report

[12] United Nations Environment Programme, Valuing Plastic: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry (2014).

[13] https://www.ellenmacarthurfoundation.org/news/new-plastics-economy-report-offers-blueprint-to-design-a-circular-future-for-plastics

[14] https://www.ellenmacarthurfoundation.org/publications/the-new-plastics-economy-rethinking-the-future-of-plastics

explains that compostable plastic packaging — if coupled with the appropriate collection and recovery infrastructure — can help return nutrients from the packaged content (e.g. food) to the soil. The report outlines a series of actions and steps needed to drive this systematic change. These steps, and their benefits are as follows:

- Compostable packaging can help return organic nutrients to the soil in applications where currently plastic packaging would be considered 'contaminated' due to food residues.
    - Compostable bags have been proven to increase the amount of food waste returned as nutrient to the soil.
- Compostable and recyclable materials need to be separated and follow different after use pathways.
    - It is generally understood that compostable plastics interfere in today's plastic recycling systems and that vice versa, plastics can contaminate compost within an industrial composting system.
- Appropriate In-vessel (industrial) composting and anaerobic digestion infrastructure needs to be in place.

1.2.3 UK Plastic Pact 2025

Background

The Plastics Pact[15] is a collaborative initiative between government, industry and producers, delivered by The Waste and Resources Action Programme (operating as WRAP), that aims to create a circular economy for plastics. It brings together the entire consumer plastics packaging value chain behind a common vision and ambitious set of targets to achieve by 2025. These are as follows:

- Eliminate problematic or unnecessary single-use packaging through redesign, innovation or alternative delivery models
- 100% of plastics packaging to be reusable, recyclable or compostable
- 70% of plastic packaging effectively recycled or composted
- 30% average recycled content across all plastic packaging

To date, a total of 68 members have signed up, who together are responsible for an estimated 80% of UK consumer plastic packaging. Defra, the Welsh Government and the Scottish Government are also all behind the pact.

Key dates

The initiative was launched in April 2018. The UK 2025 Roadmap is intended as a framework to help guide organisations towards achieving the targets. There are three key milestones which underline when certain activities need to be undertaken by and the outcomes they will deliver:

- April 2019 – 1st anniversary of the initiative
- 2022 – The mid-point of the initiative
- 2025 – The year the Pact aims to have achieved its targets

How will this policy affect the bio-plastics industry (including risks and opportunities)?

The first key target of eliminating problematic or single-use packaging presents an opportunity for bio-plastics businesses, since those materials being phased out will need to be replaced with a suitable alternative (such as bio-plastics). There are also key targets around increasing the proportion of plastic packaging that is reusable, recyclable or compostable. This could lead to increased support and investment for businesses producing compostable plastic (i.e. an opportunity); however, it may also indicate a decrease in materials that were previously replaceable (i.e. non-recyclable). Similarly, overcoming the issue of unrecyclable black plastic is mentioned as an immediate focus of the Pact. Black plastic is currently both unrecyclable and used to package food and therefore, at present, presents a major opportunity for substitution by compostable packaging.

15 http://www.wrap.org.uk/content/the-uk-plastics-pact

1.2.4 European Strategy for Plastics

Background

The European Strategy for Plastics in a Circular Economy[16], adopted by the European Commission on 16th January 2018, aims to transform the way plastic products are designed, produced, used and recycled in the EU[17]. The strategy is part of Europe's transition towards a circular economy, and will also contribute to reaching the UN Sustainable Development Goals, the global climate commitments of the EU climate action plan (2015) and the EU's industrial policy objectives. The strategy proposes several EU measures and identifies key actions for national and regional authorities and industries (Table 2). These include:

Table 2 European Strategy for Plastics measures

Measure	Actions	Examples/sub-actions
Improving the economics and quality of plastics recycling	Actions to improve product design	New rules to ensure that by 2030 all plastics packaging placed on the EU market can be reused or recycled
Curbing plastic waste and littering	Actions to reduce single-use plastics	Analytical work, including the launch of a public consultation, to determine the scope of a legislative initiative on single-use plastics
	Actions on compostable and biodegradable plastics	Develop harmonised rules on defining and labelling compostable and biodegradable plastics
Driving investment and innovation towards circular solutions	Actions to promote investment and innovation in the value chain	Examine the feasibility of a private-led investment fund to finance investments in innovative solutions aimed at reducing the impacts of primary plastic production

Key dates

- 16th January 2018 - European Strategy for Plastics in a Circular Economy adopted

How will this policy affect the bio-plastics industry, including risks and opportunities?

Amongst these measures and actions are several opportunities and risks. For example, measures to improve plastics recycling and targets to ensure all plastic is reused or recycled by 2030 could create a threat to the bio-plastics industry by reducing the quantity of replaceable materials and packaging items. However, certain bio-plastics can also be recycled; for example, drop-in plastics such as bio-based PET, PE, PA and PTT, have the same chemical structure and characteristics as their fossil-based counterparts and can therefore be recycled.

Nevertheless, actions to reduce single-use plastics could present an opportunity for the bio-plastics industry by creating a demand for alternative solutions. Actions on biodegradable or compostable plastics, such as developing harmonised rules on defining and labelling compostable and biodegradable plastics, could also present opportunities for the industry. Driving investment in innovation could also open new funding sources for the industry.

Alternatively, it is important to consider that harmonised collection rules could standardise the range of material types, the use of this material, the requirements for appropriate labelling and as a result reduce the risks that bio-plastics may contaminate other dry recycling collection streams.

[16] http://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf
[17] http://ec.europa.eu/environment/waste/plastic_waste.htm

1.2.5 Resources and Waste strategy (Defra)

Background

This strategy sets out how the UK government will preserve material resources by minimising waste, promoting resource efficiency and moving towards a circular economy in England[18]. Key milestones and targets support those defined in the UK's Plastic Pact and include:

- Eliminate avoidable plastic waste over the lifetime of the 25 Year Environment Plan
- Work towards all plastic packaging placed on the market being recyclable, reusable or compostable by 2025
- Removal of single-use plastics from the central Government Estate by 2020
- Roll-out of a deposit return scheme by 2023*
- Consistency of waste and recycling collections including introduction of food waste recycling to England*
- Extended producer responsibility for packaging comes into force by 2023*

*subject to consultation

Key dates

- 18th December 2018 - the strategy was published
- Milestone dates – as referred to above

How will this policy affect the bio-plastics industry (including risks and opportunities)?

The key part of the strategy for bio-plastics is that it requires separate food waste collections for every UK household – this potentially gives a composting plastics route for all UK households. However current consultation on this matter identifies the potential risks for the bio-plastics industry. Should compostable plastics be collected in dry recycling, they may compromise quality of this stream through contamination. This is dependent on the separation technology, i.e. PVC and PP can contaminate PET.

Table 3 presents an overview of some of the key risks and opportunities arising from the strategy.

[18] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/765914/resources-waste-strategy-dec-2018.pdf

Table 3 Overview of the key risks and opportunities of the waste and resources strategy

Aim, objective or target	Opportunity or risk	Reason
Invoke the 'polluter pays' principle and extend producer responsibility for packaging	Risk	EPR places significant responsibility on producers for the treatment or disposal of products. In turn, this creates incentives to design products/packaging for recyclability or reuse. This could drive down the availability of replaceable items/material for bio-plastics producers.
Ban plastic products where there is a clear case for it and alternatives exist	Opportunity	By banning plastic products, this creates a need for suitable alternatives (such as bio-plastics)
Improve urban recycling rates, working with business and local authorities	Risk	Options for improved recycling rates may include increasing the amount of material that can be recycled. This could result in fewer options available to replace previously non-recycled plastic.
Launch a call for evidence on the development of standards for bio-based and biodegradable plastics	Opportunity / risk	This could stimulate engagement, interest and investment in the bio-plastics industry. However, development of such standards may also impact their production lines.

1.2.6 25-Year Environmental Plan

Background

The UK Government's recently published 25-year Environment Plan states an ambition to eliminate avoidable plastic waste by the end of 2042[19]. The most relevant commitments include:

- Reforming and extending the producer responsibility system to include products not currently covered and stimulate the secondary plastics sector
- Encouraging industry to rationalise packaging and materials formats to facilitate end-of-life processing
- Encouraging development of bio-based, biodegradable and 'environmentally friendly' plastic
- Explore the idea of plastic-free supermarket aisles
- Develop standards for biodegradable bags

Key dates

- 11th January 2018 – UK government published the 25-year Environmental Plan
- End of 2042 - Ambition to eliminate avoidable plastic waste

How will this policy affect the bio-plastics industry (including risks and opportunities)?

There are several risks and opportunities arising from the Plan. For example, by reforming and extending the producer responsibility system, and encouraging industry to amend packaging to facilitate end-of-life processing, certain items may become less replaceable if they are being designed for recyclability. Increasing plastic collected for recycling could open up new avenues for recycling of plastics that were not previously recycled, and therefore remove previously replaceable items.

Encouraging development of bio-based, biodegradable and 'environmentally friendly' plastic is a clear opportunity for the bio-plastics industry. According to the Steering Group, plastic bags are highly

[19] https://www.gov.uk/government/publications/25-year-environment-plan

replaceable. Developing standards for compostable and biodegradable bags could improve public awareness and understanding, thereby increasing their use (subject to suitable collection and treatment routes).

1.2.7 UK, Growing the Bioeconomy – A national bioeconomy strategy to 2030

Background

The Strategy is a collective approach from government, industry and the research community to transform the UK economy through the power of bioscience and biotechnology[20]. The strategy is underpinned by four strategic goals:

- Capitalise on our world-class research, development and innovation base to grow the bioeconomy
- Maximise productivity and potential from existing UK bioeconomy assets
- Deliver real, measurable benefits for the UK economy
- Create the right societal and market conditions to allow innovative bio-based products and services to thrive

In the report it is stated that the global market for bio-plastics is expected to grow from £13bn in 2017 to over £33bn by 2022[21].

Key dates

- 5th December 2018 – Strategy published
- The vision of the strategy is set to 2030

How will this policy affect the bio-plastics industry (including risks and opportunities)?

The strategy outlines the key challenge of reducing plastic waste and pollution through the development of sustainable plastics including bio-based and biodegradable packaging and bags. Therefore, one of the key strategic goals is to create the right societal and market conditions to allow innovative bio-based products and services to thrive. This is likely to generate support, interest and investment for innovative bio based plastic solutions.

1.2.8 EU Single-use Plastic Proposal

Background

The European Commission (EC) released a proposed Directive on single-use plastics on 28th May 2018, as part of its transition to a more circular economy for plastics[22]. The draft Directive would impact plastic food-contact articles and target around 70% of items thought to contribute to marine debris through several initiatives. Measures would include bans on certain items (those which have designed-in single use properties which reduce re-use options), producer obligations, awareness raising measures, labelling and consumption and collection targets.

Under the proposal, Member States would be required to take measures to significantly reduce the consumption of plastic beverage cups and food containers. They would also be required to ban certain single-use plastic products including cutlery, plates, straws and beverage stirrers[23].

Key dates

- 28th May 2018 - Proposed directive on the reduction of the impact of certain plastic products released

[20] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761856/181205_BEIS_Growing_the_Bioeconomy__Web_SP_.pdf
[21] Research and Markets, Global Bio-plastics Market Forecasts (2017)
[22] http://ec.europa.eu/environment/circular-economy/pdf/single-use_plastics_proposal.pdf
[23] https://www.packaginglaw.com/news/eu-advances-its-strategy-plastics-circular-economy

- 18th January 2019 - Document endorsed by ambassadors from EU member states[24]

How will this policy affect the bio-plastics industry (including risks and opportunities)?

The Steering Group highlighted that many commonly produced items can be easily substituted for compostable plastics based on current technology and biopolymers. These include PS single-use food contaminated containers/cups, straws, yoghurt pots and plastic cartons, as well as, PP salad bags, fruit produce containers, and microwavable meal trays. Banning some or all of these items under this Directive could present an opportunity for bio-plastics by replacing them with innovative alternatives.

1.2.9 Extended Producer Responsibility (EPR)

Extended producer responsibility aims to link up gaps in the supply chain and take into consideration the costs of the environmental impact of a product or celebrate efforts to improve the environmental benefits of a product. Expanding the range of products covered by EPR schemes to include more plastic products should be considered in order to incentivise plastic producers to consider the environmental impact of a product during the design and manufacturing stage.

As part of the Resources and Waste Strategy, retailers and producers of packaging may be required to pay for the full collection and recycling costs of packaging. Higher fees will be charged against difficult to recycle packaging (i.e. plastic trays) and lower fees for packaging which is easy to recycle or reuse. Proposals are subject to consultation. Defra's Resource and Waste Strategy is for England, however EPR is applicable more widely to the UK.

1.2.10 Deposit Return Scheme

Background

An example of EPR being adopted in Scotland is the introduction of a Deposit Return Scheme (DRS). The First Minister of the Scottish Government 2017/18 announced last year that a new Deposit Return Scheme for Scotland would be introduced. Zero Waste Scotland is leading on the design of the programme. Within a deposit return scheme, the price of a product includes a small extra amount (the deposit) which is given back when the item is returned. This provides an incentive to return the bottle or can to a deposit return point after use.

The Waste and Resources Strategy sets a target to roll-out a deposit return scheme by 2023, subject to consultation. As such, a consultation for a DRS in England, Wales and Northern Ireland is being held, which opened on 18th February 2019 and closes on 13th May 2019. The ambition of government is to ensure that DRS schemes implemented in regions of England are identical to assist in consistent messaging.

Key dates

- 18th February 2019 – Consultation opens (for a DRS in England, Wales and Northern Ireland)
- 13th May 2019 – Consultation closes

How will this policy affect the bio-plastics industry (including risks and opportunities)?

The key opportunistic materials for bio-plastics are those that are not yet recycled (since these are easily replaceable) and those which contain food residues (since food residue reduces the quality of the recyclate, increasing replaceability, and many bio-plastics are biodegradable/compostable, meaning that food residue is not an issue). As such, a DRS scheme is unlikely to be a major risk for the bio-plastics industry, since the primary materials being recycled (PET / metal cans) are already considered widely recycled and have an existing recycling avenue.

[24] https://www.europeansources.info/record/proposal-for-a-directive-on-the-reduction-of-the-impact-of-certain-plastic-products-on-the-environment/

1.2.11 Biodegradable municipal waste landfill ban

Background

The Waste (Scotland) Regulations 2012 set out a number of provisions which help Scotland move toward the objectives and targets set out in Scotland's Zero Waste Plan and help transition toward a circular economy. These provisions include a ban on biodegradable municipal waste going to landfill from the 1st January 2021, which is implemented by amending the Landfill (Scotland) Regulations 2003. From 1st January 2021, landfill operators in Scotland will be prohibited from accepting Biodegradable Municipal Waste for disposal at landfill[25].

Key dates

- 1st January 2021 – Biodegradable municipal waste going to landfill will be banned

How will this policy affect the bio-plastics industry (including risks and opportunities)?

Diverting biogenic waste from landfill means they would need to be recycled through Anaerobic Digestion or composting (assuming incineration is not the preferred alternative); this therefore opens up an end of life route for compostables; in particular, the introduction of kerbside food waste collections for households (and equivalent schemes for business) opens up a significant demand for compostable bags for kitchen waste.

1.2.12 Import/export restrictions

China's ban on plastic waste and unsorted paper imports and tighter quality standards (known as "National Sword") has seen the UK stockpiling materials or disposing of recyclables as residual waste. Until recently, China had lower standards for receiving recyclable waste material, making it an easy choice for the UK to help reach higher recycling rates and reduce landfill. However, with the ban enforced at the end of 2017, on plastics such as polyethylene terephthalate (PET) drinks bottles and all mixed paper, including increased quality control on cardboard, pressure will build on the British recycling industry and Local Authorities alike. At present, the visible impact is reflected in falling material prices, but it appears that in the longer term, the capacity for recycling some elements of the recycling stream, particularly lower grade materials, may be compromised. As a result, stockpiling of materials has occurred in the UK, as well as an increase in the amount of recyclables disposed of as residual waste, predominantly through Energy from Waste (EfW).

1.2.13 Consumer demand / driver

Public concern over the environmental impact of plastic pollution and throwaway plastics has been on the increase for many years. However, increased publicity from documentaries such as David Attenborough's Blue Planet and single-use coffee cup campaigns has meant that public demand for sustainable packaging solutions is at an all-time high. So much so, that 'single-use' was crowned Word of the Year by the Collins Dictionary in 2018.

Household brands and retailers have in turn responded with strong commitments for improving packaging solutions. For example,

- Morrisons pledged to reduce their single-use packaging and provide 100% recyclable plastic by 2025.
- Lidl are exploring black plastic packaging alternatives to improve recyclability of their products
- The Co-operative are working with bio-plastic producers to create compostable carrier bags and encouraging householders to place them in the food waste bins.
- Waitrose has brought forward its commitment to make sure all of its own-brand packaging is widely recyclable, reusable or home compostable within two years (from November 2018)

25 https://www.sepa.org.uk/regulations/waste/landfill/biodegradable-municipal-waste-landfill-ban/

Figure 1 Example headlines from retailers

Iceland to adopt new 'plastic free' mark on own brand sustainable packaging

Tesco to ban non-recyclable plastic packaging by 2019

Kellogg's UK announces new sustainable packaging actions

Co-op to replace plastic bags with compostable carriers

1.3 Likely impact of drivers

So what impact will these drivers have?

What is clear from Section 1.2 is that there is a paradigm shift in terms of how we view plastics, and this is driving significant change across the industry.

The range of drivers have a central theme of reducing the negative environmental impact of plastic (and other) packaging. The drivers look to achieve this by incentivising all elements of the packaging chain, from producers to consumers, to modify their actions and behaviours through a variety of economic, practical and legislative levers. This is being demonstrated by the ongoing work on extended producer responsibility (EPR) that will drive them to pay greater attention to what is put on the market and what happens to that plastic after its use.

Specifically, in the UK, the Plastic Pact is a direct response to the increased public awareness of the negative environmental impact of plastic pollution. The Pact introduces a specific target whereby 70% of plastic packaging will be recyclable and compostable by 2025.

The key challenge is that over the last 50 years, plastic has evolved to become a key element of daily life, with its durability, flexibility and relatively low cost engendering an increasing level of customer convenience. Not only has this enabled plastic to replace more ‘traditional’ materials such as paper, glass and metal, it has also led to the development of ever-expanding options to increase convenience and reduce cost for manufacturers, retailers and the public consumer.

However, the benefits represented by plastics also contribute to the environmental damage they cause; their durability means that they do not degrade in a reasonable time period, taking up to 1,000 years; this means that, if not disposed of appropriately, land and marine litter represent an ongoing and increasing threat to the wider environment. The relative low cost of plastic products however, makes it difficult to develop economic and operationally practical systems to maximise the rate of collection and recycling. A further issue is that the design of products to maximise customer or consumer convenience has not taken into account either the potential use of recyclate to produce new goods or the design of products with an aim of maximising their recyclability post-use.

