Market and safety analysis of alternatives to plastic food packaging

Report to the Food Standards Agency

Marina Renton, October 2020

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Executive Summary

Plastics, once heroes of convenience, have become climate change villains. Environmental worries have driven consumer and governmental interest in moving toward using more recycled, recyclable, and compostable materials. Bio-based alternatives for food contact applications have proliferated, with potential adverse or unintended consequences, necessitating a coordinated, evidence-based response.

Novel forms of food packaging come with potential risks, such as reduced product shelf life, hazards from additive migration into food, and reactions to allergenic compounds. Much is still unknown about the safety risks associated with bio-based food contact materials (BBFCMs), and additional research and testing are needed to evaluate them. Novel materials and technologies have in some cases outpaced the regulatory framework currently in use by the United Kingdom (UK) and the European Union (EU). The UK has an opportunity to be a leader in this emerging area by adopting evidence-based, consumer-centred regulations for BBFCMs.

The remit of this project is to investigate the health and economic implications of plastic food packaging alternatives. These materials are less researched and potentially risky to health, directly and indirectly (*e.g.* decreasing shelf life). Further, the market for BBFCMs is growing, spurred by advancing research in the field, consumer interest in plastic alternatives, and governmental incentives to reduce plastic use, such as a tax on virgin plastic packaging. Their use comes with potential direct and indirect economic impacts. For instance, new materials come with new production and disposal costs, and the plastic packaging tax could result in increased prices for consumers, though this outcome is not seen as very likely.

This project articulates the state of the research on BBFCMs by analysing academic and ‘grey’ literature and conducting expert interviews. It is designed to facilitate an evidence-based, coordinated response to the proliferation of plastic alternatives, one that considers balancing consumer safety with innovation.

Figure 1. Bio-based food contact materials: factors to consider

Factors	Considerations
Health	• Insufficient research base to understand criteria that could risk health • Potential for bio-based materials to trigger allergies, conflict with special diets (*e.g.,* chitosan-based materials triggering shellfish allergies) • Risks from growing conditions for agriculture-based constituents • Constituent migration (*e.g.,* nanomaterials) into food
Regulatory	• Lack of specific regulations for BB and composite FCMs • Limited guidance for BBFCM testing • Few labelling requirements
Safety	• Effects on shelf life • Performance in adverse conditions (heat, moisture) • Interaction between substances in composite materials • Need for new testing methods or protocols
Environment	• Availability of industrial composting facilities • Consumer understanding of disposal methods • Life cycle analysis: footprint from production, shipping, use, disposal
Economy	• Manufacturing and disposal costs—labour, transport, raw materials, research and development • Indirect social costs—environmental impacts, health effects, consumer interest in sustainability • Effects of plastic packaging tax on cost of goods, catalyst to change packaging materials

The Food Standards Agency (FSA) should consider the following recommendations:

- facilitate a joined-up approach between food safety government agencies;
- partner transparently and share knowledge between sectors;
- develop evidence-based regulations for plastic alternatives; and
- participate in consumer education.

Introduction

Plastics were touted for their convenience and seeming disposability, but public perception has changed. Commentators and officials frequently credit the 2017 Blue Planet II BBC series, which documented marine plastic pollution, for generating momentum to reduce plastic use.[1]

Sustainability-minded production and consumption have become mainstream. A 2019 YouGov survey found that 82% of Britons are actively trying to reduce the amount of plastic they discard.[2] Half said that they would pay more for a product with eco-friendly packaging.[3] This interest is reflected in packaging trends. The majority of the 10 (unranked) trend topics identified by ThePackHub, a packaging services company, concern sustainability and plastics alternatives.[4]

Plastics do confer benefits. They are inexpensive, light (resulting in less shipping fuel consumption), extend shelf life, and protect food from contamination.[5] Even with current packaging norms, food waste is substantial; for example, 1.3 million tonnes of edible vegetables and salads goes to waste in the UK annually, costing citizens approximately £2.7 billion.[6]

Recent events have stymied the move away from single-use plastics. In the United States, for example, the COVID-19 pandemic has resulted in the repeal of some single-use plastic bag bans to reduce the risk of virus transmission, despite inconsistent evidence about transmission via cloth, paper, or plastic bags.[7] Similarly, increased consumption of takeaway and delivery meals, coinciding with rules against personal reusable containers for hygiene reasons, are likely also contributing to increased plastic waste.[8]

Methods

A systematic literature scan used ScienceDirect for recent (2015-present) studies to understand the current landscape of research on plastics alternatives. It employed as search terms: 'bioplastics'; 'bio-based plastics'; 'plastic alternatives'; 'bio-based

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[1] House of Commons Environment, Food and Rural Affairs Committee, *Plastic food and drink packaging,* Sixteenth Report of Session 2017-2019, 12 September 2019, 4.

[2] Victoria Waldersee, 'Most Brits support ban on harmful plastic packaging', YouGov, 19 April 2019.

[3] Ibid.

[4] ThePackHub Innovation Zone, *Packaging Innovation Briefing Report* (ThePackHub, March 2020).

[5] Ellen MacArthur Foundation, *The New Plastics Economy: Rethinking the Future of Plastics & Catalysing Action,* (Ellen MacArthur Foundation, 2016), 18,

[6] WRAP, *Evidence Review: Plastic Packaging and Fresh Produce* (WRAP, 2018),

[7] Hannah Hagemann, 'Coronavirus Fears Prompt Suspensions of Bans on Single-Use Plastic Bags', *NPR*, 13 April 2020,

[8] Daiane Scaraboto, Alison M. Joubert, Claudia Gonzalez-Arcos, 'Using lots of plastic packaging during the coronavirus crisis? You're not alone', *The Conversation,* 27 April 2020,

food contact materials'; 'bio-based food packaging'; 'safety'; and 'compostable food packaging'. Results were filtered for 'review articles', 'research articles', or 'other'. The 35 results underwent a title then abstract review. Articles were excluded that did not mention food contact applications for bioplastics or focused on a different application, such as medical. Fourteen articles were ultimately included, half of which studied one type of plastic alternative, while the remainder discussed multiple polymers. Interviews were conducted with FSA members as well as experts outside the Agency. (See appendices for review findings and an interview list.)

Background

Plastic packaging use and waste in the UK

In 2017, the UK produced 2.26 million tonnes of plastic packaging, of which about 46 percent was able to be recycled or recovered, according to official estimates, though some organisations suspect that the statistics significantly underestimate the waste.[9]

Nearly 150 businesses, including prominent food industry actors like Tesco, Kraft Heinz, and Sainsbury's, have signed onto the UK Plastics Pact, rolled out by Waste & Resources Action Programme (WRAP), a charity for efficient resource use.[10] Those who sign the Pact commit to meeting the following targets by 2025: all plastic packaging will be reusable, recyclable, or compostable; 70% of plastic packaging will be effectively recycled or composted; plastic packaging will average 30% recycled content; and unnecessary single-use plastic packaging will be eliminated.[11] WRAP has laid out a road map to achieve the targets, which names activities such as identifying criteria for eliminating 'problematic' types of packaging, developing new packaging systems, supporting local authorities to augment recycling, and labelling products with recycled packaging.[12]

Plastics' environmental impact

According to a report from the Ellen MacArthur foundation, at least eight million tonnes of plastics enter the ocean each year, and that number is expected to continue to increase.[13] Given that plastics take hundreds of years or more to break down, the environmental hazards will accumulate.[14] Furthermore, plastics' reliance on non-renewable resources[15] is not sustainable.