There are three approaches common to the drivers which aim to address these issues:

- **Eliminate avoidable plastics**
- **Shift to compostable polymers**
- **Shift from single-use plastics**

Single-use plastics are any plastic product which is used just once before being either disposed of or recycled. These items tend to be designed to maximise consumer convenience, such as coffee cups, beverage bottles for water and soft drinks, grocery bags and 'disposable' food accessories, such as cups, plates, cutlery, drinking straws and stirrers.

However, some elements of flexible plastic also contribute to this area, including wrapping material for food products and overwraps for bottles.

Approaches to addressing these issues focus primarily either on increasing the cost to consumers through direct taxation or levies, creating a disincentive to their use, or through government action to ban the use of specified single use or problematic items, either through voluntary agreements with industry or direct legislation.

1.3.1 Facilitating transition to compostable packaging

There are a number of key facilitators to support the transition to compostable packaging, these are:

- **Collections** - Food waste collection schemes available to all households in Scotland and Wales (some exemptions apply) and this is currently under consultation for England through Defra's Waste and Resources Strategy. There is limited value in having compostable plastics without appropriate collection and processing infrastructure capacity
- **Infrastructure** – Appropriate infrastructure needs to be in place to treat compostable packaging. Compostable packaging and the content of the packaging can return nutrients to the soil through anaerobic digestion and composting processes. However, the quality of the feedstock, including contamination rate, will directly impact the quality of the digestate or compost output. Therefore, it is vital that compostable packaging materials are consistent to ensure confidence in industrial composters and AD operators to allow such materials through their plants. Otherwise, the alternative solution is to include a pre-treatment step to extract unwanted items and send them for incineration or landfill. It is also likely that such infrastructure incorporates the Animal By-Products regulations. If used food packaging is included in AD plant, does it mean that there is a contamination risk and that ABP needs to be applied?
- **Clear labelling** – to support the collection of compostable packaging it will be important to ensure that materials are clearly labelled and that the consumer is supported in making the correct decisions in relation to disposing of the packaging
- **Standard for industrial composability BS EN 13432** – To meet this standard, packaging products must conform to the 'compostable' criteria of the British Standard Institution. This pass / fail criteria requires that packaging disintegrates within 12 weeks under industrial composting conditions, is absent of any negative effects on the composting process, contains low levels of heavy metals, and within 6 months the biodegradation of the sample must generate at least 90% of the carbon dioxide of the control material.

The result of these drivers and enablers creates a real opportunity for the uptake of compostable packaging in UK and Europe.

Following on from the drivers and opportunities for compostable packaging Section 2 will take a look at the current plastic packaging market.

2 Understanding the current market

2.1 Plastic packaging placed on market

Plastic packaging has served the packaging market for decades. It provides several important functions which consumers have come to rely on. This includes protection of products from damage or contamination; preservation to ensure products last longer and allow for easier transportation, therefore enabling access into wider markets, all of which helps to reduce waste.

It is estimated that the total EU packaging market is circa 84Mt[26] with plastics packaging accounting for approximately 20Mt of this volume. In 2017, it was estimated that 2.361Mt tonnes of plastic packaging was placed on the UK market[27] of which approximately 65% (1.529Mt), see Table 4, is defined as consumer packaging. This significant tonnage identifies the key role that grocery and non-grocery packaging dealt with by householders plays in the market.

2.1.1 Consumer plastic packaging by polymer type

Consumer packaging is the item seen at point of purchase. For example, this includes shampoo bottles, ice cream tubs, cereal boxes etc. According to WRAP, 1.529Mt of consumer plastic packaging was placed on the UK market in 2017. A breakdown of this tonnage by polymer type and application is presented in Table 4 Consumer plastic packaging tonnage by format and polymer in 2017.

Table 4 Consumer plastic packaging tonnage by format and polymer in 2017[28]

Consumer plastic packaging tonnage by format and polymer (2017) (kt)									
	HDPE	LDPE	PE	PET	PP	PS	PVC	Other	Total
Film (exc. carrier bags)	71	110	21	28	110	2	9	17	*368*
Carrier bags	*18*	*9*							*27*
Bottles	268	0	1	347	17	0	0	0	*633*
PTTs	9	1	4	155	85	32	13	2	*301*
Other	55	23	1	40	76	3	2	0	*200*
Total	**403**	**134**	**27**	**570**	**288**	**37**	**24**	**19**	***1,529***

2.1.2 Report focus - Flexible packaging

Plastic packaging can be broadly separated into **'rigid'** and **'flexible'** form. For the purposes of this report we focus on flexibles as this offers the greatest substitution potential. All film is classed as flexible and, bottles and pots, tubs and trays (PTT) are classed as rigid.

Flexible packaging is used to create an effective barrier between the product and its environment and is characterised by its flexible form and ability to change shape. Flexible packaging ranges from simple

[26] CEFLEX, based on Plastics – The Facts 2016 and FPE Market Report Summary 2016
[27] WRAP (2018) PlasticFlow 2025
[28] WRAP (2018) PlasticFlow 2025

film to more complex multi-material forms, such as is typical with a pouch. The product application determines the materials used for flexible packaging and the different combinations of materials available allow a large variety of packaging products which meet specific requirements in terms of shape, size and appearance.

Typically, flexible packaging is made up of PE, PP and polyethylene terephthalate (PET). However, polymers such as polyamide (PA), polyvinylidene chloride (PVdC) and ethylene vinyl alcohol (EVOH) are used to form structures with differing barrier requirements.

Table 5 Typical barrier requirements for packaging. illustrates the variety of physical barriers required for product packaging and example polymer/ materials used to meet these requirements.

Table 5 Typical barrier requirements for packaging.

Barrier	Example polymer
Oxygen	EVOH, aluminium
Carbon dioxide	Aluminium metallised films
Wet / Dry	EVOH
Aroma compounds	EVOH
Light	Aluminium
Temperature	PET (Cold) PP (Hot)
Resistance (damage prevention, shape retention)	PE, paper

Total EU consumer flexible packaging is estimated at 4 Mt per annum. Of the 4Mtpa, it is estimated that 3Mt is comprised of mono PE or PP, or a mix of PE/PP[29]. This aligns with studies which found that approximately 80% of the flexible packaging market is mono-material[30]. At present, many flexible packaging products are classed as 'Not Yet Recycled', however if they could be collected by segregated PE or PP film fraction, technically these materials could be recycled. This illustrates that, should materials be effectively collected, existing infrastructure would be able to recycle these conventional plastics[31]. However, it is worth noting that contamination and colouring may limit the recycling potential of these materials.

We identified two different figures for flexible consumer packaging placed on the UK market. The first scenario estimated the total consumer flexible plastic packaging market to be circa 600,000 tonnes. This is based on a 40% flexible market split (FIACE, 2016)[32] of the total UK consumer packaging market of 1.529Mt[33] as per Table 4. The second estimate was of 414,000 tonnes as per the WRAP Market Report.[34]

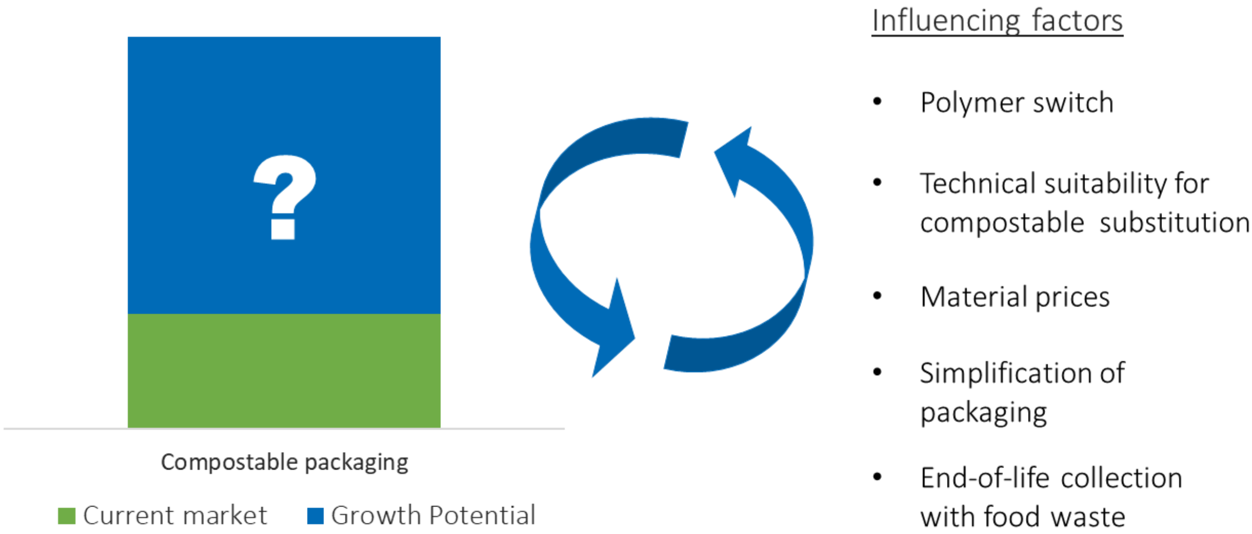
It is assumed that multi-material packaging represented between 0.8 and 1Mt of the EU total consumer flexible packaging market in 2016[3]. Due to the existing challenges that remain for treating and recycling multi-material packaging, and the ability for bio-plastics to meet many of the barrier requirements for packaging, compostable substitution should be focussed in this area. At present, the majority of polymers and plastics are derived from oil and gas. However, many of the chemicals involved in industrial processes to produce these products can be replaced by bio-based sources and significant R&D within this area is driving the UK chemical industry. Bio-plastics is a small but growing market for

[29] CEFLEX, based on Eurostat 2016 data
[30] REFLEX Project (2016) The REFLEXT Project
[31] FIACE (2016) Mapping flexible packaging in a Circular Economy.
[32] FIACE (2016) Mapping flexible packaging in a Circular Economy.
[33] WRAP PlasticFlow 2025
[34] WRAP 'Plastics Market Situation Report Spring 2016' http://www.wrap.org.uk/sites/files/wrap/Plastics_Market_Situation_Report.pdf.

flexible packaging: see Section 3 for more detail. These materials will become increasingly important in the composition of flexible packaging moving forward.

The substitution potential for compostable packaging is highly dependent on a large variety of factors which impact on one another and influence the size of the market. These factors have been taken into consideration for this study and detailed in Figure 2 below.

Figure 2 Market growth potential



3 Bio-plastics placed on market

3.1 Introduction to bio-plastics

In comparison to conventional plastics, bio-plastics help to avoid the use of fossil fuels as they are derived from biomass. A drive towards bio-plastics helps to promote a circular economy by decoupling the manufacture of plastics from the use of predominantly fossil-derived feedstocks.

The term bio-plastics covers a range of fossil and biological-based materials. There are two broad concepts for this group of materials and it is important to distinguish between the two:

- **Bio-based plastics** – these are plastics partly made from biological material such as sugar cane, corn, potatoes, grains or vegetables oils. They are not necessarily biodegradable.
- **Biodegradable plastics** – these materials can be broken down easily by micro-organisms. They can be made from biogenic or fossil-based materials[35].

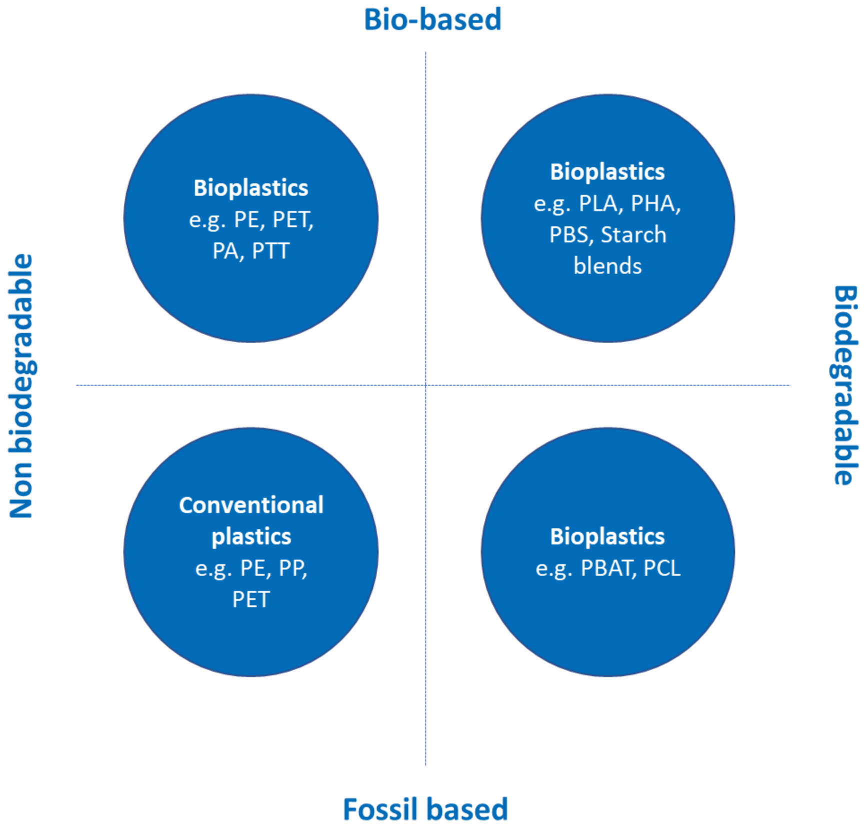
There are two further sub-groups amongst the bio-based plastics group:

- **Drop-in bio-based plastics** – plastics within this group have the same chemical structure and characteristics as their fossil-based counterparts and are recyclable but are made from biogenic materials. However, they are not bio-degradable. They include bio-based PET, PE, PA and PTT.
- **'Novel' bio-based plastics** – plastics within this group have relatively new chemical structures and are designed to be biodegradable. They include polylactic acid (PLA) or Polytrimethylene terephthalate (PTT) and Polybutylene Succinate (PBS).
  Note. Although the phrase 'novel' is used to describe these bio-based plastics, PLA as a material has been in development for over a decade and oil-based PTT was patented in 1941.

Figure 3 illustrates the relationship between conventional, bio-based and biodegradable plastic.

[35] Plastics Europe (2016), Plastics – the Facts 2016: An analysis of European plastics production, demand and waste data, http://bit.ly/2C39H7H

Figure 3 Interrelationship between conventional, bio-based and biodegradable plastics[36]



As research and development continues to progress, the emergence of new bio-based chemicals presents a strong opportunity to grow the bio-plastics industry. Through innovation and collaboration, researchers and producers are working with bio-based chemicals across the UK (and globally) to create a variety of new bio-plastics with the capability of meeting or exceeding the barrier requirements of conventional plastics (wet/dry/temperature).

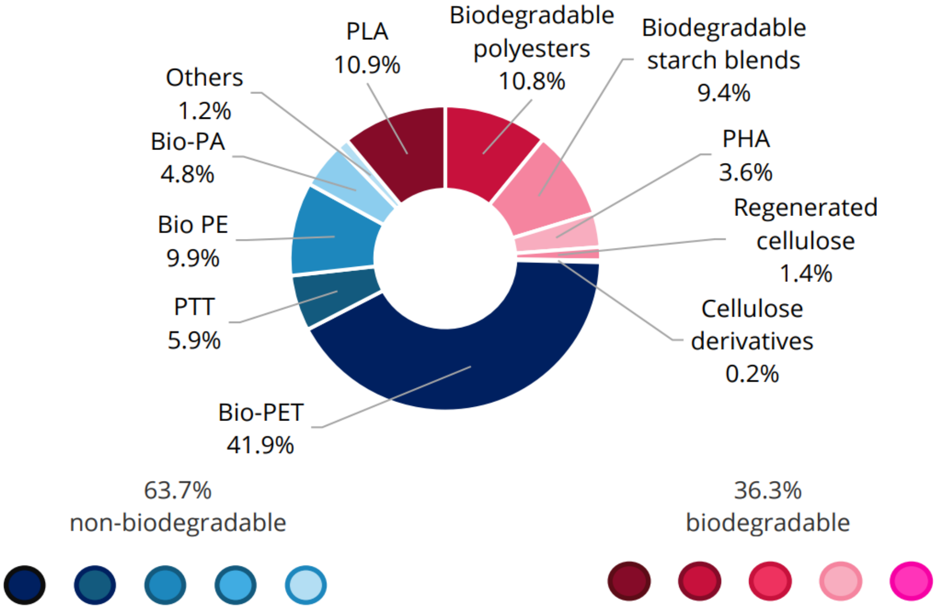
3.2 Current market share of bio-plastics

Compostable packaging is not new, and the appearance of compostable packaging solutions have already started to increase in UK stores. The chemical capabilities of compostable packaging offer the unique opportunity to target and substitute multi-material flexible packaging in a variety of applications.

However, the market share for bio-plastics is still relatively small. Bio-plastics currently make up approximately 1% of global plastics production. The largest growth area is expected to be for drop-in bio-based plastics which are anticipated to have a 75% share of the total bio-based plastics market by 2021[37]. Figure 4 shows the breakdown of bio-based plastics currently placed on the market. 36.3% of the bio-based plastics are classed a biodegradable and consist of PLAs, polyesters, starch blends, PHA, and cellulose derivatives.

[36] WRAP (2018) Understanding plastic packaging and the language we use to describe it
[37] European Bio-plastics (2016), Bio-plastic market data 2016

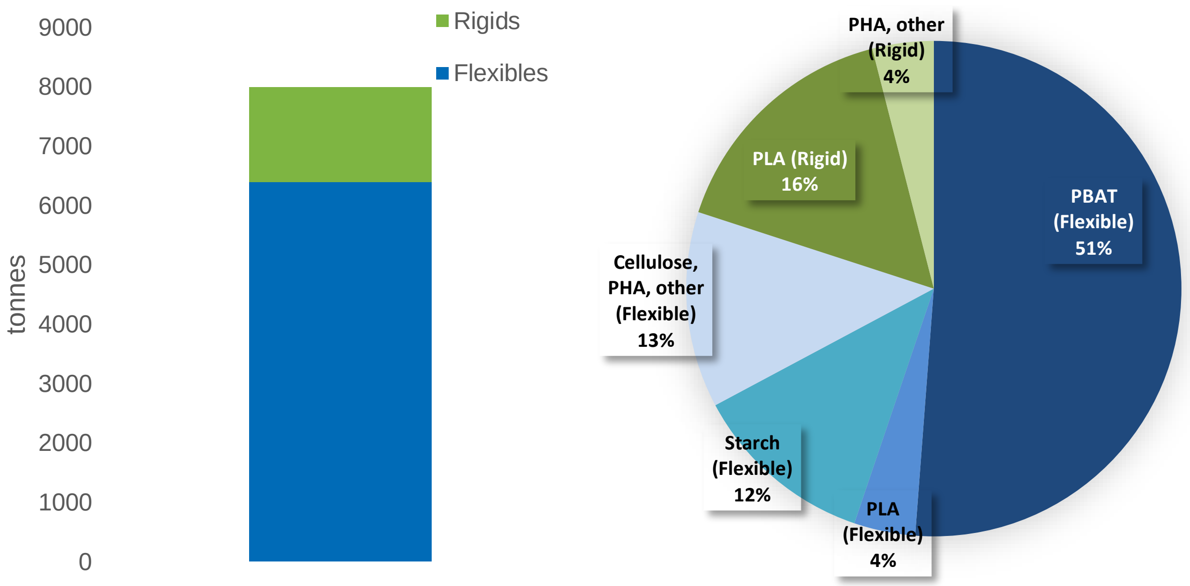
Figure 4 Breakdown of bio-based plastic currently placed on the market (2018)[38]



3.2.1 Breakdown of biodegradable bio-plastics by polymer type UK.

According to information gathered by members of BBNet, the current UK market for biodegradable bio-plastics is estimated at approximately 8,000 tonnes (+/- 1,000t). The breakdown of this market by biopolymer is illustrated in Figure 5. This shows that a significant proportion of the biodegradable plastic market goes towards producing flexible plastic products.

Figure 5 UK biodegradable plastics market 2018



38 Resourcing the Future Partnership (2018) Eliminating avoidable plastic waste by 2042.

4 Future market opportunities for compostable packaging

At present, the majority of consumer flexible packaging is sent for landfill or energy recovery. This is due, in part, to the challenging infrastructure for collecting and recycling PE films. As a result, the collection and sorting of flexible packaging remains a challenge for many local authorities across the UK. Increasing public demand and global trends towards sustainability and away from using fossil-based reserves however, allows for significant market growth potential for compostable packaging. The social move towards compostable packaging is supported by the significant R&D in the UK which provides world leading research into bio-based chemicals that seek to replace and improve upon those derived from fossil fuels.

Research estimates that the global compostable packaging market is likely to grow at a compound annual growth rate (CAGR) of 5.1% between 2018 and 2028[39].

5 Compostable substitution potential

To understand the UK market opportunity for compostable packaging, it was required to firstly understand the packaging it could most readily replace and secondly the size of this potential market.

Therefore, with the support of the steering group, a list of the most common plastic packaging applications was created. As can be seen in Table 6 this has been categorised firstly by the polymer type used (LDPE, HDPE, PP, PS etc) and then split by whether it is a food or non-food product.

We then applied a RAG (Red, Amber, Green) score against each packaging item to illustrate the substitution potential for compostable packaging. A RAG assessment presents a visual status assessment using traffic light colours. The following criteria was used to illustrate the substitution potential of current packaging items:

- Green – a compostable alternative is already available or could be in the short term;
- Amber – could potentially be substituted and there is biopolymer potential by 2025, may be some existing challenges to overcome; and
- Red - not likely to be possible by 2025.

The results can be seen in Table 6 Substitution Potential RAG assessment results

[39] **Compostable Plastic Packaging Material Market: Global Industry Analysis 2013-2017 and Opportunity Assessment 2018-2028**

Table 6 Substitution Potential RAG assessment results

Please note that information presented within this table is for illustrative purposes only and is not intended to be exhaustive.

PP		HDPE		LDPE		PVC		PET		PS		Multi-layer
Food	Non-food	Food	Non-food	Food	Non-food	Food	Non-food	Food	Non-food	Food	Non-Food	Food
Margarine tubs	Overwrap	Milk bottles	Bleach bottles	Pliable lids	Refuse sacks	Stretch film (mushrooms)		Water bottles	Polyester fibre for fill	Protective packaging	Protective packaging for electronics	Milk cartons *wet, shelf life, hot
*Dry PP - competition from other mono materials	Cotton buds	Plastic bags	Cleaning products bottles	Sauce bottles	Computer hardware (CDs, cards etc)	Labelling / sleeve		Carbonated drink bottles	Blister packs	Take out boxes (foam)		Juice cartons
Biscuit wrappers			Shampoos / conditioner bottles	Six pack rings	Dispensing bottles			Salad trays		Coffee cup lids		Sandwich
Flow wrap			Soap bottles	Stretch wrap	Stretch wrap (film)			Packaging trays		Plastic cartons		Dairy products
Confectionery wrappers			Food storage containers	Organic sacks	Recycling sacks			Blister packs		Frozen desserts cartons		Coffee pods
Fruit produce (bags)			Plastic bags (single use)		Bags for life					Yoghurt pots		Dry, moisture barrier
Salad bags					Organic sacks					Straws		Cereal bags
*contaminated / wet PP					Mailing film					Single use food contaminated containers / cups		Pouches
Microwave meal trays					Ziplock bags					Egg cartons		Liners
										Cutlery		Cereal bars

Not possible / Long term possibility
Potential substitution / available in the medium term, however some existing challenges
Already available / available in the short term

5.1 Substitution Potential

5.1.1 Results of RAG assessment

The following assessment was made from the RAG status of each type of packaging.

- Items deemed as **possible** (shown in green) indicate where biodegradable bio-plastics are currently substituting conventional plastics on the market or where substitution can easily be achieved based on current technologies. From looking at the items highlighted 'green' in Table 6, initial results demonstrate that the applications with the largest substitution potential fall into the category of food product packaging, short lived, single use items. This includes packaging such as confectionery wrappers, fruit produce bags, pouches and microwave meal trays.

- Items deemed as **possible in the medium term, with some challenges,** (shown in amber) are determined as those, smaller niche applications with no clear justification for substitution.

- Items deemed as **not possible**, (shown in red) are those presenting significant challenges for substitution that are not likely to be overcome before 2025. As shown in Table 6, these are generally those containing liquids and/or products requiring a long shelf life. Influencing factors include;
    - Small market
    - Technology does not exist to create bio-plastic equivalent
    - Long life (shelf life over 1 year)
    - Withstand prolong exposure to temperatures (over 100°C)
    - Retain moisture over a few days
    - Non-food
    - Performance (strength, life)

As discussed, the substitution potential is dependent on a large variety of factors which could influence the market, as shown in Figure 2 above. These include:

- Polymer switch:
    - PT to PE switch,
    - Conventional plastic to bio-based
- Substitution to compostable and biodegradable
- Multi to mono (simplification)

Additionally, the substitution potential depends on whether or not the material can be recycled (i.e. materials that are contaminated with food, multi-layer or contain colour cannot be recycled and therefore have the biggest substitution potential).

Other drivers include those as discussed in Section 1.2, particularly;

- Retailer ambition/desire from brand owners
- Introduction of mandatory food waste collection,
- Oil prices
- Availability and accessibility of biochemicals (see Section 6)
- Political appetite
- Desire to capture food waste that is attached to packaging and therefore – see Figure 6

Figure 6: Food contaminated plastics: a win:win solution?

CONTAMINATED PLASTCS: A WIN: SITUATION?

Plastic can often become too contaminated with food waste to be sent for recycling. When this is the case it needs to be sent for disposal either incineration or landfill.

This however, presents an opportunity for the compostable packaging market. If the focus for compostable packaging was prioritised for packaging that often becomes contaminated and therefore are either placed in a general waste bin, or rejected at Material Recycling Facilities, a double benefit could be achieved. Not only would landfill avoidance be achieved but if composted additional benefits could be achieved in terms of soil nutrients

Biopolymer producers are focusing research in this area to create biodegradable packaging solutions that can address these barriers. This can also be extended to lightweight multilayer constructions where it is economically, and sometimes physically impossible to currently recycle these structures.

5.1.2 Size of market – flexible and rigid packaging

The size of the potential market for compostable packaging was estimated using the available information of the plastic packaging market as discussed in Section 2, and the results of the RAG assessment (see Table 6). The current plastics market was categorised into the following; flexible packaging and rigid packaging.

A number of assumptions have been made to determine the potential compostable packaging market. These are summarised below:

- Ratio of flexible to rigid packaging, 60:40[40]
- Plastic polymer split (as reported by Valpak)[41]
- Composition of flexible packaging stream (as reported by REFLEX)[42]
- Ratio of multi-material to mono-material packaging, 20:80[43]

To provide a transparent approach to the calculations two scenarios were developed for flexible consumer plastic packaging:

- **Scenario 1** using the FIACE figures (see Section 2) of 600,000 tonnes flexible plastic packaging (Figure 7).
- **Scenario 2** using the WRAP figures (see Section 2) of 414,000 tonnes flexible plastic packaging (Figure 8).

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40 FIACE (2016) Mapping flexible packaging in a Circular Economy.
41 WRAP PlasticFlow 2025
42 https://ceflex.eu/public_downloads/REFLEX-Summary-report-Final-report-November2016.pdf
43 FIACE (2016) Mapping flexible packaging in a Circular Economy

Figure 7 Scenario 1 (600,000 tonnes)

Scenario 1 using the FIACE figures (see Section 2) of 600,000 tonnes.

PP	HDPE	LDPE	PVC	PET	PS	Other
Flexibles (40%)			**Rigid (60%)**			
600,800t			**901,200t**			

Multilayer 20%	Single Polymer (80%)
19% of which can be substituted	**1% of which can be substituted**
114,152t	**6,008t**

Rigids
1% of which can be substituted
9,012t

Potential Flexible Tonnage	
Green	77,004
Amber	42,796
Red	360
Total	**120,160t**

Potential Rigid Tonnage	
Green	7,210
Amber	1,802
Red	0
Total	**9,012t**

Based on the feasibility of substituting current packaging as per Table 6, this assessment shows that **77,000t** of flexible packaging placed on the UK market is 'technically feasible' to substitute with compostable packaging in the short term; with the potential to increase this by approximately 43,000t should challenges in technology and infrastructure be overcome by 2025.

Regarding rigids, it has been estimated that approximately 1% is deemed suitable for substitution with compostable packaging alternatives. This equates to approximately 9,000t of rigid plastic packaging.

Please note that this is based on using current available composting technology.

Figure 8 Scenario 2 (414,000 tonnes)

Scenario 2 using the WRAP figures of 414,000 tonnes.

PP	HDPE	LDPE	PVC	PET	PS	Other
Flexibles (40%)			**Rigid (60%)**			
414,000t			**1,088,000t**			

Multilayer 20%	Single Polymer (80%)
19% of which can be substituted	**1% of which can be substituted**
78,660t	**4,140t**

Rigids
1% of which can be substituted
10,880t

Potential Flexible Tonnage	
Green	53,062
Amber	29,490
Red	248
Total	**82,800t**

Potential Rigid Tonnage	
Green	8,704
Amber	2,176
Red	0
Total	**10,880t**

Based on the feasibility of substituting packaging as per Table 6, these results show that in Scenario 2 53,062t of flexible packaging placed on the UK market it is deemed 'ready' to be substituted by compostable packaging in the short term, with the potential to increase this by almost 30,000t.

Regarding rigids, it has been estimated that approximately 1% is deemed suitable for substitution with compostable packaging alternatives. This equates to almost 11,000 tonnes of rigid plastic packaging.

Please note that this is again, based on using current available composting technology.

5.1.3 Size of the market - plastic bags

We have excluded plastic bags from the scope of this study. However, we feel it is important to recognise the role bags could play in the growth of the biodegradable compostable plastics market.

To demonstrate the potential for plastic bags it is interesting to look at the example of Italy. The case study below highlights the 100,000 tonnes market for compostable carrier bags alone (Figure 9).

Figure 9 Case Study: Italian ban on non-biodegradable bags

Case Study: Italian ban on non-biodegradable bags

Since 2011, Italy has progressively phased out the use of non-biodegradable bags and replaced them with certified compostable bio-plastics. This is a result of the ban on non-biodegradable plastic bags at shops and retail points, that came into effect on 1st January.

Italy was once one of Europe's top consumers of plastic bags, consuming around a fifth of all plastic bags used annually across Europe. The impacts of this revolution have been wide reaching and include:

- **Leverage on the bio-based sector and opportunities for integration with traditional chemistry**, creating a climate conducive to high-risk investments as a force for growth in the country. In particular:
  - The development of products related to bio-plastics
  - Bio-plastics market potential of about 150,000 tonnes / year
  - Turnover potential of around 1.5 billion euro, with the creation of several thousand jobs
  - Greater confidence by companies active in the sector
- **Leverage effect on agriculture**: industry and agriculture increasingly allied in a common mission to preserve local resources and ecosystems.
- **Positive environmental effects**: including a boost to waste collection and improved availability of quality compost. In particular, it has contributed to reductions in greenhouse gases, increased the quality of organic waste collection and decreased the use of disposable bags by between 35 to 50% in supermarkets.
- **Effects on citizens and society** i.e. growth and employment through driving the forces of strong innovation.

Bio-plastic sector turnover in 2017 was 545 million euros, from 367 million euros in 2012; national production was 73,000 tonnes in 2017, compared to 41,600 in 2011[1]. The latest figures for 2018 suggest that the plastic bag market alone in Italy was 49,500 tonnes.

Given that Italy has a similar population to the UK one scenario would be to assume that if a similar policy was introduced then the market for compostable bags could be similar. This would equate to a market of 49,500 tonnes.

However, given that the UK has introduced a plastic bag ban it is appropriate to use the existing figures for plastic bags. The calculations below give an indication of the potential market for compostable bags if the UK was to adopt similar policies to Italy based on current bag usage.

Carrier bags

It is estimated that in 2017 the UK used 2.1bn plastic bags per year[44] which is an 83% reduction since the introduction of the plastic bag ban. If these bags were compostable, and assuming an average weight of 9g per bag, this would create a possible market of 18,000 tonnes for compostable carrier bags.

Fruit & vegetable bags

Using Recoup figures of 1.3bn[45] fruit and vegetable bags used in the UK per year and an average weight of 2g the total tonnage of bags equates to 2,600 tonnes of potentially compostable bags.

Food waste caddy liners

If food waste collections are rolled out across England and Wales as proposed in the Waste and Resource Strategy, adding to the bin liners already used in Scotland and Wales then we could assume the following:

- with 27 million households receiving a food waste collection (at 60% participation);
- and assuming 3 caddies are put out per household/week (52 weeks/year);
- with each caddy bag weighing 3g

This would amount to circa 7,500 tonnes market potential of compostable liners per year.

Compostable carrier bags and caddy liners could create a market of between 28,100 tonnes to 50,000 tonnes depending on the policies that are adopted.

5.2 Looking ahead to 2025

It is understood that currently around 8,000 tonnes of compostable bio-plastics are placed on the UK market. However, from our analysis of the market, the UK could potentially significantly increase this to between 90,100 and 138,000 tonnes as detailed in Table 7 below.

Table 7 Potential substitutable market

	Tonnes
Potential Flexibles market	53,000 - 77,000
Potential Rigid market	9,000 – 11,000
Carrier Bag potential	28,100 – 50,000
Total	**90,100 – 138,000**

Table 8 Biopolymers required to meet 2025 biopolymer requirement illustrates the total tonnages for biopolymers that we would require if we are to meet the total potential substitutable market by 2025.

[44] https://www.edie.net/registration/regwall.asp?mid=90934&origin=https%3A%2F%2Fwww%2Eedie%2Enet%2Fnews%2F5%2FPlastic-bag-charge-UK-sustainability-statistics-from-Defra-2017%2F&title=Plastic+bag+charge%3A+10+fascinating+facts+about+the+scheme%27s+sustainability+success
[45] http://www.recoup.org/

Table 8 Biopolymers required to meet 2025 biopolymer requirement

		2025
	Estimated tonnage	100,000
Flexible	*77.3%*	77,250
PBAT	*59%*	*45,578*
PLA	*5%*	*3,863*
Starch	*15%*	*11,588*
Regenerated cellulose, PHA, other	*21%*	*16,223*
Rigid	*17.3%*	17,250
PLA	*70%*	*12,075*
Regenerated cellulose, PHA, other	*30%*	*5,175*
*Other**	*6%*	5,500

*Continual R&D in the chemical industry is expected to introduce new and improve the performance of biopolymers to the market. As such, industry experts predict that this market share could be around 6%. The factors influencing the growth are discussed below in Section 5.2.1

5.2.1 Factors influencing growth to 2025?

5.2.1.1 Research & development (R&D) capability in the UK

Facilitation in this transition will come from the UK's expertise in biorefining and bioeconomy. With leading research and development supported by universities and corporates, the UK is well positioned to disrupt the current chemical industry and drive growth for biochemicals industry. Within the UK there are around 25 industry players and approximately 10 universities that are actively developing bio-based chemicals.[46] Support from industry associations such as the Bio-based and biodegradable industries association (BBIA) and BBNet is also helping to advance the UK circular bioeconomy by representing companies involved in the production of biodegradable polymers and improving consumer awareness of the environmental, economic and social impacts of bio-based plastics.

The UK has excellence in bioscience research and development and the bioresources needed to generate the biochemicals for compostable packaging, it now needs the Government directive to drive the growth. Over the last 10 years this has included a commitment of over £80M to support biotechnology projects from multiple groups including the Integrated Biorefining Research and Technology Club and Industrial Biotechnology Catalyst programme, Innovate UK, the Engineering and Physical Sciences Research Council (EPSRC) and the Biotechnology and Biological Sciences Research Council (BBSRC)[47]. The UK is home to world leading universities and developers and recent investments made in bioscience and biotechnology means that the UK is in a strong position to take a lead on bio-based technology innovation.

With the incorporation of emerging biochemicals as discussed in the LBNet UKBioChem10 report[46] significant growth could be realised. Table 9 below presents the ten bio-based chemicals which present a strong business opportunity for the UK. The development of which is driven by demand for sustainable chemicals, the knowledge and experience of research institutions and where infrastructure exists to commercialise these.

[46] LBNet (2018) UKBioChem10
[47] NNFCC (2018) Bio-based & Biodegradable Plastic in the UK – A market perspective

Table 9 Top 10 Bio-based chemicals[40]

Top 10 Bio-based chemicals	Usage
LACTIC ACID	"Lactic acid can be used to produce biodegradable polyesters such as PolyLactic Acid (PLA) which could replace many plastics used in packaging, automotive parts and textile fabrics. Lactic acid can be produced by the fermentation of sugar or starch."
2,5-FURANDICARBOXYLIC ACID (FDCA):	"Can be used to make polymers such as PEF as an alternative to PET which is a fibre used to make plastic bottles, food packaging and carpets."
LEVOGLUCOSENONE	"An alternative to solvents used in pharmaceuticals manufacturing, flavours and fragrances. One Australian company has created levoglucosenone from biorefinery waste."
5 HYDROXYMETHYL FURFURAL (HMF):	"Potential to replace chemicals in plastics and polyesters, and also for producing high energy biofuel."
MUCONIC ACID:	"Derivatives could replace non-sustainable chemicals used in the production of PET and nylon fibres."
ITACONIC ACID:	"A replacement for petroleum-based acrylic acid, used to make absorbent materials for nappies; and resins used in high-performance marine and automotive components."
1,3-BUTANEDIOL (1,3-BDO):	"A building block for many high value products including pheromones, fragrances, insecticides, antibiotics and synthetic rubber"
GLUCARIC ACID:	"Prevents deposits of limescale and dirt on fabric or dishes, providing a green replacement for phosphate-based detergents"
LEVULINIC ACID:	"Used in the production of environmentally friendly herbicides, fruity flavour and fragrance ingredients, skin creams and degreasers."
N-BUTANOL	"Used in a wide range of polymers and plastics, as a solvent in a wide variety of chemical and textile processes and as a paint thinner."