Plastics' public health risks

Consumers are aware of the problematic role plastics have come to play in everyday life. A literature review of perceptions and behaviours relating to plastic use found that consumers prefer bio-based materials over conventional plastic, regardless of biodegradability.[16,17] Given consumer interest in making environmentally friendly and healthful choices, efforts are advised to ensure that those choices are grounded in unambiguous information and come with limited unintended consequences.

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[9] Louise Smith, *Plastic waste,* Briefing Paper Number 08515, House of Commons Library, 7 January 2020.
[10] 'The UK Plastics Pact members', WRAP, accessed 1 April 2020.
[11] 'Eliminating Problem Plastics', WRAP, accessed 1 April 2020.
[12] WRAP, *A Roadmap to 2025—The UK Plastics Pact.* (WRAP, 2018),
[13] Ellen MacArthur Foundation, *The New Plastics Economy,* 12.
[14] Ibid., 22.
[15] Ibid., 20.
[16] Lea Marie Heidbreder, Isabella Bablok, Stefan Drews, Claudia Menzel, 'Tackling the plastic problem: A review on perceptions, behaviors, and interventions', *Science of the Total Environment* 668(2019): 1077-1093.
[17] For a definition, see 'Alternative Food Packaging' section.

Conventional plastics (fossil fuel-based) may pose risks to human health. The two areas of greatest concern are chemical additives and the fact that plastics, when broken down into microplastics, might be inadvertently ingested.[18] (Microplastics can also be present in the environment through other means, such as intentional addition to products or through washing clothes made from synthetic fibres.[19] An EU ban on intentionally-added microplastics took effect in 2020.[20]) A recent study compiled a database of chemicals likely associated with plastic packaging (about 60% of which is for food and drinks) and, of the 906 chemicals identified, 63 ranked high for human health hazards; additionally, seven of the substances were classed as (very) persistent, (very) bioaccumulative, and toxic,[21] and 15 were classed as endocrine [hormone] disruptors.[22] If a product contains a hazardous chemical, it is not necessarily present or migrating into food at levels that could be harmful; risk assessments are crucial for this reason.

UK strategy and policy to decrease plastic waste

Regulations are already in place to limit the health risks posed by plastics, including in food safety; regulations and education may require updating as new materials gain prominence.

England's Resources and Waste strategy (2018) outlines five 'strategic ambitions':

1. To work towards all plastic packaging placed on the market being recyclable, reusable or compostable by 2025;
2. To work towards eliminating food waste to landfill by 2030;
3. To eliminate avoidable plastic waste over the lifetime of the 25 Year Environment Plan;
4. To double resource productivity by 2050; and
5. To eliminate avoidable waste of all kinds by 2050'.[23]

The strategic aims point to a logical increased interest in plastic alternatives, incentivising research and development into safe and sustainable packaging.

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[18] Heidbreder et al., 'Tackling the plastic problem'.
[19] 'Microplastics: sources, effects and solutions', European Parliament, 22 November 2018.
[20] Ibid.
[21] **Persistent**: Resistant to breaking down in the environment and accumulate instead; **Bioaccumulative**: Build up within bodily tissues; **Toxic**: Capable of adversely impacting physical or environmental health. Source: 'Get the Facts: Persistent, Bioaccumulative and Toxic Chemicals (PBTs)', Safer Chemicals, Healthy Families, Science & Environmental Health Network, accessed 14 July 2020.
[22] Ksenia J. Groh, Thomas Backhaus, Bethanie Carney-Almroth, Birgit Geueke, Pedro A. Inostroza, Anna Lennquist, Heather A. Leslie, Maricel Maffini, Daniel Slunge, Leonardo Trasande, A. Michael Warhurst, and Jane Muncke, 'Overview of known plastic packaging-associated chemicals and their hazards', *Science of the Total Environment* 651 (2019):3253-3268.
[23] HM Government, *Our Waste, Our Resources: A Strategy for England* (HM Government, 2018), 17.

Beginning in 2022, the UK government will introduce a plastic packaging tax (£200 per tonne) on plastic produced in or imported into the UK if it fails to contain at least 30% recycled plastic.[24] The consumer economic impact of the tax is not expected to be significant, since plastic packaging usually accounts for a small portion of a good's cost, nor is the tax expected to have a particular impact on protected groups.[25] The details and potential impacts of the tax remain unclear as consultation is ongoing, but approximately 20,000 businesses are expected to be affected (plastic packaging producers and importers).[26] The proposed tax has been met with praise from environmental groups but criticism from manufacturers of packaged foods, one reason being concerns that recycled content is not permissible for certain food contact applications, and unrecycled plastic remains the only option, but there is no mechanism for passing the tax onto consumers.[27] Companies that have opted not to participate in the UK Plastics Pact and those that use packaging that is not widely recycled are slated to be the most affected by the tax, though exceptional events such as the COVID-19 pandemic have the potential to disrupt the tax's effectiveness with, for instance, a decline in oil prices.[28]

In October 2020, a ban on supplying plastic straws, drinks stirrers, and cotton buds, save for medical exceptions, came into force.[29] Other government proposals to reduce plastic packaging waste involve an extended producer responsibility (EPR) scheme that would require businesses to take on the costs of the end-of-life processes for their products;[30] more nation-wide consistency regarding what materials are collected for kerbside recycling;[31] a clearer recycling label scheme;[32] and a deposit return scheme for drinks containers.[33]

The Resources and Waste Strategy was prompted by the publication of the UK's 25 Year Environment Plan, which incorporates a goal of zero plastic waste by the end of 2042.[34] Some of the planned actions consider developing and testing alternative materials in addition to improving plastic recycling and reuse. There is an interest in additional research and development.[35] Furthermore, through the Bioeconomy

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[24] 'Plastic Packaging Tax', HM Revenue & Customs, Gov.uk, 11 March 2020,
[25] Ibid.
[26] Ibid.
[27] Thomas Parker, 'What is the UK's plastic packaging tax and how could it impact the industry going forward?', *NS Packaging*, 13 March 2020.
[28] Simon Ede, Yassir Ahmed, E. Wah Wan, Kitty Stacpoole, 'Disruptive Sustainability: Implications of the 2022 Plastic Packaging Tax', Charles River Associates, June 2020,
[29] Department for Environment, Food & Rural Affairs and The Rt Hon George Eustice MP, 'Start of ban on plastic straws, stirrers and cotton buds', Gov.uk, 1 October 2020,
[30] House of Commons Environment, Food and Rural Affairs Committee, *Plastic food and drink packaging,* 11.
[31] Ibid., 15.
[32] Ibid., 17.
[33] Ibid., 19.
[34] HM Government, *A Green Future: Our 25 Year Plan to Improve the Environment,* (HM Government, 2018), 86.
[35] Ibid., 87.

Strategy, the 25 Year Environment Plan pushes developing bio-based and biodegradable plastics.[36] These initiatives do not automatically involve the FSA (though new materials will need to go through an FSA authorisation process), but they will lead to changes in the materials on the market and their applications in the food industry, and the FSA, as the protector of consumers' food safety interests, will be tasked with responding to them. Food safety is a vital consideration underpinning packaging innovation; engaging the FSA throughout the development and regulatory process is important to keeping safety a central concern.