5.2.1.2 Supportive policy framework

As introduced in Section 1.2 emerging policy will help to generate support, interest and investment for innovative bio-based plastic solutions.

For example, the goals of 'Growing the Bioeconomy: A National Bioeconomy Strategy to 2030' aim to make the most of the UK's world leading research and innovation to grow the bioeconomy; and create the right societal and market conditions to allow growth in novel bio-based products, ultimately leading to measurable benefits for the UK circular economy. It is estimated that support for this strategy will help to accelerate growth within the UK bioeconomy, enough to double the size of the market over the next 10-15 years.[48]

This strategy demonstrates a key push from government and industry to transform the UK economy through the power of biotechnology.

[48] Growing the bioeconomy (2018) A national bioeconomy strategy to 2030.

5.2.1.3 Market forces

Potential growth will be dependent on a range of external market forces including cost of material, competition and collection and industrial treatment technologies. This includes:

- Alternative solutions to compostable packaging (i.e. plastic manufactures switch PP materials to PE to increase recyclability),
- Competition from oversea markets with capacity to produce bio-plastics.
- Oil prices
- Availability and accessibility of biochemicals (see Section 6)
- Cost / functionality of second generation bioresources (sugars etc)
- Political appetite

6 Bioresource Requirement

6.1 Biopolymers required to produce compostable packaging

With a sound understanding of the potential packaging market which could be served by compostable packaging, it is then necessary to understand the bioresources required to produce the necessary biopolymers and investigate whether this demand can be met through UK biomass feedstock.

As discussed in Section 3, the most appropriate biopolymers required to produce compostable packaging are presented below in Table 10.

Table 10 Biopolymers and their packaging application

Biopolymers	Example application
PLA (Polylactic Acid)	Flexible –films Woven or non-woven fibres - Tea bags Rigid – Cups
PBAT (Polybutylene Adipate Terephthalate)	Bottles, coating and foam
PBS (Polybutylene Succinate)	Plastic bags, rigids, film
Starch	Wide ranging applications including cutlery, plates, cups
PHA	Compost liners and bags (achievable by PHA blends), fibres, rigids, film, bottles
Regenerated cellulose	Films
Other	Films, bags, bottles, food packaging

6.2 Biochemicals to produce biopolymers

The chemicals required to make bio-based plastics are derived from plant or animal-based feedstocks which includes starch, sugar, fats and oils, and biomass derived from crops and organic waste. Bio-based chemicals offer the opportunity to generate low carbon energy at the end of the product's life, providing the feedstocks are sustainably managed and sourced. It is worth noting however, that the production of bio-plastics is likely to be secondary to food production.

By working with the University of York we were able to identify the most appropriate biochemicals required to deliver the biopolymers as per Section 6.1. PHAs have many different polymers which are formed from many different feedstocks. For this reason, they have been discounted from this study.

Note. These are examples of the quantity of biomass required for typical existing bio-plastics derived from a variety of UK sources.

The main source of data for this analysis were the Defra crop statistics[49].

6.2.1 PLA: poly(lactic acid)

The formation of PLA from lactic acid (LA) requires first formation of PLA oligomers, followed by back-biting to the lactide and finally ring-opening polymerisation of the lactide to yield PLA. The yields from each of these steps are near quantitative (assumed here as 99% for each) and thus for the following feedstocks.

Primary biomass

The crops presented in Table 11 are those that are most intensively farmed in the UK, principally as food crops, although a small percentage of wheat, maize and sugar beet are also utilised in industrial applications. Sugar cane is imported from Brazil.*

Table 11 Primary biomass required PLA

Crop	tons needed to produce 1 ton of PLA	ktons produced per annum (UK)
wheat	1.8	14,903
barley	1.8	7,078
maize	1.8	3,360
sugar beet	7.7	6,802
potatoes	7.4	6,560
field beans	7.2	620
oats	2.0	866
sugar cane*	13.0	66*

Energy crops

Both Miscanthus and short rotation coppice are primarily grown for energy generation in biomass boilers. Data here for the latter has been generated using short rotation willow as this is the crop most commonly used after Miscanthus (Table 12). Values calculated are for dry mass. Forestry residue is material left in woodland post harvesting and generally is 10-15% by mass compared to the lumber harvested. The average value has been used here, it is inclusive of moisture content (61%) as the values are for green wood and only softwood has been considered. According to the Forestry Commission around 2 Mt of residue is available from UK forests, but not all of this is accessible. It is more likely that manufacturers will try to access sawmill residues (also called a co-product) – but panel board mills and animal bedding markets rely on this co-product and will be in strong competition for this resource.

Table 12 Energy crops for PLA

Crop	tons needed to produce 1 ton of PLA	ktons produced per annum (UK)
forestry waste	10.7	1,340.9
Miscanthus	3.8	87.5
short rotation coppice	3.5	28.2

Second generation Biomass

[49] These can be downloaded here: https://www.gov.uk/government/statistical-data-sets/agriculture-in-the-united-kingdom. We used the latest version accessible on 04/03/19.

Second generation biomass includes by-products of food production, including in-field residues such as straw. If the cellulose can be extracted from the straw it represents an appreciable resource that can be depolymerised to give sugars for use in the synthesis of platform molecules. We have additionally included the steam autoclaving of municipal solid waste (the Wilson process), the organic fraction of which can be converted into a fibre rich in free sugars. It must be noted, however, that this resource is likely to be contaminated with trace components that may need to be eliminated prior to use of organic wastes (Table 13).

Table 13 Second generation biomass for PLA

Feedstock	tonnes needed to produce 1 ton of PLA	ktons produced per annum (UK)
wheat straw	5.9	6,354
barley straw	7.0	3,117
maize stover	4.8	960
oilseed rape straw	5.5	897
oat straw	6.5	505
MSW	11.7	15,734

6.2.2 PBAT: poly(butyleneterephthalate-co-butyleneadipate)

PBAT can be made as either a partially or fully bio-based polyester. If partially bio-based then any one of the monomers (1,4-butanediol (BDO), adipic acid (AA) or terephthalic acid (TA)) can be bio-derived. For the UKBioChem10 report LBNet covered production of adipic acid (from muconic acid) and terephthalic acid (from muconic acid or HMF/FDCA – here we have used the HMF to FDCA to diethyl terephthalate route) and therefore the numbers below are for a 100% bio-based PBAT (best case scenario). Although it can be varied it is typically for the molar ratio of adipic acid to terephthalic acid (TA) to be 1:1, this means that the monomers are normally present I the polymers in the following ratios 2:1:1 BDO:AA:TA.

Note, an excess of 1,4-butanediol is used in the first step (to PBAT oligomers) but we assumed this is recovered and reused and therefore a 2:1:1 BDO:AA:TA molar ratio is used for the calculations. The route to bio-TA requires an excess of reactants in a number of steps (e.g. ethene) and in each case we have assumed this can be recovered and reused. As such, only the feedstock required to produce sufficient quantities of the reactants that have been consumed have been calculated.

Primary biomass

Sugars are the feedstock for the production of 1,4-butanediol *via* fermentation, while the furan component of terephthalic acid synthesis is chemo catalytic and the ethene/ethanol is derived from fermentation. The adipic acid for Table 14 has been obtained from muconic acid *via* sugar fed fermentation. Most current muconic acid research however is focused on lignin fed fermentation.

Table 14 Primary biomass required for PBAT

Crop	tons needed to produce 1 ton of PBAT	ktons produced per annum (UK)
wheat	7.1	14,903
barley	7.1	7,078
maize	7.0	3,360
sugar beet	30.5	6,802
potatoes	29.6	6,560
field beans	28.8	620
oats	7.9	866
sugar cane*	51.9	66*

Energy crops

The cellulose content of the crops can be used to produce BDO and TA, while the lignin content can be used to produce AA. If this polymer was produced at an integrated bio-refinery using forestry lignin-rich residues, it would yield an excess of AA (Table 15).

Table 15 Cellulose crops to produce PBAT

Crop	tons needed to produce 1 ton of PBAT (cellulose)	tons needed to produce 1 ton of PBAT (lignin)	ktons produced per annum (UK)
forestry residue	28.9	9.7	1,340.9
miscanthus	10.2	15.6	87.5
short rotation coppice	9.5	8.4	28.2

Second generation Biomass

This evaluation follows the same methodology as the energy crops, with exception of the MSW, where we have used the total sugar fermentation route applied to primary biomass (Table 16).

Table 16 Second generation biomass for PBAT

Crop	tons needed to produce 1 ton of PBAT (cellulose)	tons needed to produce 1 ton of PBAT (lignin)	ktons produced per annum (UK)
wheat straw	15.9	9.0	6,354
barley straw	19.1	10.1	3,117
maize stover	12.9	10.9	960
oilseed rape straw	14.9	9.4	897
oat straw	17.6	9.2	505
MSW	43.2	n/a	15,734

6.2.3 PBS: poly(butylene succinate)

We have assumed a 90% yield of succinic acid from sugar (molar yield). This has been used to determine the optimum yields of succinic acid (SA) from the various feedstocks. The yields for 1,4-butanediol are the same as those required for the PBAT example above. Note, an excess of 1,4-butanediol (BDO) is used in the first step (to PBS oligomers) but we assumed this is recovered and reused and therefore a 1:1 BDO:SA molar ratio is used the calculations.

Primary biomass

Below (Table 17) is the primary biomass required to produce PBS.

Table 17 Primary biomass to produce PBS

Crop	tons needed to produce 1 ton of PBS	ktons produced per annum (UK)
wheat	3.6	14,903
barley	3.6	7,078
maize	3.6	3,360
sugar beet	15.6	6,802
potatoes	15.2	6,560
field beans	14.7	620
oats	4.0	866
sugar cane*	26.5	66*

Below, tables 18 and 19 detail the specific crops or biomass required to produce PBS.

Energy crops

Table 18 Energy crops required for PBS

crop	tons needed to produce 1 ton of PBS	ktons produced per annum (UK)
forestry waste	20.1	1,340.9
miscanthus	7.1	87.5
short rotation coppice	6.6	28.2

Second generation Biomass

Table 19 Second generation feedstock requirement for PBS

feedstock	tons needed to produce 1 ton of PBS	ktons produced per annum (UK)
wheat straw	11.1	6,354
barley straw	13.3	3,117
maize stover	9.0	960
oilseed rape straw	10.4	897
oat straw	12.3	505
MSW	43.2	15,734

6.2.4 Starch

Table 20 shows the starch content of each crop at harvest. Grains have a higher dry matter content than vegetables, so per tonne fresh weight they have more starch content.

Table 20 Starch content in harvest crop

Crop	Starch content in harvested crop
wheat	73
barley	73
maize	74
sugar beet	17
potatoes	17.5
field beans	18
oats	66

6.3 Bioresources required to produce biochemicals

6.3.1 Current bioresource requirement

To understand the feedstock that could be available for bio-plastics production we examined agricultural production in the UK. In this analysis we included the major cereal and root vegetable crops in the UK and their potential for producing residues that could be used for bio-plastics. In this analysis we have assumed:

1. That all current resources used for food and livestock feed continue to be used in this way. This means that the main food crops are not available for bio-plastic production, just the residues from their production. In our analysis we have assumed that residues and co-products from crop production are accessible to be used for bio-plastic feedstocks, providing they are not used for livestock feed or bedding.
2. We have estimated the residues left from crop production by either using an estimate of the yield of straw/stover or by estimating a percentage of the crop that will be left on the field or rejected as not meeting harvest quality requirements. For potatoes and sugar beet there is no figure for residues and we have assumed 10% of the crop is left as residue on the field or due to rejection.
3. These residues and co-products often already have a market. Some crop residues are used for fodder on the field; others may be used for energy. We have not taken these markets into account.

Data used

The crops examined were: barley, oats, wheat and minor cereals straw; oil seed rape straw; potatoes; and sugar beet. The results will provide a conservative value for the residues available, as other crops that could provide residues are not included (e.g. crops produced in relatively small quantities such as linseed).

The main source of data for this analysis were the Defra crop statistics[50]. Additionally, Nix (2019) was used to obtain straw yields per ha for cereal crops. Data for oil seed rape straw was taken from Anglian straw trials (EPRL 2003), which examined the use of oil seed rape in biomass combustion and provided an average yield of 1.5t/ha.

[50] These can be downloaded here: https://www.gov.uk/government/statistical-data-sets/agriculture-in-the-united-kingdom. We used the latest version accessible on 04/03/19.

Assumptions

Information on residues from potato and sugar beet is not readily available so the following assumptions were made:

- For potatoes residues on field and rejects were assumed to be 10% of the yield. We are also aware that there is a starch resource in potato processing waste. This waste represents around 15% of the crop processed, so we have included this in our figures. We believe around 2.4% of this waste is starch (23400t/y) (Broeren et al 2018)

- For sugar beet the farmers were deducted 6.6% of the crop weight, which was assumed to be unusable tops (‘tare’). We therefore assumed residues were 6.6 of the crop yield around 5.5t/ha. The figure from Draycott (2006) is lower at 3.27t/ha, but only includes the leaves and breakages in the field.

- For maize we assumed a yield of 5 t/ha for stover.

Results for crop residues

The net resource from this analysis provides a crop residue resource figure in excess of 14 Mt/year. These results are shown in Table 21 (Appendix 1). However, it is prudent to take into account existing uses for certain bioresources as they may arise but may not be available due to an existing use. A key stream that already has a use is straw. At present 6.2 Mt straw/year (both wheat and barley) is used for animal bedding, so the accessible resource is, in reality, closer to 8Mt/y.

In addition to straw, many of these bioresources have other uses that should be considered. They may be ploughed into the field for soil conditioning or to prevent issues such as erosion and water logging; they may be used as forage or fodder; and can be used in energy production (combustion or anaerobic digestion).

Table 21 Available bioresources

Crop residues	Available Bioresources (t)
Potatoes Waste	1,617,317
Sugar Beet Waste	496,833
Maize Waste	960,000
Barley Straw Available	3,116,667
Oats Straw Available	505,167
Oil Seed Rape Straw Available	897,000
Minor Cereals Straw Available	255,200
Wheat Straw Available	6,353,667
	14,201,850

A further consideration is the amount of straw that is currently used in bioenergy. Currently there is a capacity for 955,000t straw/y to be used for electricity generation from straw, which competes with the bio-plastics option. Many of the straw burning plants have been in operation for some time and it could be that by 2025 they will be considering refurbishment. At this point considering some sort of refinery prior to combustion may enable a straw bio-plastics route as well as combustion. This needs to be investigated further but could provide an added value to the business case.

Consequently, we regard this as a theoretically accessible resource, which will only be available should a high value market (such as bio-plastics) be established. We have noted that potato and other crop starch is already used to produce bio-plastics in the UK[51].

Additional residues that may be available

There are around 180,000 ha of other crops, which could potentially provide an estimated yield of 5.6 Mt/y of crops. Assuming residues represent 10% of this, this makes an additional 0.56Mt/y residues.

This figure could be augmented with feedstock from the food processing supply chain (such as co-products from cereals production, sugar processing and brewing and distilling), but we have not assessed the quantities available. Cereal co-products (which are not included above) could add to this total, but currently are used in breakfast cereals and animal feed (Nabim, 2009). Around 1.6t/ha are produced, meaning that just under 3 Mt/y could be available from this source. This has been examined for the production of poly lactic acid (PLA) (Arvaniti *et al.,* 2014)[52].

Assuming that 2% of food in the food supply chain becomes a residue, this provides an additional potential resource of some 0.8Mt/y of food processing residues. In addition to this the University of York has provided figures for municipal solid waste organic matter of 15.7Mt and a potential for 115.7Mt of energy crops, representing a considerable additional resource. If only 2 % of these resources were used, this would represent 2.8Mt additional feedstock (i.e. increasing the resource to 12.1Mt/y in total).

For crops such as sugar beet the food and drink processors use the crop very efficiently leaving little residue and for this reason we did not include residues or co-products from the processing of food in our estimates. However, as detailed above only a small percentage of waste would provide significant additional resources. We also believe that if a market for food processing residues or co-products develops for bio-plastics the food and drink processing sectors will be interested in these new products.

Note – although food and feed uses are excluded, other uses such as bioenergy may compete for these resources.

[51] See, for example: https://www.biopac.co.uk/packaging-materials and http://biomebio-plastics.com/product-ranges/flexible-films/

[52] https://cereals.ahdb.org.uk/publications/2014/november/20/feasibility-of-lactic-acid-production-from-cereal-milling-residues-in-the-uk.aspx

6.3.2 Summary

Table 22 provides a summary of the resources potentially accessible for biopolymer production.

Table 22 Summary table - resources potentially accessible for bio-plastics feedstocks

Crop residues	Available Bioresources (t/y)
Potatoes Waste	1,406 228
Sugar Beet Waste	496,833
Maize Waste	960,000
Barley Straw Available	3,116,667
Oats Straw Available	505,167
Oil Seed Rape Straw Available	897,000
Minor Cereals Straw Available	255,200
Wheat Straw Available	6,353,667
	13,990,726
Estimated resources	
Other crop residues	560,000***
Food processing residues	800,000
Cereal co-products**	300,000
Organic waste from municipal waste*	314,000
Energy crops*	2,314,000
Sub total	4,288,000
Total (minus straw use****)	12,078,762

* These are taken from estimates supplied by the University of York and assume just 2% of these resources are available for bio-plastics production. The energy crops available are estimates for future planting potential.
** assuming 10% of this residue stream could be available to bio-plastics.
*** assumes that residues represent 10% of crop resource.
****straw use is assumed to be 6.2Mt/y as indicated in the text.

The information in Section 6, summarised in Table 22 above highlights that there is sufficient bioresource to provide the UK's potential substitutable market for bio-plastics.

For illustrative purposes Table 23 shows the total amount of biopolymers that could be made from the primary bioresource requirement as described in Section 6.2. This clearly demonstrates that the UK has sufficient bioresource to meet the estimated market demand as discussed earlier in Table 8 (Scenario1). Please note these are illustrative and standalone and they do not take into consideration alternatives uses.