Safety and testing of plastics and bioplastics: EU regulations

The EU has taken steps to reduce plastic pollution, including by requiring all plastic packaging on the EU market to be reusable or recyclable by 2030.[37] It has also adopted a single-use plastics proposal targeting the 10 single-use plastic products and fishing equipment most commonly found in marine litter (*e.g.,* plastic straws).[38] Furthermore, producers will need to take on financial responsibility for clean-up and waste management (like the UK's EPR scheme) and assist with consumer education on certain types of packaging and incentivised to develop eco-friendlier alternatives.[39]

Currently, the UK is bound to EU regulations regarding FCM safety. The EU framework regulation for FCMs (Commission Regulation (EC) No 1935/2004) lays out general principles, requiring that FCMs be safe and inert. In other words, materials must not 'release their constituents into food at levels harmful to human health' nor 'change food consumption, taste and odour in an unacceptable way'.[40] The framework also provides more specific rules in certain circumstances; it contains 'special rules on active and intelligent materials (they are by their design not inert)'; 'powers to enact additional EU measures for specific materials (e.g., for plastics)'; 'the procedure to perform safety assessments of substances used to manufacture FCMs involving the European Food Safety Authority'; 'rules on labelling'; and rules for 'compliance documentation and traceability'.[41]

Plastics, including bioplastics, are covered by Regulation (EU) No 10/2011, which maintains a list of authorised substances permitted to be used intentionally in the manufacture of plastics.[42] The regulation also specifies migration limits for each substance as well as an overall migration limit of 10 mg/dm^2 of food contact surface.[43] (This limit differs in the case of a food intended for infants and young

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36 Ibid.
37 'Closing the loop: Commission delivers on Circular Economy Action Plan', European Commission, 4 March 2019.
38 'Single-use plastics: New EU rules to reduce marine litter', European Commission, 28 May 2018.
39 Ibid.
40 'Legislation', European Commission, accessed 18 April 2020.
41 Ibid.
42 'Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food (Text with EEA relevance)', OJ L 12, 15.1.2011.
43 Ibid.

children.[44]) The regulation establishes rules for migration testing and requires packaging manufacturers to obtain a Declaration of Compliance with data supporting the material's safety.[45] Recycled plastics have different requirements; regulation (EC) No 282/2008 covers recycling processes and quality assurance for recycled plastic FCMs.[46]

Regulations also exist for active and intelligent materials, those meant to protect food by either releasing or absorbing substances near or onto the food (active) or monitor and indicate a food's condition (intelligent).[47] Certain packaging methods might involve adding antimicrobial substances to a bioplastic material, which would subject the manufacturer to multiple sets of regulations.[48]

A separate category of regulations exists for FCMs derived from regenerated cellulose film, defined as 'a thin sheet material obtained from a refined cellulose derived from unrecycled wood or cotton…Regenerated cellulose film may be coated [with cellulose or plastic] on one or both sides'.[49] The regulation includes a list of approved substances and any restrictions on their use for regenerated cellulose film (Directive 2007/42/EC). Lastly, the EU has regulations for ceramic items intended to come in contact with food (Directive 84/500/EEC).

Plastic alternatives

Alternatives to plastic typically fall into one of three categories—a reversion to more 'traditional' means of packaging, such as metal or glass; using innovative materials, most commonly bioplastics, which look and feel similar to typical plastic packaging but are made from natural materials and may break down differently by being biodegradable or compostable; and non-plastic-mimicking alternatives, such as products derived from wheat or algae. The remit of this project is to investigate new, innovative alternatives to plastic packaging, so the research has concerned the latter two categories of materials. These new materials are less researched and potentially risky for human health, both directly and indirectly (*e.g.* by decreasing shelf life if other mitigating actions are not taken).

The UK government uses the EU's definition from the Directive on Single-Use Plastics, which defines a plastic as a material made of a polymer that may have been altered through the inclusion of additives or other substances.[50] Naturally occurring polymers are not included in the definition, but bio-based and compostable plastics are.[51]

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44 Ibid.
45 'Legislation', European Commission.
46 Ibid.
47 'Active and intelligent packaging substances', European Food Safety Authority, accessed 14 July 2020.
48 Interview with Tim Chandler, 2 April 2020.
49 'Commission Directive 2007/42/EC of 29 June 2007 relating to materials and articles made of regenerated cellulose film intended to come into contact with foodstuffs (Text with EEA relevance.)', L 172/71.
50 HM Treasury, *Plastic packaging tax: consultation,* (HM Treasury, February 2019), 13.
51 Ibid., 14.

Bio-based plastics use polymers from plant sources (*e.g.,* starch, cellulose, lignin).[52] Both fossil fuel- and bio-based plastics are potentially biodegradable (microorganisms can break them down into water, gasses, and biomass) and might also be compostable, meaning that they break down under specific (often industrial) composting conditions (*e.g.,* temperatures of 55-60 degrees Celsius).[53]

Other biological materials can serve as the basis for packaging materials (Table 1). (See Table 2 for most common biomass-based polymers.) The Shellworks, a company that makes packaging material out of waste shellfish shells, has stated that the chitin used is the second most abundant biopolymer in the world after cellulose.[54]

Table 1. Non-plant biological sources for packaging

Fungi-based	Algae-based (alginic acid)
Mycofoam (Ecovative, New York), fungal mycelium-based alternative to Styrofoam[55]	• Evoware (Indonesia), edible packaging for dry goods[56] • Ooho by Notpla (London), flexible packaging derived from seaweed that was used to replace single-use plastic at the 2019 London Marathon[57]

Compostable, biomass-based polymers are increasingly common, though they often require special environments to decompose.[58]

Table 2. Most common biomass-based polymers (European bioplastics, 2014)[59]

Material	Prevalence
Cellulose polyesters	33%
Polylactic acid (PLA)	31%
Starch blends	26%
Polyhydroxyalkanoate (PHA)	5%

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[52] House of Commons Environment, Food and Rural Affairs Committee, *Plastic food and drink packaging,* 26.
[53] Ibid., 26-27.
[54] 'Commonly Asked Questions…', The Shellworks, accessed 18 April 2020.
[55] UN Environment, *Exploring the potential for adopting alternative materials to reduce marine plastic litter* (United Nations Environment Programme, 2018), 54,
[56] Ibid., 67.
[57] 'Ooho!', Notpla, accessed 15 April 2020,
[58] UN Environment. *Exploring the potential for adopting alternative materials to reduce marine plastic litter,* 69.
[59] Ibid.

Compostable materials are compelling alternatives to fossil fuel-based plastics for food packaging because the materials can still be composted when contaminated with food waste, which is not the case with traditional kerbside recycling.[60] However, the current waste disposal/recycling infrastructure makes widespread compostable packaging unlikely. Not every local authority in England offers separate food waste collection (51% do), and even then the food waste is often not processed in a manner suitable for compostable materials, resulting in them being filtered out and sent to a landfill or incinerator.[61] Furthermore, compostable packaging risks incorrect disposal (*e.g.,* a compostable item might look like recyclable plastic and contaminate a recycling stream).[62] Recycling stream contamination impacts the recycling system, requiring more trips to a recycling centre, longer sort times, potential damage to equipment, cost to properly dispose of the contaminants, and lingering contaminants degrading the quality of the recycled materials.[63]

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[60] Houses of Parliament, Parliamentary Office of Science & Technology, 'Plastic food packaging waste', Post Note, Houses of Parliament Parliamentary Office of Science & Technology, July 2019.
[61] Houses of Parliament, Parliamentary Office of Science & Technology, 'Compostable food packaging', Post Note, Houses of Parliament Parliamentary Office of Science & Technology, July 2019.
[62] Ibid.
[63] WRAP, *Dry recyclables: improving quality, cutting contamination* (Wrap, 2015), 9-11.

Alternative food packaging

The Department for Business, Energy & Industrial Strategy (BEIS) and the Department for Environment Food & Rural Affairs (Defra) issued a call for evidence (2019) on standards for bio-based, biodegradable, and compostable plastics. The call defines some key terms, summarised below for consistency.

> Bio-based plastics: 'made using polymers derived from plant-based sources such as starch, cellulose, or lignin. Bio-based plastics can be engineered to be biodegradable, equally they can be made to function exactly like conventional fossil-based plastic (i.e. to have the same durability)'.[64]
>
> Biodegradable plastics: 'can be broken down into water, biomass, and gasses such as carbon dioxide and methane. Biodegradability depends on environmental conditions such as temperature, humidity, microorganisms present, and oxygen'.[65]
>
> Compostable materials: 'a sub-set of biodegradable plastics that break down safely into water, biomass and gasses under composting conditions. Industrial composting conditions are the most optimal'.[66]

The call for evidence sought data to inform a review, revision, or development of standards for conventional plastic alternatives relating to both their environmental and human health impacts. While bio-based, biodegradable, and compostable plastics have significant potential for environmental benefits, the evidence base is not yet clear, or at least it has not yet been consolidated. The call for evidence also included questions about labelling requirements to better inform consumers about the content and biodegradability of the packaging materials.[67] There is clear public and private sector interest in bio-based alternatives to plastic packaging, but, despite bold claims about the advantages of new materials, more research is needed before these claims can be responsibly substantiated.

Despite uncertainty, types of food packaging using materials other than fossil fuel-based plastic have increasingly come onto the market.

ThePackHub's packaging innovation report features cutting-edge designs and materials that, while not yet used at a large scale, might herald the future of packaging design. For example, FCMs profiled in March 2020 include:[68]

- Disposable cutlery from potato peelings that decomposes in the environment within a couple of months (Potato Plastic, Sweden);

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[64] Department for Business, Energy & Industrial Strategy and Department for Environment Food & Rural Affairs, *Standards for Bio-Based, Biodegradable, and Compostable Plastics: Call for Evidence* (Department for Business, Energy & Industrial Strategy, Department for Environment Food & Rural Affairs, 2019), 8.
[65] Ibid.
[66] Ibid.
[67] Ibid., 18.
[68] ThePackHub Innovation Zone, *Packaging Innovation Briefing Report,* March 2020.

- Edible, bio-based and biodegradable coatings for fresh and dried foods to prolong shelf life (Columbus' egg solution, IUV, Italy);
- A seaweed-lined takeaway box that decomposes in home composting (NotPla, UK)
- Bioplastic film from by-products of cellulose refinement that blocks most UV rays and is more airtight than usual plastic film (University of Oulu, Finland);
- An algae-based, compostable material that changes colours when food begins to spoil or has been tampered with (Primitives, United States)
- Carton made from renewable wood fibres that is grease- and liquid-resistant (Aqua and Aqua+, Stora Enso, Finland).

It is important to understand the safety and infrastructure considerations to produce, test, and dispose of emerging materials to ensure the health of the public and the environment, preferably while fostering innovation.

The market for alternative food packaging

When considering the market for plastic alternatives, it is important to also take into account the negative externalities associated with conventional plastics. The advantages of plastics are mentioned elsewhere in this report and are considerable (see Introduction). The negative externalities associated with plastic packaging in particular are reportedly valued at 40 billion USD, taking into account ocean pollution and the carbon footprint of utilising fossil feedstocks.[69]

The Ellen MacArthur Foundation has proposed a vision for a 'New Plastics Economy', which has three parts: 1) enhancing uptake of efficient disposal practices (*e.g.,* recycling, biodegradation); 2) lowering the amount of plastics that end up in the natural environment as well as limiting other externalities; and 3) exploring innovative options for renewable sources of plastic.[70] The third part is most relevant to this research and carries the potential economic benefit of reducing business' exposure to the risk associated with fluctuating prices for fossil fuel feedstock. [71]

According to European Bioplastics, demand for bioplastics is growing. In 2019, global production capacity for bioplastics stood at 2.11 million tonnes, but it is anticipated to grow to 2.43 million tonnes by 2024.[72] Bioplastics currently represent approximately one percent of the amount of plastics produced each year (more than 359 million tonnes).[73] Globally, more than half of the bioplastics market (1.14 million tonnes) lay in rigid or flexible packaging in 2019,[74] though data is not available for what proportion of that packaging was used for food.

Compostable food packaging has potential to replace traditional plastic packaging for foods in some circumstances, including outdoor events, where foods will be disposed of along with their packaging; fresh fruit and vegetables (higher water

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[69] Ellen MacArthur Foundation, *The New Plastics Economy,* 12.
[70] Ibid., 24.
[71] Ibid.., 30.
[72] 'Bioplastics market data', European Bioplastics, accessed 7 April 2020.
[73] Ibid.
[74] Ibid.

vapour transmission rates in compostable materials will extend shelf life); long shelf-life products that are not sensitive to moisture; and foods like confectionary contained in lightweight packaging that is often not recycled.[75]

To ensure an environmental benefit, the entire packaging life cycle must be considered, including production and disposal. A 2019 House of Commons report expressed scepticism about the current potential for widespread compostable packaging:

> 'Although industrially compostable plastic packaging is appealing as an alternative to conventional plastics, the general waste management infrastructure to manage it is not yet fit for purpose. In addition, we are concerned that consumers are confused about how to dispose of compostable packaging…. We therefore don't support a general increase in the use of industrially compostable packaging at this stage. It can, however, play a role in closed loop environments….This must be accompanied by robust communication to avoid contamination of recycling'.[76]

In the EU, bio-based plastics currently have a small market share, accounting for between 0.5 and one percent of plastic consumption.[77] They are presently more expensive to produce than conventional plastics but are likely to be more environmentally sustainable, and in that sense possibly less costly.[78]

In the UK in 2014, demand for about 4,000 tonnes of finished bio-based plastics existed, and 75% was imported from Europe.[79] The UK bioplastics industry accounted for about 1,000 jobs and added approximately £50.5 million to the economy, which represented a very small portion of the plastic consumption in the UK (0.2%).[80] Of this demand for bio-plastic products, 500 tonnes can be attributed to food packaging, while an additional 200 tonnes can be attributed to food service supplies, such as cutlery.[81]

The market is predicted to grow. One analysis from the Centre for Economics and Business Research predicts that, with the right legislative and commercial

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[75] E.L. Bradley, *Biobased materials used in food contact applications: an assessment of the migration potential* (York: Food and Environment Research Agency, Food Standards Agency, December 2010), 30, 30.
[76] House of Commons Environment, Food and Rural Affairs Committee, *Plastic food and drink packaging,* 30.
[77] European Commission, *A European Strategy for Plastics in a Circular Economy*, January 2018, 23.
[78] HM Government, *Our Waste, Our Resources,* 126.
[79] NFCC*, Market Perspective: Bio-Based & Biodegradable Plastic in the UK*, April 2018, 15.
[80] Ibid.
[81] Centre for Economics and Business Research, *The future potential economic impacts of a bio-plastics industry in the UK: A report for the Bio-based and Biodegradable Industries Association (BBIA)* (Centre for Economics and Business Research, October 2015), 30.