Table 23 Tonnes of polymer produced based on bioresources available

Crop	PLA		PBAT		PBS	
	tons needed to produce 1 ton of PLA	Equivalent tonnes of PLA which could be produced	tons needed to produce 1 ton of PBAT	Equivalent tonnes of PBAT which could be produced	tons needed to produce 1 ton of PBS	Equivalent tonnes of PBS which could be produced
Wheat	1.8	*3,529,815*	7.1	*894,883*	3.6	*1,764,908*
Barley	1.8	*1,731,482*	7.1	*438,967*	3.6	*865,741*
Maize	1.8	*533,333*	7.0	*137,143*	3.6	*266,667*
Sugar beet	7.7	*64,524*	30.5	*16,290*	15.6	*31,848*
Potatoes	7.4	*218,556*	29.6	*54,639*	15.2	*106,402*
Oats	2.0	*252,584*	7.9	*63,945*	4.0	*126,292*

7 Carbon benefits

To assess the carbon benefits of compostable packaging a comparative Life Cycle Assessment (LCA) was conducted in order to determine the relative Global Warming Potential (GWP) impacts of producing 1 tonne of plastic using traditional low-density polyethylene (LDPE) compared with a bio-plastic alternative known as Polylactic acid (PLA). Taking into account the impact of raw material extraction, transport, and end of life, this assessment identifies the areas of high impact in terms of global warming potential (GWP).

7.1 Overview

The initial results showed that the traditional LDPE system is preferable to virgin PLA, emitting 2,189 $kgCO_{2e}$ per tonne, 35% less than the PLA system. However, further analysis revealed that this impact was driven by eco-invent's[53] assumptions regarding grid mix and feedstock. Sensitivity analysis was undertaken to vary these two parameters to understand the extent to which they affected the results.

Results of the sensitivity analysis were as follows:

- PLA was found to be preferable if it was produced using a Scottish grid mix rather than a UK grid mix. While the UK grid mix lowered the PLA system's carbon footprint, it still emitted 27% more CO_2 than LDPE.
- Exploring the potential impacts of using waste bioresources as a replacement for the maize feedstock contained in the LCA model used. This analysis assumed the bioresources arose for free but charged the PLA system with a transport burden for freighting by-products to a PLA convertor. Combining this analysis with the grid sensitivity revealed that PLA using the UK average grid mix was also preferable to LDPE.

[53] Software package used for LCA analysis

- Finally, a sensitivity analysis was undertaken into the end of life considerations of these two plastics. The analysis found that LDPE has the potential to avoid significant amounts of CO_2 emissions through recycling. However, this is dependent on high quality post-consumer LDPE reaching recycling facilities. Even under a scenario where 90% of LDPE is placed into a recycling bin no more than 10% of this can be contaminated with food waste for LDPE to be preferable to PLA (using UK grid). If PLA is produced using a Scottish grid mix, LDPE is never found to be the most preferred option.

7.2 Methodology

ISO 14040 defines Life Cycle Assessment to be the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. It establishes a four-step process for undertaking an LCA:

1. Goal and scope definition
    a. The study's overall goal
    b. The system boundary
    c. The functional unit
    d. Primary v secondary data
    e. Environmental criteria to use
2. Life cycle inventory
    a. List of the actual 'flows' within the model: materials, emissions, energy and waste
3. Impact Assessment
    a. Assesses the 'flows' environmental impacts, for instance in terms of global warming potential
4. Interpretation
    a. Final step, drawing conclusions and identifying refinements to the previous three stages.

The goal of this study is to assess the potential environmental benefits of bio-plastics as a replacement for traditional plastics.

7.3 System boundary

The system boundary for this study is cradle-to-grave. The initial results analyse LDPE and PLA's cradle-to-gate impact before delving into end of life later in the report. The study includes the extraction of raw materials, transportation, and end of life treatment. The use phase is not considered to be relevant for this product.

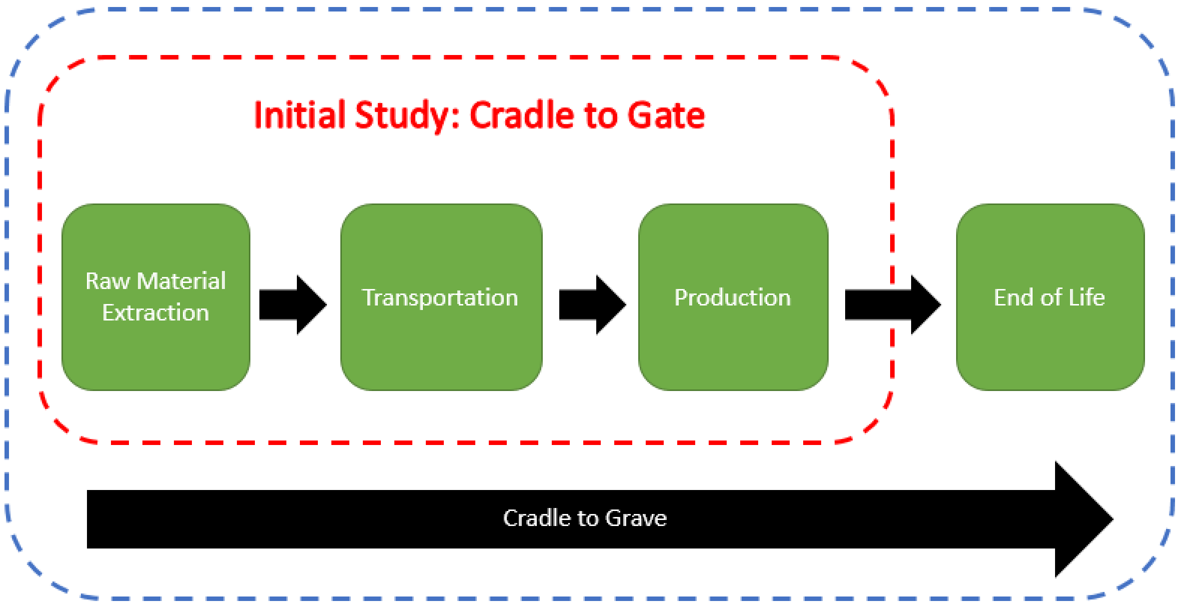
PLA has been chosen as an example to examine the sensitivities included in the life cycle assessment of bio-plastics.

Data on the raw material extraction, transportation and production of the plastics was taken from the eco-invent 3.4 database whereas the end of life stage is modelled using data from the Scottish Carbon Metric[54]. This is illustrated in the boundary diagram for the two systems in Figure 10 below.

The PAS2050 guidance specifies the list of product life cycle processes to be included in the assessment. This study's system boundary captures these processes, with the exception of land-use change which is considered to be minimal. As such this process has not been modelled within this study, beyond the land-use impacts embedded within the Scottish Carbon Metric, UK GHG Conversion Factors, and eco-invent LCA database.

[54] https://www.zerowastescotland.org.uk/content/what-carbon-metric

Figure 10 Model Boundary Diagram



The function of both systems is to produce plastic. The functional unit has therefore been set as 1 tonne of plastic.

More information regarding the LCA background data can be found in Appendix 2.

7.4 Environmental Impact Criteria

This study uses the IPCC 2013 GWP_{100a} method, developed by the Intergovernmental Panel on Climate Change[55]. Table 24 details the Environmental Impact Criteria used by the IPCC.

Table 24 Environmental Impact Criteria

Impact	Unit	Description and rationale
Global warming potential (GWP)	kg CO2 eq.	Contribution to global warming climate change, measured in kilogrammes of CO2 emissions equivalent.

7.5 Specification of LCA

7.5.1 LDPE

This study considers LDPE to be representative of traditional film plastics. LDPE is a low-density polyethylene thermoplastic which is made using petroleum-based fossil fuels.

LDPE is a popular material due to its flexibility and strength as well as its chemical properties which mean it can withstand water and chemicals such as acids, alcohols or oils. LDPE is also easily processed and recycled with a low production cost. Therefore, LDPE is widely used in food packaging, plastic grocery bags and other household items as well as in wider industrial uses such as water or gas pipes, insulation and more.

[55] http://www.ipcc.ch

The LDPE data used in this study is taken from eco-invent 3.4 process for Polyethylene, low density, granulate {RER}| production | Cut-off, U. This data is based on data from the European plastics industry between 1997-2017.

7.5.2 PLA

This study considers PLA (Polylactic Acid) as a proxy for bio-plastic films. PLA is bio-plastic which can be produced using different renewable crop resources such as maize.

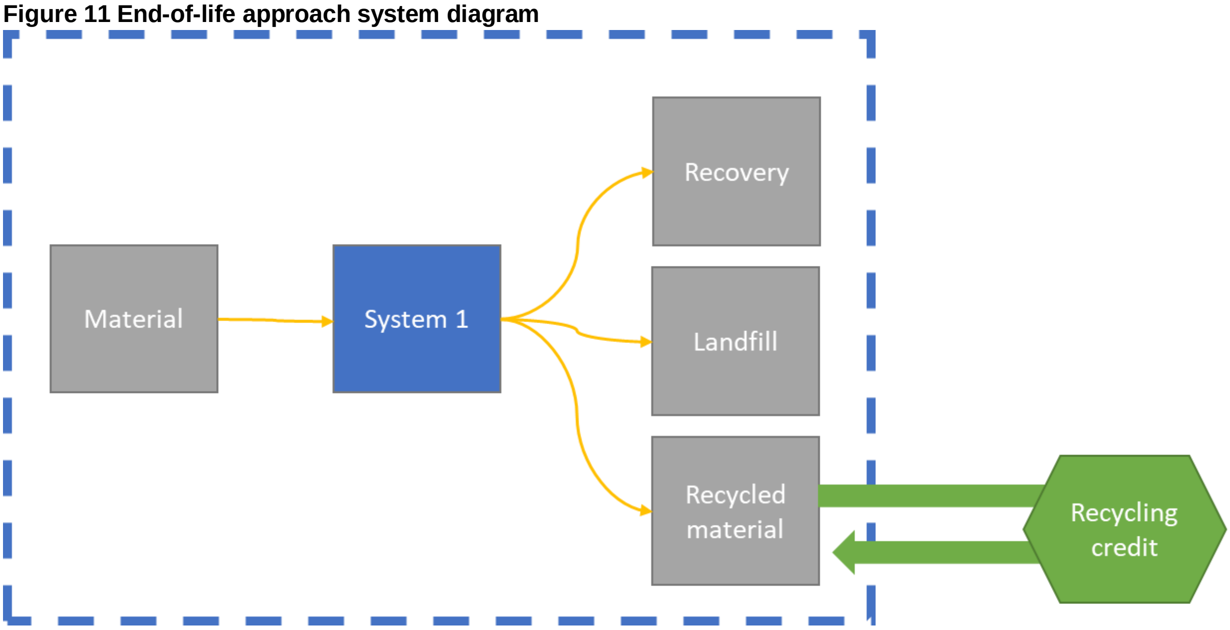
The PLA data in this study is taken from the eco-invent 3.4 process for Polylactide, granulate {GLO}| production | Cut-off, U. This data is based on information from the world's largest bio-plastics plant in Nebraska USA from 2006-2017 and assumes that the bio-plastic is produced using maize grain. However, as PLA can be made from a number of different feedstocks, not just maize, this is investigated in a later sensitivity analysis. The initial results use an unadulterated version of the eco-invent PLA process. Later sensitivities edit this process to change the feedstock and/or grid mix to understand how sensitive the results are to these assumptions.

7.5.3 End-of-life

As noted above, the initial results only consider a cradle-to-gate approach. However, end of life is an important consideration for this study since some bio-plastics can be composted even when contaminated with food but cannot be recycled. Consequently, this is explored through a sensitivity analysis using the Scottish Carbon Metric approach.

The LCA model uses the Scottish Carbon Metric values for sending different materials for recycling, composting, landfill and incineration. Under this end-of-life approach, the life cycles that send materials onto new lifecycles (such as recycling) receive a charge for the activities associated with processing and a credit for avoiding activities associated with virgin material extraction. Secondary systems that use recycled materials do not receive a credit, thus avoiding double counting. This is illustrated in Figure 11 below.

Figure 11 End-of-life approach system diagram



7.6 Initial results

The initial results, shown in Table 25 below, compare one tonne of LDPE and one tonne of virgin PLA (as contained in the eco-invent data base). The results show that PLA emits ~3,400 kgCO2e/tonne, which is 54% more than traditional LDPE.

Table 25 Initial top-level results, GWP_{100a}

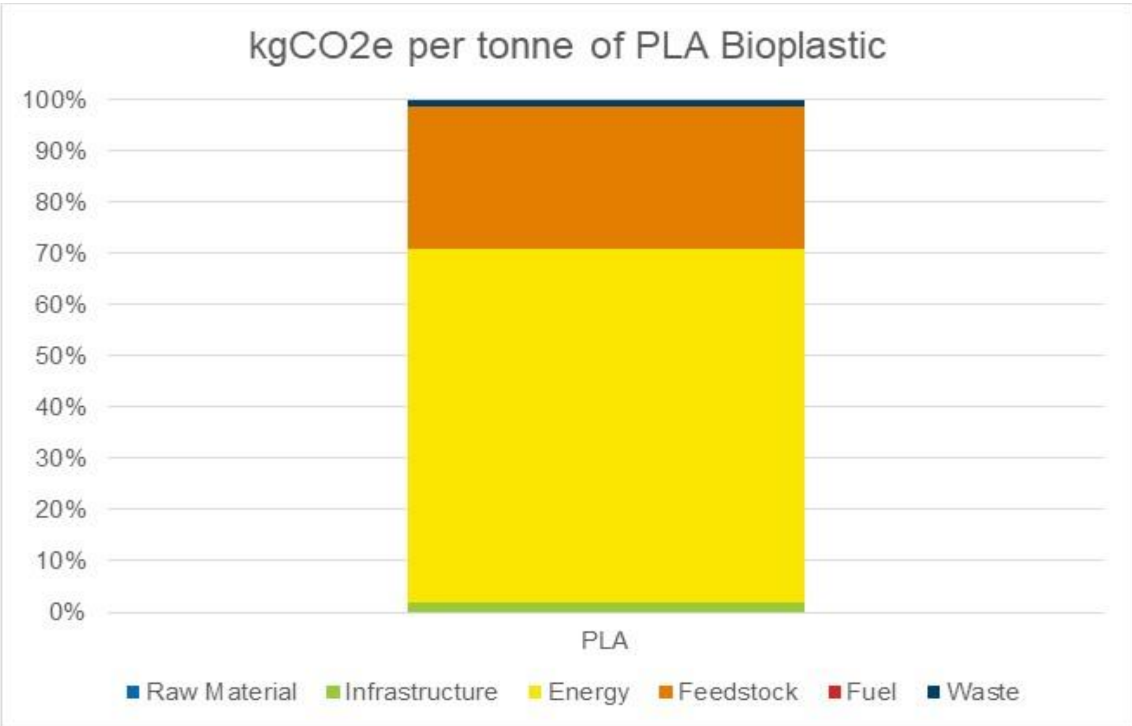
System	$kgCO_2e$ per Tonne of Plastic
LDPE	2,189
PLA	3,386

It is important to understand why PLA appears to have a higher global warming potential than LDPE. Table 26 below breaks down the PLA results per component stage showing where the biggest impacts occur. It is not possible to go into the same level of detail for LDPE due to data restrictions within the eco-invent database. These impacts are illustrated in Figure 12 below. This shows that energy is responsible for the largest impact, more than double the impact of growing the maize feedstock.

Table 26 results split by stage, kgCO2e per Tonne of PLA

	Raw Material	Infrastructure	Energy	Feedstock	Fuel	Waste
PLA	0%	2%	69%	28%	0%	1%

Figure 12 GWP_{100a} Results per t, split by life cycle stage



7.6.1 Sensitivity

As energy and feedstock contribute the largest burden to PLA, these were investigated further as part of the sensitivity analysis.

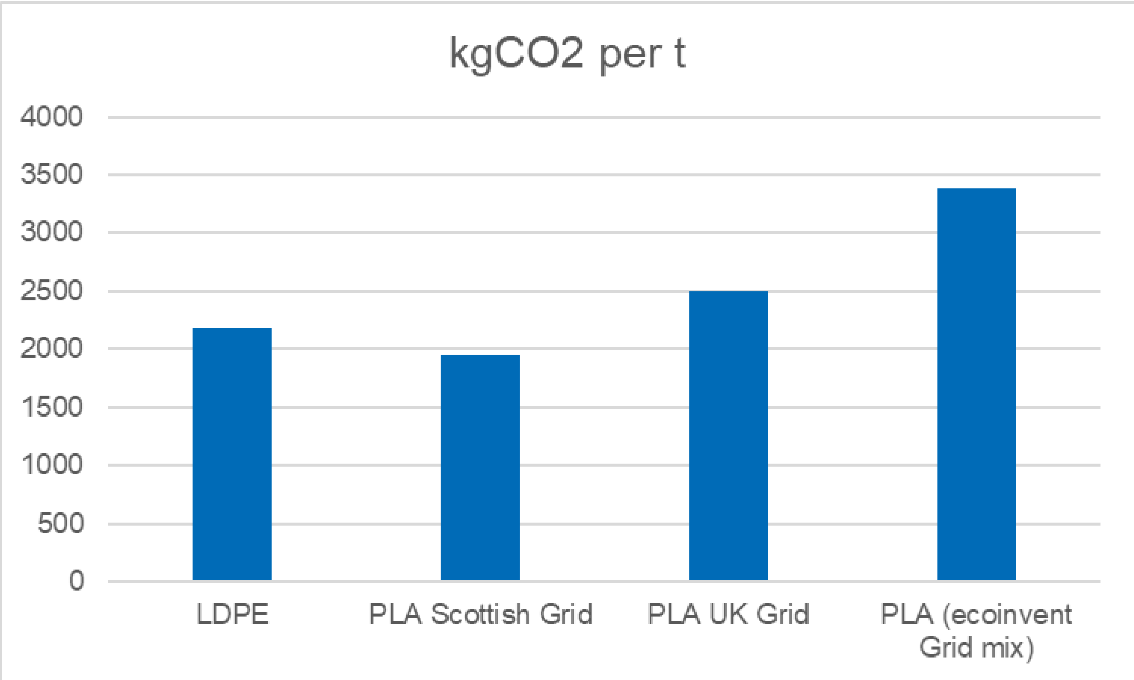
7.6.1.1 Electricity

45% of the impact of virgin PLA arises from electricity, with 24% from other energy sources. This is linked to eco-invent's assumptions regarding how the electricity is produced. To understand how the impacts change using UK and Scottish electricity generation data, the original eco-invent dataset was amended to swap eco-invent's grid assumption for the UK's grid emission factor, as contained in the UK's 2018 GHG conversion factors[56], and a Scottish grid mix for investigative purposes.[57]

Figure 13 below plots the results for PLA using the different grid mixes in comparison with LDPE. It can be seen that changing the grid mix has a significant impact on the results. Using the UK grid mix PLA still has a larger global warming potential than LDPE, however it is significantly smaller than the initial PLA results using a standard grid mix from eco-invent. Although PLA currently loses out to LDPE on this grid mix, it is important to note that the UK grid is continuing to decarbonise with projections for significant decarbonisation in the near future. It is reasonable to assume that the impact of producing PLA will decrease in the future as the grid decarbonises.