framework, UK production of bioplastics could increase to 120,000 tonnes, resulting in £1.29 billion of gross value added to the UK economy.[82] Bioplastic food packaging would account for 40,000 tonnes, and bioplastic food service products would account for 20,000 tonnes.[83] The bioplastics industry could make an aggregate employment contribution of 35,447 full-time equivalents (FTEs).[84]

Major brands such as Coca-Cola, PepsiCo, Heinz, and Unilever have adopted some bioplastic packaging types, suggesting mainstream acceptance and market penetration.[85] The bioplastics industry accounted for about 23,000 European jobs in 2013, according to an analysis by EuropaBio, but this number could increase to up to 300,000 European jobs by 2030.[86] Developing bioplastics still requires more research and development costs than conventional plastics, resulting in their costing more, but, as supply chains become more efficient and research advances, bioplastics prices have fallen, and the trend is expected to continue.[87]

The UK packaged food market is large, signifying a high potential for packaging materials to replace plastics. In 2019, sales of packaged food amounted to £63,293,000,000.[88]

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82 Ibid., 6.
83 Ibid., 31.
84 Ibid., 43.
85 European Bioplastics, ‘Frequently Asked Questions on Bioplastics’, February 2020,
86 Ibid.
87 Ibid.
88 ‘Packaged Food in the United Kingdom’, Euromonitor, November 2019.

Safety evidence

Literature scan

The FSA has commissioned multiple studies on BBFCMs which summarise the commonly used materials, associated risks, advantages, and areas for further research and/or policy. The key findings of these reports are summarised below.

Table 3. FSA-commissioned studies on BBFCMs

Author(s)	Title	Year	Methods	Main Findings
Graham Bonwick, Emma Bradley, Iona Lock, Rosario Romero[89]	Bio-Based Materials For Use In Food Contact Applications: Report to the Food Standards Agency (Fera Science)	2019	Literature review (scientific and grey)	‘1. Limited research has been undertaken into the development of [BBFCMs] derived from agri-food by-products, and the associated risks to the consumer. 2. BBFCMs can exhibit barrier properties similar to traditional fossil-based plastics enabling comparable…performance… 3. Information on the presence of inorganic contaminants…and their capacity to transfer…is required. 4. Polypeptide-based materials used for packaging may include substances that are known or suspected allergens or are extracted from matrices that contain allergens. The effects of processing to produce packaging materials may alter allergenicity in unpredictable ways, depending on whether the allergenic epitopes are destroyed or revealed, for example due to conformational changes of the polypeptides. Very limited information is available on the allergenicity of BBFCMs as well as the potential for transfer of allergens to food. 5. Current analytical methods and risk assessment processes for establishing contaminant chemical transfer from fossil-based plastics to food are

[89] Graham Bonwick, Emma Bradley, Iona Lock, Rosario Romer, Bio-Based Materials For Use In Food Contact Applications (Fera Science, June 2019).

				expected to be appropriate for or adaptable to BBFCMs'.
E.L. Bradley[90]	Biobased materials used in food contact applications: an assessment of the migration potential	2010	Lit. review and migration testing of 13 samples of BB materials	'There was little measurable migration from the materials tested. Where migration was observed the simulants defined in the legislation (for plastics) overestimated or provided a good approximation to the migration into foods.' Findings are consistent with those of the 2004 report (see below).
L. Castle[91]	Investigation of the nature and extent of biodegradable polymers used in direct food contact applications	2004	Lit. scan and data analysis	'The methods of test for migration…are likely to be directly applicable to testing most biodegradable polymers. Since the methods of test are supposed to be directly related to the actual conditions of use in contact with food, and mimic these, then if a biodegradable polymer is suitable for a particular application in contact with food then a correctly specified test procedure should be applicable also. One caveat is that tests for overall migration might not be technically possible for humidity-sensitive materials.'

The 2019 Fera literature review focused on prominent 'economically significant' bioplastics: polylactic acid (PLA), polyhydroxyalkanoate (PHA), polyhyrdoxybutyrate (PHB), polybutylene adipate tetrapthalate (PBAT), polybutylene adipate (PBA), polybutylene succinate (PBS), polybutylene succinate adipate (PBSA), and starch.[92] It evaluated the evidence for prominent potential safety hazards, summarised below.

Table 4. Prominent hazards associated with bioplastics[93]

Hazard	Findings

[90] E.L. Bradley, *Biobased materials used in food contact applications.*
[91] L. Castle, *Investigation of the nature and extent of biodegradable polymers used in direct food contact applications* (Food Standards Agency, June 2004).
[92] Graham Bonwick, Emma Bradley, Iona Lock, Rosario Romer. *Bio-Based Materials For Use in Food Contact Applications,* 15.
[93] Ibid.

Contaminant migrant: Heavy metals and trace elements	Heavy metals can be found in biomass depending on the growing environment; bioaccumulative ones (*e.g.* lead) are of greatest concern. Heavy metals have been found to migrate into food, though usually at very low levels. With composite BBFCMs, heavy metal migration has been found with the use of metallic nanoparticles.
Contaminant migrant: Persistent organic pollutants	No data yet on persistent organic pollutants in BBFCMs and migration risk.
Contaminant migrant: Residues	No data yet on pesticide or veterinary medicine migration.
Contaminant migrant: Natural toxins	*E.g.,* mycotoxins from moulds. No data yet.
Contaminant migrant: Process contaminants	*E.g.,* acrylamide or other chemicals occurring as a result of heat or fermentation. No data yet.
Nanomaterials	Some research on certain 'hard' nanomaterials in certain composite BBFCMs, and migration tends to be below current legal limits. Limited data exists on the toxicity of leachables from BBFCMs. Other 'soft', or natural, nanomaterials are used in types of packaging or coatings, and no data was found on the migration of toxicity of those materials, though they are generally assumed to be safe due to their origin in biological materials. Authors recommend every nanocomposite BBFCM be tested for nanoparticle migration, given the risks.
Endocrine active chemicals	*E.g.*, Bisphenol A (BPA). No data on presence or migration.
Genetically modified materials	No studies have yet covered genetically modified materials and their migration from BBFCMs.
Allergens	Few studies of allergens in biomaterials, though some research on their use in medical applications.
Shelf life	Many studies have looked at the addition of antimicrobial packaging films and active and intelligent materials to bio-based food packaging for antimicrobial purposes. Further risk assessments needed for antimicrobial additions to bio-based materials. BBFCMs have not been widely studied for use at a large scale, in unstable or unfriendly storage conditions, and over an extended period of time.

Additional research is needed to evaluate the safety of BBFCMs, though their risks seem well documented.

To further the analysis, an additional literature review was conducted using the ScienceDirect database (see Methods section). The literature review did not produce many new results relative to the 2019 review.

Plastic alternatives have applications, sometimes more established ones, in fields other than food packaging, and medical and industrial applications were commonly discussed. PLA was the most commonly discussed material, with a consensus that it is promising and already in widespread use but has weaknesses, such as brittleness and poor heat stability and water barrier properties. Other novel materials were mentioned, namely rice straw and fish gelatine/chitosan. The articles uncovered through the literature review were more likely to focus on the environmental/circular economy impacts of transitioning to using more bio-based materials, and less consideration was given to food safety and public health, nor was consumer preference a strong focus. Future research should prioritise public health and food safety considerations for novel materials. The literature rarely addressed the risk of allergenic effects from bio-based materials, though one article suggested that, with chitosan, allergens should be minimal. There is a need for further research on environmentally friendly food packaging and its effects on shelf life, particularly when nanotechnology is involved to promote shelf life. The use of nanomaterials in food packaging was mentioned frequently, though often alongside the recognition of a paucity of research on the subject.

Qualitative interviews

In addition to literature review, more than 10 qualitative interviews were conducted with experts at the FSA, in academia, and in testing laboratories. All interviews were conducted over the phone and lasted between 30 minutes and one hour.

A starting interview guide can be found in Appendix A. Synthesised themes are summarised in Table 5.

Table 5. Qualitative interview findings

Theme	Findings
Emerging Materials	• Categories of BB packaging: bioplastics and other BBFCMs (some compostable, made from natural materials such as wheat, chitin, seaweed) • Novel materials: agriculture waste, wheat, chitin, bamboo, seaweed • Increased demand for testing paper materials with a plastic or non-plastic coating • Do not neglect the possibility of reducing or foregoing packaging
Safety	• **Allergens** —More research needed on risk, labelling requirements, specific scenarios (e.g., if a material is meant to come into contact with the mouth for a prolonged period, like a straw)94 • **Agriculture**—Does the environment in which the biological source of a material was grown affect performance? (I.e., what are the safety and performance effects of a hot summer, rainy growing season, contaminants in the soil?) • **Composite materials**—Ensure that certain combinations do not induce potentially risky reactions • **Nanomaterials**—Can add silver nanoparticles or silica clay to bioplastics as colorants or for antimicrobial properties to rival or out-perform traditional plastics, but migration and safety risks need to be carefully evaluated • **Active and Intelligent Materials**—New types of packaging may claim to improve food quality by, e.g., adding antimicrobial chemicals to slow spoilage. Such claims might necessitate reclassifying packaging material as 'active and intelligent', subjecting it to different regulations (not inert by design)
Changing Economic Incentives	• Plastic packaging tax, consumer interest in reducing plastic incentivise using alternate materials[95,96]
Need for Additional Research	• **Life Cycle Analysis—**What are the direct, indirect environmental effects of producing, using, and disposing of BBFCMs? • **Safety and Effectiveness—**Research needed on potential health impacts and fit for purpose

[94] Relatedly, packaging made from certain materials (such as chitosan, found in shellfish) could come into conflict with dietary restrictions (e.g., veganism, Kosher) even when the food they contain does not, prompting a need to consider labelling requirement.
[95] The plastic packaging tax could be determined to apply to bioplastics as well. Source: HM Revenue & Customs, *Plastic Packaging Tax Consultation Document* (HM Revenue & Customs, 2020), 8.
[96] See 'UK Strategy and Policy to Reduce Plastic Waste' for more details on market implications of packaging tax.

	• **Proactivity—**FSA has research capacity to evaluate new products, and proactive research would allow the agency to conduct surveillance and anticipate new products coming to market. It will oversee risk assessment for novel FCMs post-EU exit
Complex Regulatory Environment	• EU regulations do not specify an authorisation or risk assessment process for BBFCMs specifically • Consider instituting a coordinated approach with the EU post-EU exit • Limited existing guidance on testing procedures, technical guidance for tests, for material strength, integrity, and comparisons (e.g., should bioplastics be evaluated against conventional plastics?) and few regulations for certain nanotechnologies • Few labelling requirements, which could risk misleading consumers (e.g., a manufacturer could claim that product is made from bamboo when it is in fact a bamboo-plastic blend), though Regulation 1935/2004 forbids misleading consumers
Complications for Categorisation and Testing	• **BBFCMs and Categorisation—**Edible packaging would subject a material to food additive as well as FCM requirements and might necessitate a packaging ‘use by’ date; composites of bio-based and conventional plastics could be subject to plastic and BBFCM regulations as well as a declaration of composition • **Definitional Clarify**—Are some bio-based materials plastics? Can products be deemed ‘plastic-free’ if they still contain some plastic polymers? • **Testing Processes**—Need to understand FCM effect on shelf life—both how long the product lasts and how long the packaging itself is viable. Some plastic alternatives have seen variable results, such as being more stable at room temperature but not at high temperatures. They most commonly fail on tests for grease and moisture resistance, while their strength, integrity (leak resistance), and oxygen and water transmission rates vary. Packaging from alternative plastics can often go through similar tests to conventional plastics, though they might need to be adapted on a case-by-case basis • **Consistency**—Different batches of the same material might be inconsistent if, *e.g.,* the source material was cultivated in a different environment. Testing for migration is less straightforward because the chemicals contained in a bio-based material are unknown; identifying component parts becomes step one
Need for Coordinated Relationships Between Government, Industry, Academia	• Companies might be reluctant to share the composition of their materials for commercial confidentiality reasons • Some start-ups or university laboratories do not realise the costs to run a material through food contact certification

	tests (tens of thousands of pounds). Partnership between 'modern regulators' (like the FSA) and product developers would help with transparency throughout the research and development (R&D) process and might save manufacturers from unexpected roadblocks • Different government agencies oversee different components of the food system (e.g., Defra oversees waste management, while packaging safety is the FSA's purview). Without a joined-up approach, efforts risk being inefficient, and a well-intentioned action at one part of the food system risks introducing unintended consequences elsewhere
Consumer Issues	• Consumer education needed if increasing prevalence of BBFCMs (e.g., disposal practices to avoid recycling contamination, littering)

Recommendations and analysis

UK government efforts to reduce plastic waste have emphasised increasing industrial and kerbside recycling.[97] But, as the research has shown, food packaging is intertwined with multiple facets of the food system, such as safety, allergies, testing, and consumer preference.

Table 6. Recommendations overview

Recommendation	Summary	Timing
Facilitate a joined-up approach between government agencies involved in a safe UK food supply chain	Convene a multi-agency coalition to oversee BBFCMs and ensure that policies are designed to promote consumer and food safety as well as environmental vitality. Coalition should oversee life cycle analyses to understand multidimensional impacts of using less plastic.	Short-Term (~1-2 years)
Partner and share knowledge between private, public, academic sectors	Facilitate a confidential process by which the FSA can collaborate with start-ups and university laboratories developing innovative FCMs to guide them through the approval process.	Short-Term (~1-2 years)
Develop clear, evidence-based regulations for plastic alternatives	Commission further research on plastic alternatives; institute new regulations for BBFCMs; validate new regulations with stakeholders.	Medium-Term (~2-5 years)
Participate in consumer education	Develop public service announcements for food packaging safety concerns, *e.g.*, appropriate storage conditions, reuse guidelines, signs that packaging is no longer usable.	Medium-Term (~2-5 years)

Recommendation 1. Facilitate a joined-up approach between government agencies overseeing the UK food supply chain

UK food policy is overseen by multiple government agencies, some of which (Defra and BEIS) have already appeared in this report. A recent report mapped government responsibilities for food policy-making in England and found 16 agencies with some food policy authority in 2020.[98] A joined-up, systems-based approach to policymaking promotes policy coherence: 'it requires identifying where there are disconnects or contradictions between policies or issues, and assessing any new policy interventions for their effects on government goals elsewhere, to ensure policies work in the most effective way possible'.[99]

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[97] Houses of Parliament, Parliamentary Office of Science & Technology, 'Plastic food packaging waste'.