Using the Scottish grid mix, PLA is favourable over LDPE. This is because the Scottish grid mix is already greener than the UK as a whole with renewables making up a substantial share of the overall mix.

Figure 13 Electricity Sensitivity



7.6.1.2 Feedstocks

The eco-invent data assumes that the feedstock for PLA is maize. However, maize is just one of a number of potential feedstocks which could be used to produce bio-plastics, as discussed in Section 6. Indeed, by-products from the food industry, that are currently treated as wastes, are a potential feedstock for the process.

Since by-products from the food industry are wastes, for the purposes of modelling PLA feedstocks, they can be considered to arise for free. This follows the polluter pays principle, by which materials

[56] This is a combination of Electricity generated: Electricity UK; T&D- UK electricity; WTT- UK electricity (generation) and WTT- UK electricity (T&D)

[57] Data for the Scottish grid mix was taken from carbonintensity.org[57] and modelled in SimaPro using ecoinvent data for electricity production via different sources (wind, nuclear etc).

remain in one life cycle boundary until they reach their lowest value. Food by-products are assumed to be part of the original life cycle up until they can be delivered to the PLA plant.

To model this scenario, Ricardo removed the burden of producing maize as contained in the original eco-invent database and added a transport burden for collecting food by-product and delivering it to a PLA plant. It is assumed that the PLA plant is located 100km distance from the source of food by-products and that 1.5kg of by-product is required per kg of PLA. This is modelled with 150kg/km of lorry road freight, using the eco-invent process[58].

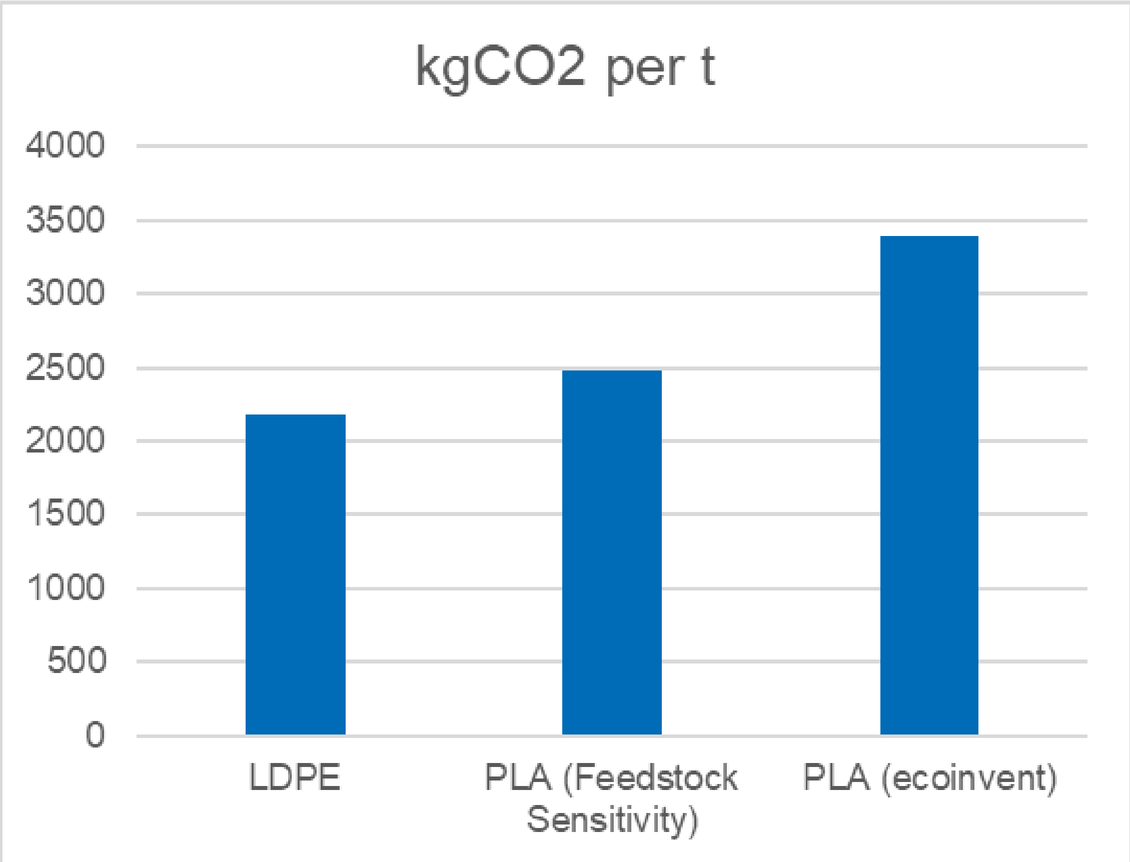
Table 27 shows the results of this sensitivity and it can be seen that, even assuming a lengthy journey of 100km, the transport burden accounts for just 0.01% of the total PLA burden.

Table 27 PLA Feedstock Sensitivity Breakdown by stage

	Raw Material	Infrastructure	Energy	Transport	Fuel	Waste
Bioresource PLA	0.00%	2.72%	94.10%	1.31%	0.19%	1.67%

The overall results are plotted in Figure 14 below, showing that although removing the burden of producing the feedstock reduces the global warming impact of PLA significantly it is not enough to out perform LDPE.

Figure 14 Feedstock Sensitivity Results



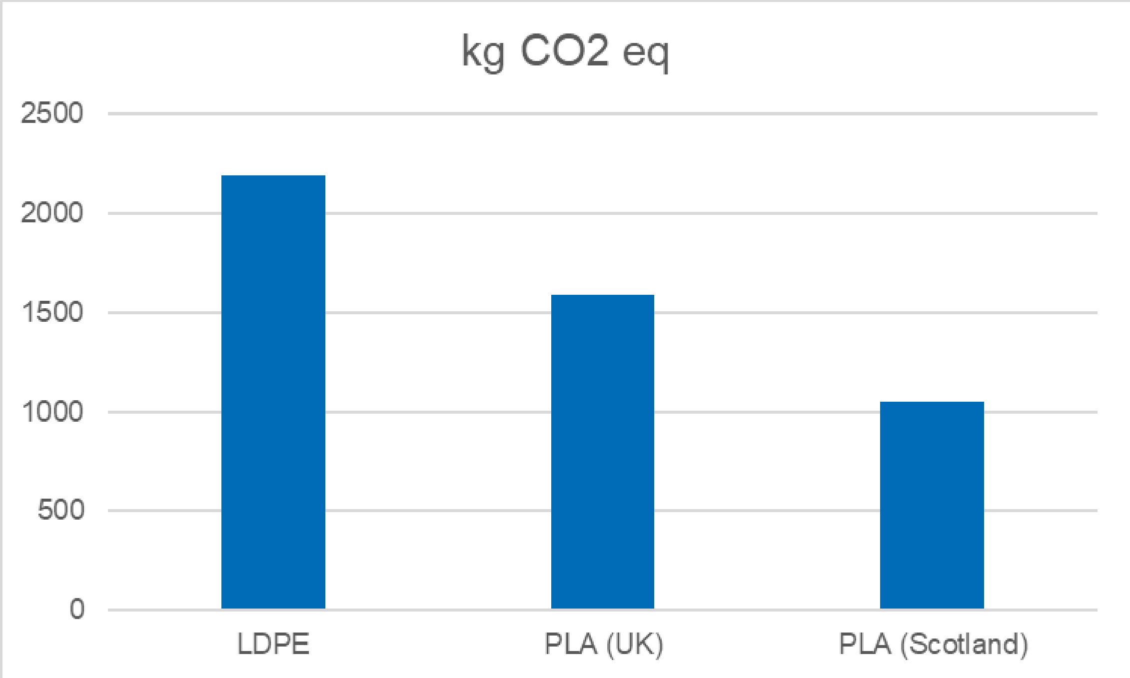
[58] Transport, freight, lorry 7.5-16 metric ton, EURO5 {GLO}| market for | Cut-off, U.

7.6.1.3 Combined Feedstock and Electricity Sensitivity Results

If the two sensitivities above, which review the feedstock and grid electricity assumptions, are combined, then PLA is found to be preferable to LDPE using either the UK grid mix or the Scottish grid mix. This assumes that the feedstock arises burden free as a by-product and only the transport of the waste feedstock is allocated to the bio-plastic systems.

Figure 15 shows that PLA produced in Scotland, using the Scottish grid mix, has approximately half the global warming impact than LDPE produced in Scotland. However, even using the UK average grid mix, PLA has a lower warming potential than if it is produced using by-products.

Figure 15 Cradle to Gate (Feedstock and electricity sensitivity) per tonne of plastic

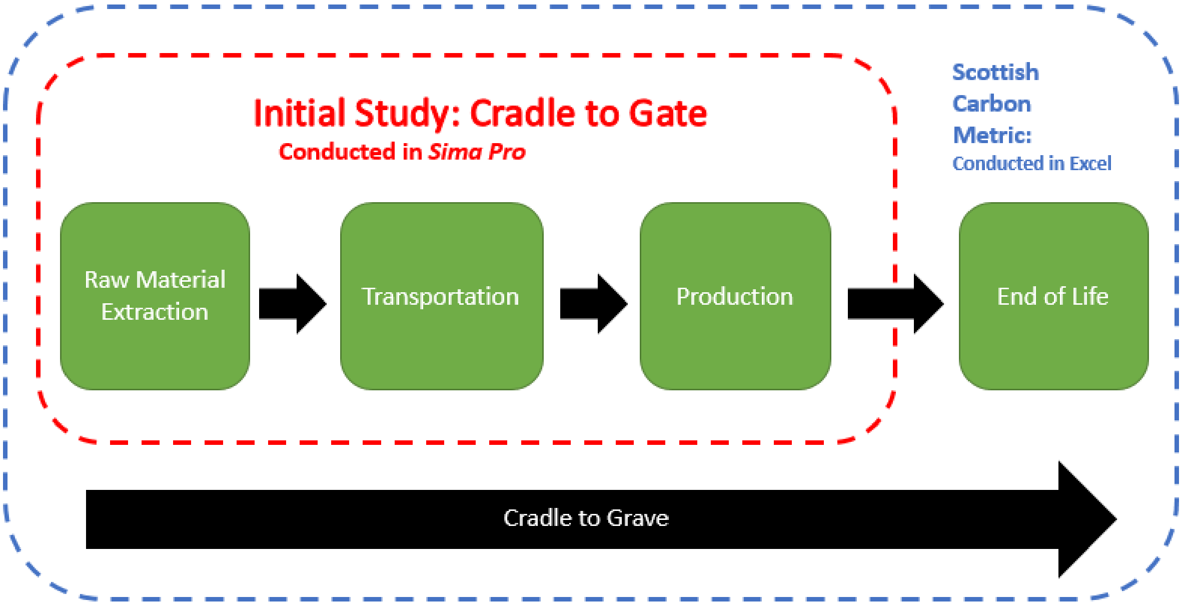


7.6.2 End of Life

As discussed previously, end of life is an important consideration for bio-plastics. While some bio-plastics can be recycled PLA cannot. However, it has the advantage that it can be disposed of via composting, even if it is contaminated with food. To fully capture the benefits of this end of life treatment it would be necessary to consider additional food scraps entering the composter via used bio-plastics and potential impacts of degrading bio-plastics. However, this is not assessed within the scope of this study. Instead PLA's end of life is modelled using the Scottish Carbon Metric values for plastic incineration, landfilling and animal and mixed food wastes.

The end of life modelling was carried out using MS Excel and combined with the cradle-to-gate results calculated in SimaPro. This is illustrated in Figure 16 below.

Figure 16 Model Diagram



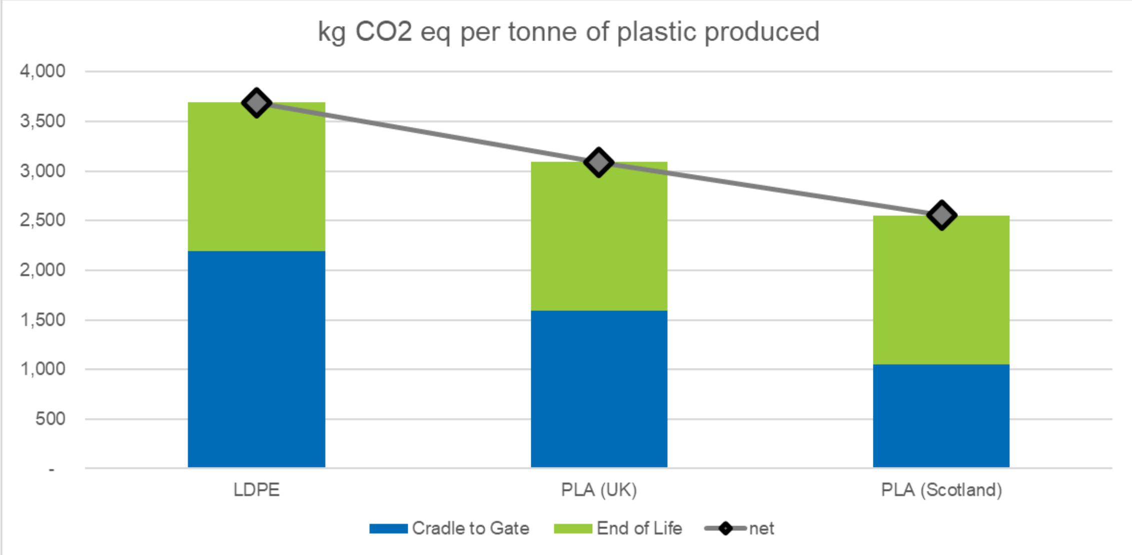
End of life considerations can be highly variable. How a user chooses to dispose of a material (bin choice), the state of material (contamination) and end of life treatment (final fate) all affect the eventual characterisation that ought to be applied.

To model this, a user interface was built within MS Excel to enable these variables to be accounted for. It is assumed that 10% of waste is sent to landfill irrespective of the scenario, the model then uses an assumption regarding how much waste is segregated from the general waste stream (bin choice) to determine how much material to send to incineration or recycling/composting (final fate).

The results are shown in Figure 17 to Figure 19 and compare different ratios of incineration to recycling/composting, where PLA is composted when it is segregated and LPE is recycled. The cradle-to-gate impacts, discussed in previous sections, are shown in blue and the end of life impacts in green. Following the Scottish Carbon Metric approach to end of life results in some systems receiving a credit at end of life (from recycling for example), consequently some green bars are plotted as negative impacts (which is preferable). To understand how this affects the overall result, the net total of each system is shown via the grey diamonds.

When 0% of plastics are segregated from general waste, 90% of both LDPE and PLA waste are assumed to be incinerated with remainder going to landfill. Under this scenario, PLA is favourable using both the UK and Scottish grid.

Figure 17 Cradle to Grave GWP at 0% of plastics correctly segregated

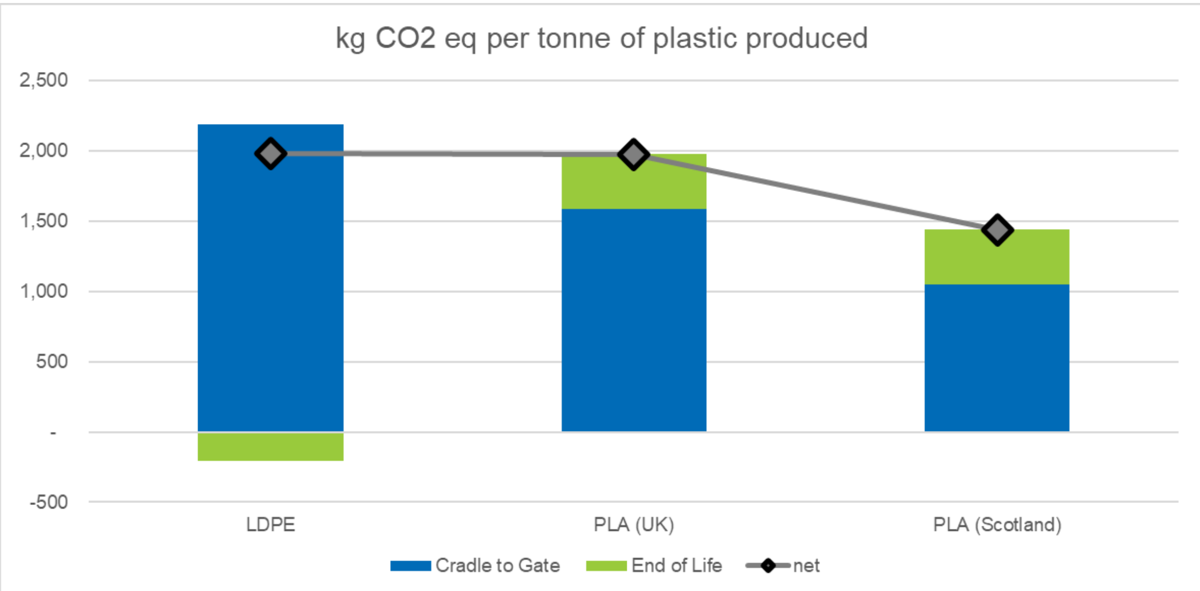


However, once 64% of plastics are assumed to be segregated from general waste, the results change. As can be seen in Table 28 and Figure 18, LDPE is given a credit for end of life recycling which results in the net impact being less than PLA using the UK grid. PLA using the Scottish grid still has a significantly lower global warming potential (GWP) than LDPE.

Table 28 Cradle to Grave GWP in kgCO_2e per tonne of plastic (at 64% of plastics correctly segregated)

	Cradle to Gate	End of Life	net
LDPE	2,189	- 207	1,981
PLA (UK)	1,589	388	1,978
PLA (Scotland)	1,053	388	1,441

Figure 18 Cradle to Grave GWP at 64% of plastics correctly segregated



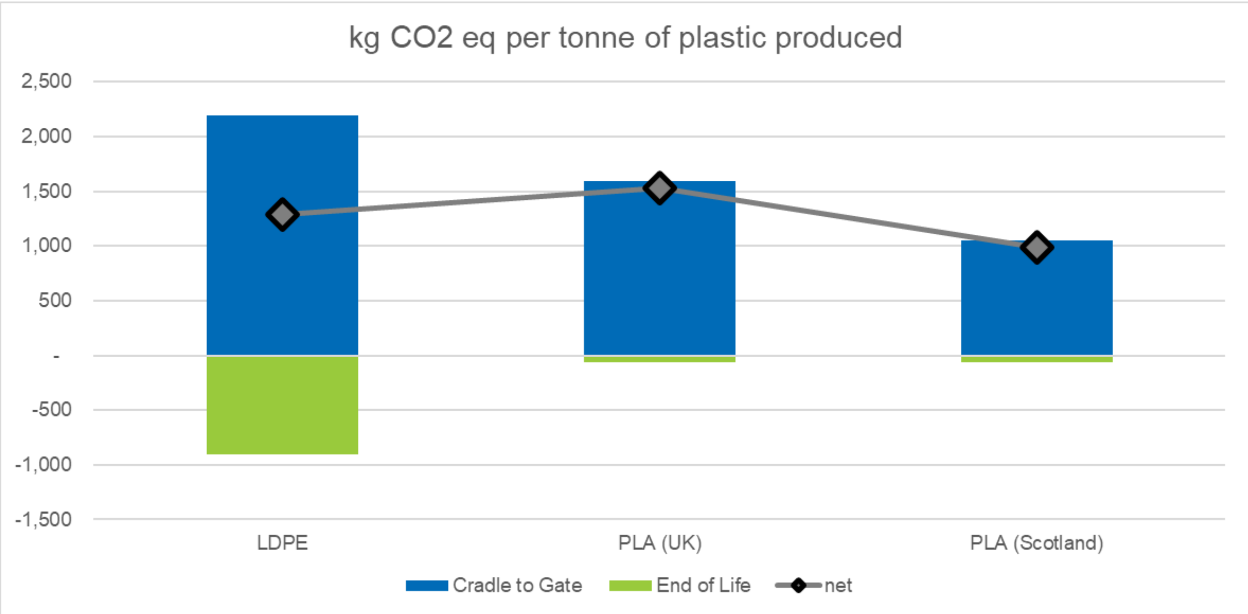
As can be seen in Table 29 and Figure 19, even when 90% plastics are segregated from general waste, PLA using the Scottish grid mix is preferable to LDPE. This is due to the low cradle to gate impact which remains more significant than the large credit that LDPE receives from end of life recycling.

Based on the current end of life assumptions it is not possible for LDPE to out perform PLA using the Scottish grid mix. To put this into context, the analysis suggests that per tonne of LDPE produced, 1.48 tonnes would need to be recycled before LDPE has a lower carbon footprint to PLA produced using a Scottish grid mix.

Table 29 Cradle to Grave GWP in kgCO_2e per tonne of plastic (at 90% of plastics correctly segregated)

	Cradle to Gate	End of Life	net
LDPE	2,189	- 900	1,288
PLA (UK)	1,589	- 63	1,527
PLA (Scotland)	1,053	- 63	990

Figure 19 Cradle to Grave GWP at 90% of plastics correctly segregated



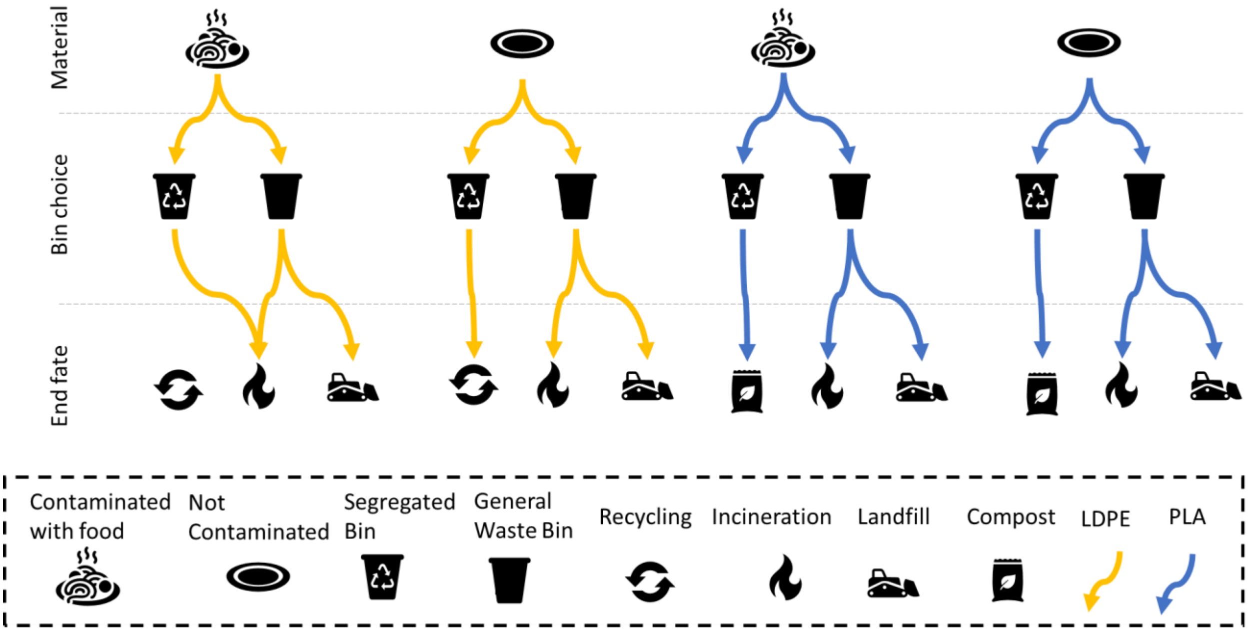
7.6.3 Contamination Sensitivity

As noted above, the state of materials is another variable that affects the final fate of materials. This is particularly pertinent for bio-plastics since they can be disposed of along with food waste, whereas LDPE is considered contaminated if it is covered in food waste and cannot then be recycled. Contaminated materials, although they may be deemed recyclable, have to be disposed of via landfill or incineration.

To account for this complexity a further sensitivity was undertaken to determine the cradle-to-grave results under different contamination scenarios.

This was modelled using the interface described in the previous analysis, however an additional contamination field is added so that the % of materials segregated from general waste (bin choice) but must then be disposed of by incineration could be accounted for. This process is depicted in Figure 20 below. As within the original analysis 10% of waste is assumed to be sent to landfill irrespective of the scenario.

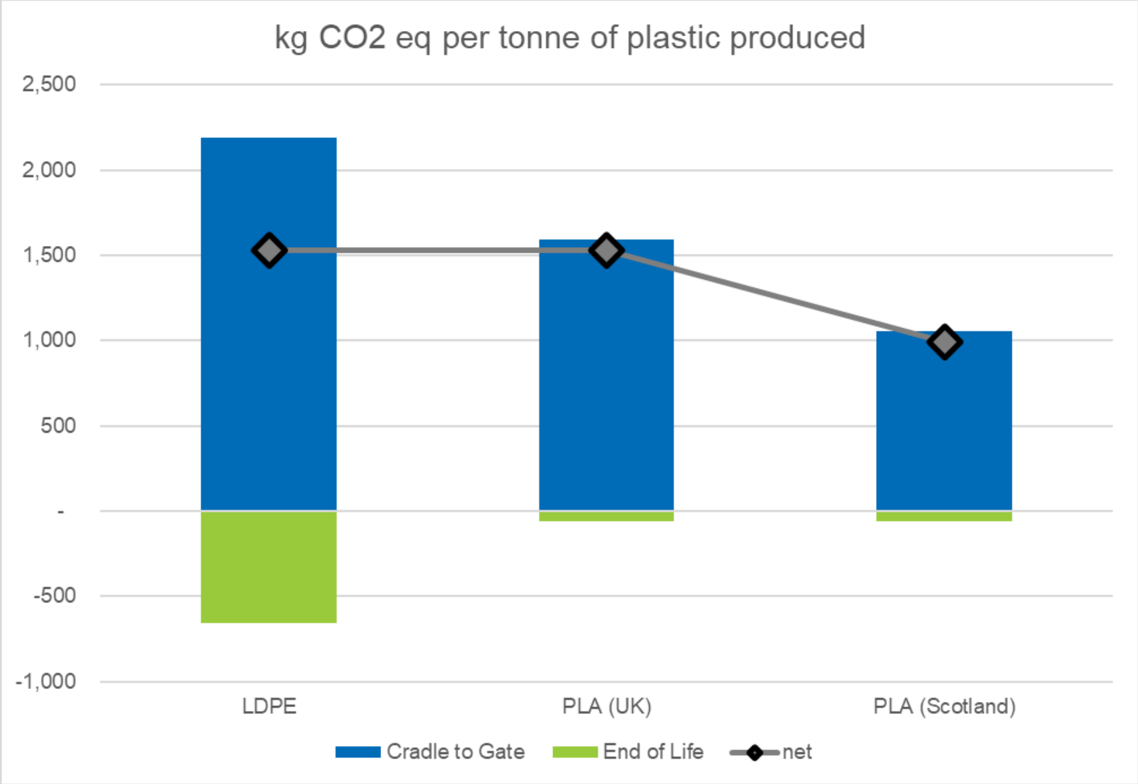
Figure 20 End of Life Contamination Sensitivity Diagram



When 0% of plastic is segregated from the general waste stream, the results do not change from the original end of life results above, as none of the plastics are sent to recycling. PLA using both the UK grid and Scottish grid is preferable to LDPE.

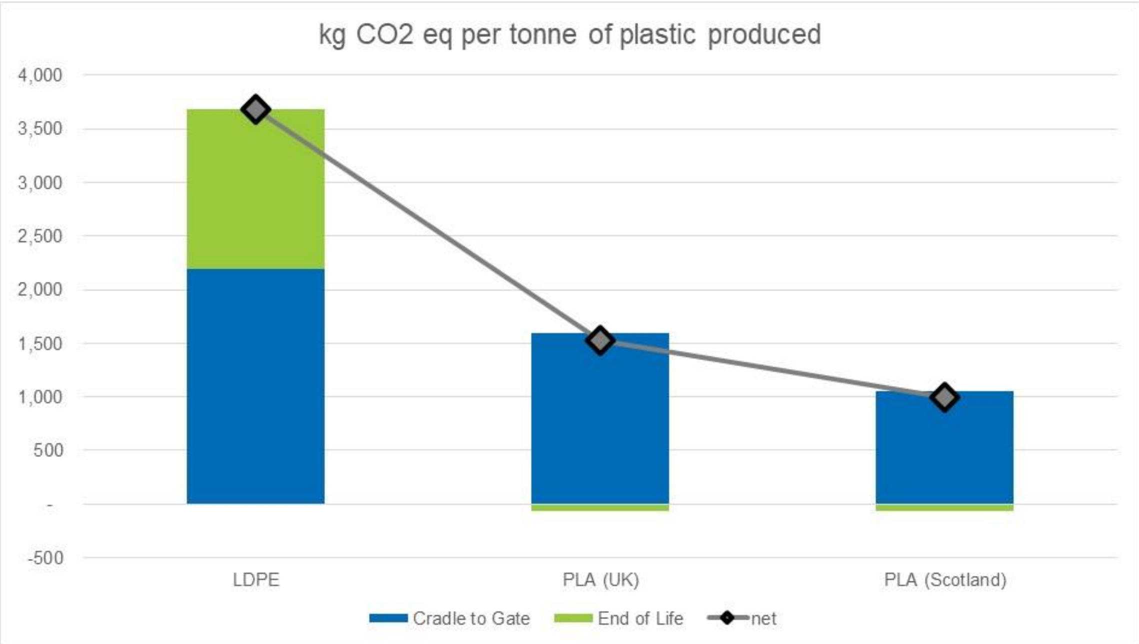
However, when 90% of waste is segregated from general waste, contamination has an important impact. If just 10% of the LDPE segregated from general waste is contaminated with food, then LDPE becomes the least favourable option. These results are shown below in Figure 21.

Figure 21 90% segregated from general waste, with 10% food contamination



If all the waste segregated from general waste is contaminated, LDPE is found to have an impact 59% larger than PLA using UK grid, and 73% larger than PLA using Scottish grid. These results are shown below in Figure 22.

Figure 22 90% segregated/ 100% Contaminated Results



7.7 Recommendations for Future Study

Ricardo recommends undertaking a future LCA study using primary data, once information regarding bio-plastics becomes more readily available. This would allow for a more detailed and company specific LCA which could delve into different scenarios and options in more detail.

A future study could also explore the end of life considerations in more detail. Ricardo notes that composting bio-plastics raises questions of nutrient quality due to additional food coatings and PLA residue. It is unknown whether biodegradable PLA would introduce undesirable compounds to compost that require further treatment or if it could simply contribute to the production of a valuable resource or fertiliser. This study has assumed that PLA would not affect compost production significantly, however this is an interesting area for further research, especially if composting the bio-plastic is going to be recommended and framed as a sustainable option.

7.8 Conclusion

This study has assessed the life cycle impacts of using PLA as a bio-plastic alternative to LDPE, using two life cycle inventories from the eco-invent v3.4 database. Both systems are compared using a functional unit of 1 tonne of plastic.

The initial results showed that the traditional LDPE system is preferable to virgin PLA, emitting 2,189 kgCO2e per tonne, 35% less than the PLA system. However, further analysis revealed that this impact was driven by eco-invent's assumptions regarding electricity grid mix and feedstock. Sensitivity analysis was undertaken to vary these two parameters to understand the extent to which they affected the results.

The original eco-invent PLA process was amended to replace its grid mix with a UK grid mix and then with a Scottish grid mix. This analysis had a significant impact on the results and PLA was found to be preferable if it was produced using a Scottish grid mix (Scotland has a higher proportion of renewable generation capacity). While the UK grid mix lowered the PLA system's carbon footprint, it still emitted 27% more CO2 emissions than LDPE.

A further sensitivity explored the potential impacts of using waste bioresources as a replacement for the maize feedstock contained in eco-invent. This analysis assumed the bioresources arose for free but charged the PLA system with a transport burden for freighting by-products to the PLA factory. Combining this analysis with the grid sensitivity revealed that PLA using the UK average grid mix was also preferable to LDPE.

Finally, a sensitivity analysis was undertaken into the end of life considerations of these two plastics. The analysis found that LDPE did not perform well when contaminated with food waste. If the LDPE is contaminated with food waste, and cannot be recycled, then our analysis showed that PLA compostable packaging results in over 50% less CO2e being emitted compared to traditional LDPE.

8 Initial economic analysis

For the purpose of this study two tiers of analysis have been proposed. Firstly, to understand the potential scale of the market opportunity for bio-polymers and secondly, to provide a more detailed look at the supply chain transactions and how biopolymers perform relative to their conventional polymer counterparts.

8.1 Phase One – potential market scale of biopolymers

The first step in estimating the potential market for bio-polymers involved research to establish the current market price for bio-polymer materials. These prices are outlined in Table 30 below. These market values for bio-polymer materials have then been combined with the forecast market size for the biopolymers these materials have the potential to substitute and the market uptake as a result of consumer demand. The market scale has therefore been estimated on the potential material demand multiplied by the current market value of biopolymer materials. Although only an indicative calculation, this calculation still provides a reflection of the potential market opportunity for bio-polymer producers.

Table 30 Estimating the potential biopolymer market in 2025.

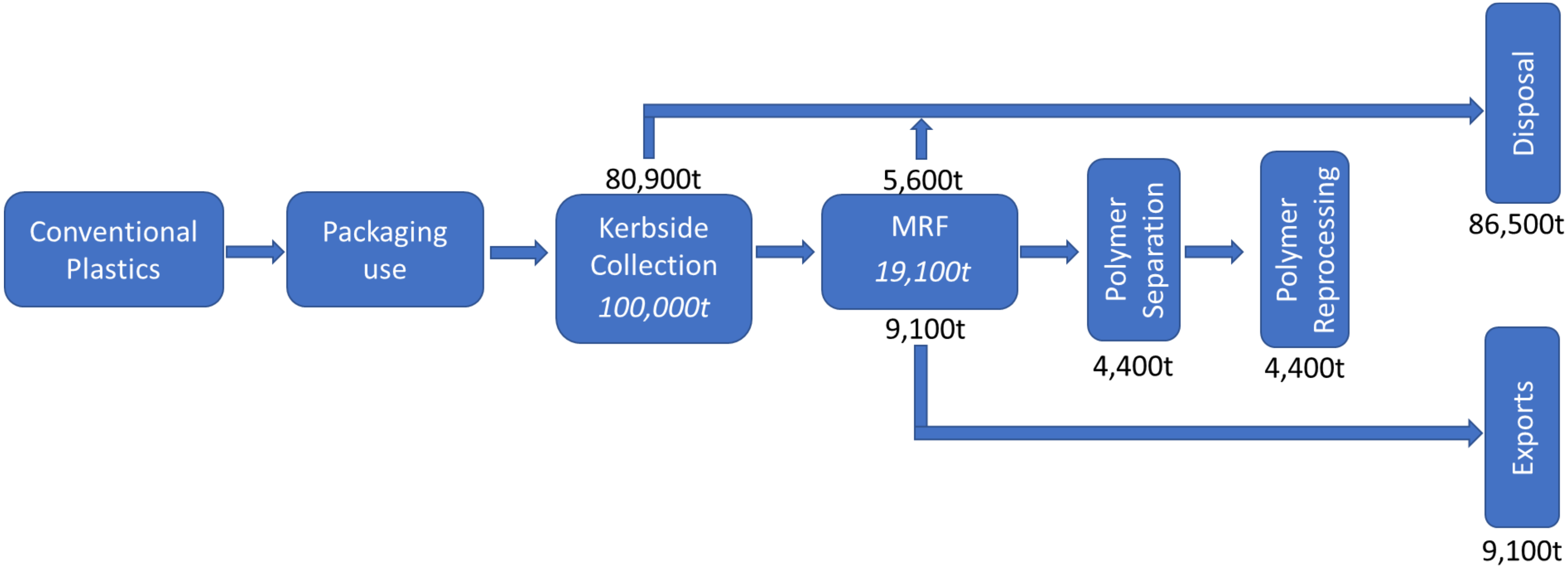
	Forecast market tonnage	Current market spot price for materials streams £/t[59]	Value of the market
Totals	**100,000**		**£267,085,125**
Flexible	**77,250**		**£208,150,125**
PBAT	*45,578*	*£2,800.00*	*£127,617,000*
PLA	*3,863*	*£1,800.00*	*£6,952,500*
Starch	*11,588*	*£750.00*	*£8,690,625*
Regenerated cellulose, PHA, other	*16,223*	*£4,000.00*	*£64,890,000*
Rigid	**17,250**		**£42,435,000**
PLA	*12,075*	*£1,800.00*	*£21,735,000*
Regenerated cellulose, PHA, other	*5,175*	*£4,000.00*	*£20,700,000*
Other	**5,500**	**£3,000.00**	**£16,500,000**

8.2 Phase 2 of Economic analysis

The second phase of the analysis takes a much more detailed look at the supply chains for both biopolymers and conventional polymers to look at the transactions and value-added activity that make conventional polymers circular (recyclable), versus the flow of bio-polymers through the supply chain to produce a compost. This type of approach provides a more thorough evaluation of how bio-polymers perform against conventional polymers and how they compare. This analysis therefore looks along the value chain looking at the costs associated with collection, sorting, treatment and disposal, to the final point of value recovery through secondary materials being circulated back into the economy. For the purpose of this analysis we have defined two simple overviews of the supply chains for both conventional polymer materials (Figure 23 and their bio-polymer equivalents Figure 24). Using both supply chains and taking into account the cost of treatment and disposal against the value of the materials returned to the economy, the net cost of the material flows was calculated. This provided an indication of the effectiveness of the value recovery system and the economic burden of processing conventional polymers versus bio-polymers to the point of primary value recovery.