[98] Kelly Parsons, *Who makes food policy in England? A map of government actors and activities* (London, Esmee Fairbairn Foundation, City University of London, May 2020), 9.

[99] Ibid., 7.

While the FSA has oversight over FCM safety, other organisations such as Defra oversee policies relating to waste disposal and sustainability. It is possible for policies to be misaligned as a result. For example, policies could be instituted to incentivise the use of compostable materials without considering how using such materials could affect food shelf life. Efforts to improve food policy coherence are important to minimise policies from one agency that could undermine outcomes monitored by another.[100]

It is advisable to convene a multi-agency coalition to oversee BBFCMs and ensure that policies are designed to promote consumer safety as well as environmental vitality. A joined-up approach will also enable more effective life cycle analyses to understand the true impact of moving away from plastic packaging.

An FCM commission should:

- Meet regularly to evaluate new FCMs and consider outreach to organisations involved in development
- Collaborate with frequent partners, such as laboratories, to make sure that it is considering their needs and concerns
- Facilitate sharing best practices, reducing duplicative research and streamlining governmental operations.

A similar or compatible recommendation is possibly already being considered nationally. In the coming months, the National Food Strategy, an ongoing independent review of England's food system, will publish an assessment of the current system and make recommendations, informed by Citizens' Assemblies, to 'transform the food system we have today into something better for the future'.[101] The first of two reports was published in July and covered the pressing recommendations sparked by the COVID-19 pandemic; while packaging is not covered, it could be included in the second report, which will discuss food system transformation.[102]

Recommendation 2. Partner transparently and share knowledge between the public, private, and academic sectors

Some interviewees highlighted the FSA's role as a modern regulator that partners with industry and academia and strives for transparency. Private firms might be working on BBFCMs without an accurate understanding of the requirements they must meet to qualify as FCMs, which could harm innovative and small enterprises.

Below is a possible knowledge sharing pathway.

1. New material identified (through company outreach or ongoing surveillance)

[100] Kelly Parsons and Corinna Hawkes. 'Brief 5: Policy Coherence in Food Systems', in *Rethinking Food Policy: A Fresh Approach to Policy and Practice* (London: Center for Food Policy, 2019), Wellcome Trust.
[101] 'Our Approach & Principles', National Food Strategy, accessed 12 July 2020,
[102] Henry Dimbleby, *The National Food Strategy: Part 1* (The National Food Strategy, July 2020), 11.

2. Initial consultation with FSA to discuss applicable regulations and possible safety concerns
3. Referral to testing facilities
4. Technical assistance with certification application

The consultation process would need to ensure confidentiality of materials in development. Worries about commercial confidentiality came up in the interviews; guaranteeing firms' privacy might encourage participation.

When considering best practices for the modern regulatory relationships, the FSA should consider features of successful public-private partnerships (PPPs). While the relationship described here does not meet the definition of a PPP—the government is not contracting with laboratories to develop new packaging materials—both sectors stand to benefit from collaboration: the FSA can further its goal of supporting innovation safely, and the organisations developing new products can receive more insight into regulatory practices and avoid being surprised by tasks. A 2019 *Harvard Business Review* article laid out some features of successful PPPs that are relevant to this approach, such as strong working relationships, transparent communication, and a sense of 'psychological safety' to share setbacks as well as successes.[103]

Recommendation 3. Develop clear, evidence-based regulations for plastic alternatives

This recommendation contains three parts: commissioning additional research to build an evidence base; enhancing regulations with evidence on bio-based materials; and validating proposed regulations with other regulatory bodies, government agencies, and private sector input.

Commissioning research

Three areas should serve as targets for additional research: 1) safety of BBFCMs, with a focus on the concerns already highlighted; 2) life cycle analyses and feasibility studies to determine production capacity and impact of new materials; and 3) consumer preference studies to understand opinions about BBFCMs.

Adding regulations for bio-based materials

Regulations should include protocols for new materials coming onto the market and could govern migration limits, testing, nanomaterial additives, and guidelines for materials that are difficult to categorise, such as plastic-bioplastic composites and edible packaging.

Validating regulations

New regulations are likely to have impacts throughout the food supply chain, from start-ups designing new types of packaging, to food companies considering switching their packaging supplier, to laboratories testing new materials for safety, to consumers trying to make environmentally-sound choices. New regulations should be products of a joint consultation process with the multiple stakeholders.

Recommendation 4. Participate in consumer education

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[103] Elyse Maltin, 'What Successful Public-Private Partnerships Do', *Harvard Business Review,* 8 January 2019,

Consumers could benefit from guidance on which materials are recyclable vs. compostable and under what conditions. While education on best disposal practices might be better positioned under Defra, the FSA can promote food safety through education on appropriate storage conditions for different types of packaging, signs that the packaging or product is no longer viable, and guidelines for reusing packaging materials.

Consumer education can be impactful. For example, a campaign undertaken in supermarkets in Vancouver, Washington, United States, to promote in-store recycling of plastic film (rather than kerbside, where it contaminates recycling) saw a 125% increase in plastic bag and film recycling.[104] The campaign involved direct communication to consumers through clearly labelled collection bins, flyers, and multiple kinds of signage.[105] An FSA campaign would not cover material disposal methods (Defra's purview), but a similar model could be used for information about proper material storage and signs of spoilage. Alternatively, the FSA could partner with another governmental organisation, such as Defra, to design a campaign targeting both environmental and safety concerns from packaging.

[104] Moore Recycling Associates, *Vancouver (WA) 2015 WRAP Campaign Evaluation Report* (American Chemistry Council, 2016), 2.
[105] Ibid., 3.

Table 6. Feasibility analysis

	Joined-up approach	Public-private partnership	Regulatory reform	Consumer education
(Absolute) Cost	**Low.** Not much required by way of additional resources, simply time and space to develop new collaboration standards and hold coalition meetings.	**Low.** Costs would incorporate outreach and meeting facilitation.	**Depends on implementation.** Need for ongoing research could be satisfied with expanding contracts or building in-house staff.	**Moderate.** A multimedia outreach campaign would help spread the word, though timing would need to be carefully considered, perhaps coinciding with a different campaign.
Political	**Uncertain;** requires more context regarding ongoing relationships and joint efforts between agencies.	**High.** Low cost involved and the focus on building public-private partnerships suggests an efficient and economy-promoting government.	**Variable;** requires further research. Political response would likely depend on the extent of the regulations.	**High.** Aligns with existing recommendations to increase the use of eco-friendly materials and opposition to over-regulation.
Implementation	**High.** Would likely need start-up time to build relationships and establish dynamics for commission communications, but the collaboration should ultimately improve efficiency and reduce duplicative or misaligned efforts.	**High.** The initiative is likely to be well received by stakeholders.	**Moderate.** Some of the regulatory additions are not optional, as the UK has left the EU. Still, developing new rules requires substantial staff time and subsequent approval and enforcement.	**High.** Requires following public awareness campaign best practices, for which precedents exist.

Conclusion

If only one theme has emerged from the research and analysis on alternatives to plastic food packaging, it would be that the subject matter is more complex than common sustainability rhetoric would suggest. The transition away from traditional plastics is accompanied by a host of potential unintended consequences, such as health hazards, allergic reactions, shorter shelf life, and a possibly worse environmental impact. With a unified approach between government agencies and other sectors that prioritises building a safety evidence base for plastic alternatives and educating consumers, the FSA can support a safe transition to secure and sustainable food packaging.