[59] https://www.wur.nl/upload_mm/1/e/7/01452551-06c5-4dc3-b278-173da53356bb_170421%20Report%20Bio-based%20Plastic%20Facts.pdf

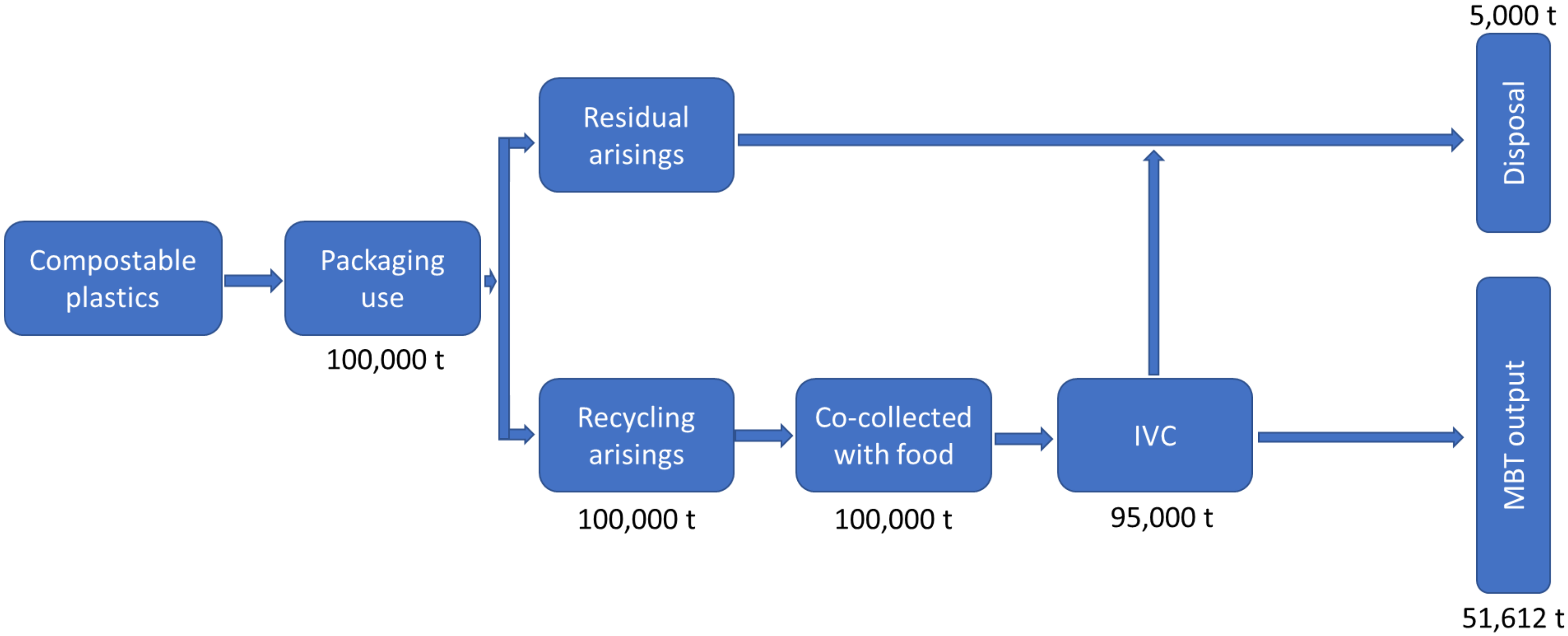
Figure 23 Outline of supply chain for conventional plastic polymer utilisation (based on 100,000t)



Transactions and processes included within the Economic analysis:

- Cost of collection either kerbside sort or co-mingled with other materials
- Transfer and sorting costs to separate plastics from contaminants and non-target materials
- Polymer separation into useable material streams for polymer reprocessors
- Cost of reprocessing of material in to PAS approved resource for use in manufacturing
- Process losses and disposal at various points in the supply chain
- Value of recycled polymer to virgin polymer use

Figure 24 Outline of supply chain for compostable plastic polymer utilisation (based on 100,000t)



Transactions and processes included within the analysis include:

- Cost of collection likely combined with food and or garden waste material
- Bulking and haulage
- Treatment costs at IVC facilities taking into account likely need for pre-processing or separate industrial composting equipment
- Value of MBT output as sold to the market

8.3 Outputs from the phase two Economic analysis

The summary of the phase two economic analysis is set out below. The aim of this analysis was to look in more detail at the supply chain of conventional plastics and bio-plastics and the additional costs of capturing and treating them within the waste/resource management system. This analysis treats all treatment and disposal activities as additional cost, but secondary materials returned to the economy as a benefit. In this regard it represents a high-level assessment of the net costs of returning conventional polymers and biopolymers to the point of value recovery. This has been undertaken to investigate if there are any potential additional benefits for the capture, treatment and recovery in switching materials and adopting bio-plastics. This also reflects the current inefficiency of the current system in truly returning waste polymers to the economy as valuable resource.

The baseline scenario for this analysis, as set out in the Tables 31 and 32 below, is based on material flows available from WRAPs plastic flow analysis (2011)[60]. Although this is now likely to be outdated relative to total plastics (particularly bottles, pots, tubs and trays) for materials that the bio-polymers are likely to replace (films and flexible plastics) it is considered to be comparable to the current system performance.

Utilising this baseline scenario, the flow of conventional polymers has been mapped through the system and economically valued in terms of the costs and benefits that are accrued, using industry benchmarks. This analysis is outlined within Table 31, demonstrating that the net cost associated with the recovery system is £11.2 million the equivalent of £112 per tonne of material.

Table 31 Indicative cost of conventional polymer through the supply chain to primary value recovery

Supply stage	Process	Tonnage	Cost / Benefit assumption (£/t)	Cost benefit (£)
Collected	Co-collected	100,000	£29.00	£2,900,000
Sent for recycling	MRF	19,100	£22	£420,200
Reprocessing		4,400	£22	£96,800
Exports		9,100		£0
Rejects sent for incineration	Incineration	5,600		£0
Disposal	Incineration	33,800	£86	£2,906,800
Disposal	Landfill	52,700	£107	£5,638,900
Secondary materials		4,400	-£180	-£793,283
Total Net Cost				**£11,169,417**

As a comparison the same approach has also been utilised to estimate the cost for biopolymer materials flowing through the system utilising the indicative mass flow as outlined in Figure 24. This analysis (outlined in Table 32) estimates the net cost of the system to be £10.1 M equivalent to £100 per tonne, demonstrating 12% lower net costs incurred through the system.

[60] https://www.valpak.co.uk/docs/default-source/environmental-consulting/plastic_spatial_flow_final_report_20aug.pdf?sfvrsn=84b26c10_2

Table 32 Indicative cost of Bio-polymer through the supply chain to primary value recovery

Supply stage	Process	Tonnage	Cost / Benefit assumption (£/t)	Cost benefit (£)
Collected	Collected with food	100,000	£53.0	£5,300,000
Sent for IVC	IVC	95,000	£49.0	£4,655,000
Rejects sent for disposal	Rejects to EFW	5,000	£86.0	£430,000
Secondary materials	Average MBT output price	51,612	-£5.9	-£305,836
Total Net Cost				**£10,079,164**

A sensitivity analysis was conducted and identified that, based on the same proportional flows, the recycling rate of conventional plastics would need to rise to 32% from 19% with 7.5% being reprocessed rather than 4.5% as per the baseline scenario (Table 33).

Table 33 Sensitivity analysis to identify the recycling and reprocessing rate required for costs of recovery to be comparable

Supply stage	Process	Tonnage	Cost / Benefit assumption (£/t)	Cost benefit (£)
Collected	Co-collected	100,000.00	£29.00	£2,900,000
Sent for recycling	MRF	32,000.00	£22	£704,000
Reprocessing		7,372	£22	£162,178
Exports		15,246		£0
Rejects sent for incineration	Incineration	9,382		£0
Disposal	Incineration	33,086	£86	£2,845,356
Disposal	Landfill	44,297	£107	£4,739,743
Secondary materials		7,372	-£180	-£1,329,061
Total Net Cost				£10,022,216

9 Data limitations and recommendations

Following this report, a number of data limitations and recommendations for future study are presented. These include:

- Further studies could investigate how to identify the remaining 20% multi-material flexible packaging market.
- Further study to assess food supply chain waste availability to count as available feedstock.
- Assess the risks and opportunities associated with flexible packaging being used for other applications, including but not limited to:
  - Flexible packaging into non-food flexibles
  - Flexible packaging into rigid packaging (non-food)
  - Flexibles into other applications?
- Further study to assess the arisings, accessibility and availability of the bioresources.

10 Summary and considerations

This report has highlighted the real potential for compostable packaging in the UK, with significant direct and indirect economic benefits capable of being unlocked as a result of more widespread adoption.

There is a strong case for investment in compostable packaging but this is contingent on a number of elements, not least a clear policy direction to support the case for investment. This section provides an outline of these considerations and suggested next steps.

10.1 Bioresource considerations

- Consider whether the bioresources discussed in section 6.3 are available
  - Assess what is available vs accessible.
- Consider whether compostable packaging is the best use of bioresources from an LCA perspective

10.2 The role of compostable packaging in the supply chain

- Consider the scope of packaging items which are substituted for compostable materials and how this aligns with current waste collection systems. For example, replacing 'on-the-go' packaging items requires that the on-street containers (bins) provide options to capture these materials (e.g. separate section) otherwise the benefits of biodegradability are redundant as the materials will be disposed of. A whole system approach must be considered that incorporates collection and treatment / disposal.
  - DRS is an example of a system to tackle 'on-the-go' plastic bottles that are not typically used in the household.
  - This study has demonstrated that the target market for compostable substitution is food-contaminated, flexible packaging options.
- Recycling of flexible plastic is challenging due to the technologies currently available (at scale) and the difficulty in separating these items and then cleaning them – compostable packaging could play an important role here. It is important to consider what will happen with flexibles –

bio-based (renewable source) and then incineration (energy recovery) or a compostable approach.

- Compostable packaging is made more attractive when the packaging is heavily contaminated with food, as it captures the food waste and when processed via AD/IVC can and avoid this food waste being lost and contaminating other recyclables.

10.3 Collections and infrastructure

- Valuing the contribution that compostable packaging can play in capturing the stream of food waste that currently is not captured in the food waste bin because it is in the general waste bin.
    - Benefit – increase the amount of food waste collected
    - Benefit – increase the collection of materials that can not be placed within the dry recyclates material stream.
- Consider the potential issue of having too much compostable packaging in the home organics collection.
    - Consider a change in the collection infrastructure for the home. If households are able to place compostable packaging along with food waste into the same bin the container will potentially need to be larger than the average 23l caddy bin provided by local authorities.
- Consider the treatment route for compostable packaging. At present, compostable materials do not fully biodegrade in Anaerobic Digestion conditions. These materials are often separated out and sent to an In-vessel Composting facility.
    - Q. Does this provide an opportunity for co-collected garden and food waste that can then go for IVC?
    - Q. What would the cost implications for this be? Whole system costs would need to be assessed

10.4 Discussion: Policy direction

There is a role for compostable packaging and this will be part of the packaging mix going forward, not least because there is already an established market. Compostable packaging has many policy drivers both across the EU and the UK with a specific policy commitment through the Packaging Pact. At the very least, it provides a viable alternative to plastic packaging that is heavily contaminated with food waste. Taking the considerations above into account the role compostable packaging will play in the future will depend heavily on the direction of policy. Future policy will inform how the Packaging Pact will be delivered and how those targets will be achieved. The key question that needs to be answered in the coming months is how much of the 70% of plastic packaging will be recycled or composted and therefore which packaging will be deemed non-recyclable or compostable and comprise the remaining 30%?

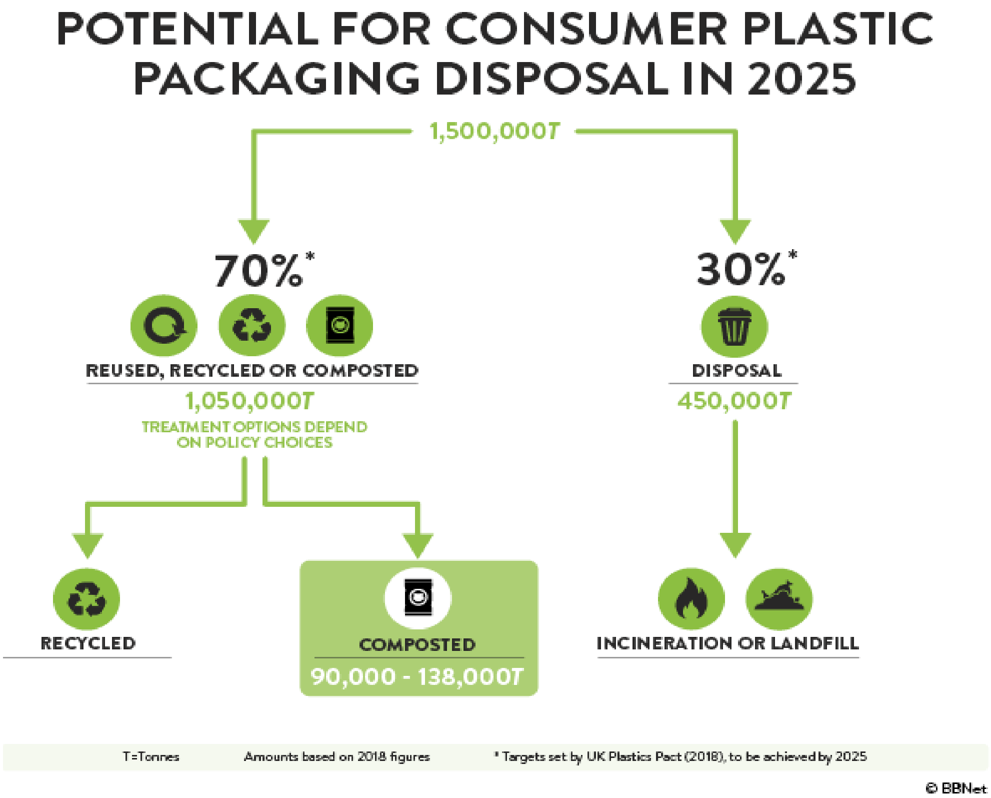


Figure 25 Achieving the 70% recycled or composted target

Figure 25 shows that the key decision-making criteria focusses on the following questions - of the plastic packaging placed on the market what will/should make up the 30% to be disposed and of the remaining 70% what is best being recycled and what is best being composted?

Key considerations are:

- Collection infrastructure in place to capture the packaging – both recyclable and compostable
- Ability to process the material
- Challenges associated with consumer behaviour and decision-making, including labelling
- Should compostable packaging be prioritised where there is not a viable option to recycle plastic?
- Where could compostable packaging be used to avoid plastics escaping into the environment and causing pollution (where materials are littered or mis-managed)
- What are the technical performance capabilities of compostable packaging?

If it is decided to have compostable packaging as part of the packaging solution, then to accommodate this there must be a collection infrastructure. If the collection infrastructure for organics is delivered at a local authority level, then it is important to maximise that investment by making the full use of the solutions offered through compostable packaging.

The next phase of the journey is to establish what is the most effective use for compostable packaging. This needs to be fully researched and considered taking into account the aspects discussed above and taking a range of stakeholders' views. It needs to be evidence-based policy making. Stakeholders, including national and local government, academia and industry should come together to discuss the legitimate and valuable role that compostable packaging can play within the value chain.

Appendices

Appendix 1 – Bioresource Mapping Output

Available bioresources available, presented in tonnes.

	Total produced (tonnes)	**Tops Waste (tonnes)**	**Production Waste (tonnes)**	**Harvested Waste (tonnes)**	**Haulms (tonnes)**	**Stover (tonnes)**	*Total bioresource produced (minus Waste - tonnes)*	**Straw (tonnes)**	**Other uses of straw (tonnes)**	*Straw Available (tonnes)*	***Total Overall (tonnes)***
Barley	7,077,600						*7,077,600*	3,116,667		*3,116,667*	***10,194,267***
Oats	866,400						*866,400*	505,167		*505,167*	***1,371,567***
Oil Seed Rape	2,217,600						*2,217,600*	897,000		*897,000*	***3,114,600***
Potatoes	6,560,333		984,050	422,178	211,089		*4,943,017*			-	***4,943,017***
Minor Cereals	114,000						*114,000*	255,200		*255,200*	***369,200***
Sugar Beet	6,802,133	496,833					*6,305,300*			-	***6,305,300***
Wheat	14,903,400						*14,903,400*	6,353,667	6,200,000[61]	*153,667*	***15,057,067***
Maize	3,360,000					960,000	*2,400,000*			-	***2,400,000***
Total	41,901,467	496,833	984,050	422,178	211,089	960,000	*38,827,317*	11,127,700	6,200,000	*4,927,700*	***43,755,017***

[61] Note - we believe that around 5.7Mt/y straw is used for animal bedding and on farm. This can be barley and oat straw as well as wheat and that oils seed rape straw is not used for this purpose.

Appendix 2 – LCA Background information and assumptions

Data: The function of both systems is to produce plastic. The functional unit has therefore been set as 1 tonne of plastic. Obtaining reasonable data for an LCA is critical and is usually the determining factor for a project's quality and also for the effort required to complete the work. LCA practitioners prefer to use primary data where possible, direct from the systems being studied, and only revert to secondary data (from literature) when required. The balance of primary and secondary data is often dictated by the budget and timescale of the study. However, for the purposes of this study secondary eco-invent data has been used as this LCA is on a potential product not an existing one.

PAS 2050 Principles PAS 2050 requires the following principles to be adhered to when carrying out an assessment

Relevance: This study follows PAS 2050's requirement for 'Relevance', reporting on both GHG emissions to, and removals, from the air. Annex A of the PAS 2050 guidance provides GWP values for emissions that should be captured in the study. These values are based on IPCC 2007 values. Please note that this study has used the more recent IPCC 2013 values as contained within the SimaPro life cycle assessment software.

Completeness: All product life cycle GHG emissions and removals arising within the system, as described in 2.1, have been included in this study.

Consistency: Both systems have been taken from the same data source (eco-invent 3.4).

Model Description

The life cycle assessment was carried out within SimaPro using ecoinvent life cycle inventories and supplemented with emission factors from the Scottish Carbon Metric and the UK 2018 GHG Conversion Factors. The LCA calculations were conducted within Sima Pro using the IPPC 2013 GWP_{100a} method.

References

1. PAS 2050:2011, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services, BSI
2. Lifecycle Assessment (LCA) Guidance for ZWS Projects, Zero Waste Scotland 2017
3. CarbonIntensity.org
4. Scottish Carbon Metric
5. UK GHG Conversion Factors, 2018
6. ecoinvent v3.4
7. SimaPro v8.5.2