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Appendix A. Qualitative interview guide

This guide was adapted and tailored depending on the interviewee's expertise. In some cases, different questions were substituted entirely.

1. What promising alternative food packaging materials have you been hearing about recently?
2. What are the potential downsides to a shift toward plastic alternatives? What are the market implications (*e.g.,* number of players, types of businesses involved)?
3. Have you heard about any safety upsides to moving to bio-based food packaging materials?
4. What balance should be struck between government and private industry regarding R&D on alternative packaging materials?
5. What infrastructure needs exist in a transition to bio-based packaging materials (*e.g.,* composting facilities, consumer education on waste disposal), and to what extent would the FSA be involved in meeting those needs?
6. What governmental capacity currently exists (*e.g.,* research scope, in-house testing capacity) for evaluating the safety of food packaging materials? Might more be needed?
7. Given the rise in use of new materials coupled with institutional changes such as leaving the EU and setting up new government systems to process and review applications to permit the use of specific products, what impacts might follow for organisational capacity?

Appendix B. Interview list

Name	Title	Organisation	Interview Date
Professor Rick Mumford FRSB MIFST	Deputy Director of Science & Head of Science, Evidence & Research Division	FSA	30 March 2020
Caroline Wood, PhD	Stakeholder Management and Policy Officer	The Science and Technology Facilities Council	1 April
Tim Chandler, MSc	Senior Scientific Officer, Food Contact Materials, Food Additives, Flavourings and Contact Materials Branch, Food Policy Division	FSA	2 April
Alexander Cooper, PhD	Toxicological Risk Assessor, Chemical Risk Assessment Unit	FSA	3 April
Lynneric Potter	Food Packaging Technical Lead	Campden BRI Group	3 April
Ben Goodall, PhD	Science Partnerships Lead	FSA	7 April
Emma Bradley, PhD	Head of Programme – Food Quality and Safety	Fera Science Ltd.	8 April
Olivia Osborne, PhD	Toxicological Risk Assessor, Chemical Risk Assessment, Science Evidence and Research Division	FSA	16 April
Kelly Parsons, PhD	Post-Doctoral Food Policy Researcher	University of Hertfordshire	17 April
Frances Hill	Regulated Products Risk Assessment Team Leader	FSA	21 April

Appendix C. Literature review results

Citation	Article Type	Notes
Farah, Shady, Daniel G. Anderson, and Robert Langer. 'Physical and mechanical properties of PLA, and their functions in widespread applications—A comprehensive review'. *Advanced Drug Delivery Reviews* 107 (2016): 367-392.	Review	PLA Advantages: environmental friendliness (from renewable resources, biodegradable, recyclable, compostable, low production carbon footprint); biocompatibility (nontoxic or carcinogenic); processability; energy efficiency (cost and environmental benefits); low oxygen permeability; resistance to microbial growth (high M_w PLA); many biomedical purposes PLA Disadvantages: brittle; slow breakdown in the body; hydrophobic (concerning in medical contexts); no reactive side-chain groups It is commonly made into food packaging films, which are transparent and accepted by customers. Challenges for non-medical applications include cost and difficulties associated with giving the bio-based polymer the same barrier properties as conventional plastics.
Bilo, Fabjola, Stefano Pandini, Luciana Sartore, Laura E. Depero, Giovanna Gargiulo, Andrea Bonassi, Stafania Federici, and Elza Bontempi. 'A sustainable bioplastic obtained from rice straw'. *Journal of Cleaner Production* 200 (2018): 357-368.	Research	Rice straw: waste product that contains a high content of cellulose, hemicellulose, and lignin. Authors describe a process to make a bioplastic from rice straw that is completely compostable and has properties that make it a promising new source of bioplastic.
De la Caba, Koro, Pedro Guerrero, Trang Si Trung, Malco Cruz-Romero, Joseph P. Kerry, Joachim Fluhr, Marcus Maurer, Froukje Kruijssen, Amaya Albalat, Stuart Bunting, Steve Burt, Dave Little, and Richard Newton. 'From seafood waste to active seafood	Review	Literature review to understand whether packaging from food processing waste is safe and could extend shelf life, with an interest in allergens, the environment, and socioeconomic effects. Food waste sources studied: fish gelatine and chitosan. Chitosan-gelatine films have been found to reduce oxidation and spoilage. More information needed on potential allergenic properties—there should be minimal allergens remaining in

packaging: An emerging opportunity of the circular economy'. ***Journal of Cleaner Production*** **208 (2019): 86-98.**		the packaging, but individuals of differing levels of sensitivity would need to consider the risks. Chitosan films have environmental advantages over other bio-based and non-bio-based polymers by using waste products (rather than relying on other crops), producing fewer toxic effects on incineration, and prolonging shelf life.
Zafar, Rabia, Khalid Mahmood Zia, Shazia Tabasum, Farukh Jabeen, Aqdas Noreen, and Mohammad Zuber. 'Polysaccharide based bionanocomposites, properties and applications: A review'. ***International Journal of Biological Macromolecules*** **92 (2016): 1012-1024.**	Review	Types of polysaccharide-based bio-nanocomposites with food packaging applications: chitosan-based, cellulose based, starch-based. Bio-nanocomposite films have applications for food packaging, conferring both environmental and shelf life benefits.
Moustafa, Hesham, Ahmed M. Youssef, Nabila A. Darwish, Ahmed I. Abpou-Kandil. 'Eco-friendly polymer composites for green packaging: Future vision and challenges'. ***Composites Part B.*** **172 (2019): 16-25.**	Review	Authors envision a future for green and intelligent food packaging, especially composite polymers from lignocellulosic biomass. Nanomaterials and antimicrobial packaging have potential to prolong shelf life. Recommendations for future research: '1) price or cost effectiveness of food package material manufacturing as an issue which needs to be dealt with in advance… 2) eco-friendly additives and agents are recommended for green package material, 3) EU regulations and legislations for food package material must be applied and activated not only in the industrial world, but also in the developing countries to meet high level of food safety and transparency to consumers.' Research on green food packaging, effects on shelf life, storage remains limited.
Jem, K. Jim and Bowen Tan. 'The development and challenges of poly (lactic acid) and poly (glycolic acid)'. ***Advanced Industrial and***	Review	Potential for blends of PLA, PGA in food packaging, though for now they have only been used for medical purposes. PGA: more expensive to produce than PLA; might not be feasible at scale without further innovation. PLA: most

***Engineering Polymer Research.* (2020.)**		promising bio-based plastic for rigid packaging but performs worse relative to conventional thermoplastics in the areas of heat stability and water barrier properties.
Castro-Aguirre, E, F. Iniguez-Franco, H. Samsudin, X. Fang, and R. Auras. ‘Poly(lactic acid)—Mass production, processing, industrial applications, and end of life’. *Advanced Drug Delivery Reviews* 107 (2016): 333-366.	Review	Covers production, processing, and applications of PLA. PLA is Generally Recognised as Safe by the US Food and Drug Administration. Aside from food packaging, it can be used in the medical, textile, and agriculture industries, as well as potentially for environmental remediation. For food packaging, oriented PLA has good heat resistance and clarity relative to non-oriented PLA, but it is brittle and produces noisy packaging. Non-oriented PLA is used for fresh and low shelf life products. PLA is readily mass-produced and can be derived from renewable resources.
Briassoulis, D. and A. Giannoulis. ‘Evaluation of the functionality of bio-based food packaging films’. *Polymer Testing* 69 (2018): 39-51.	Research	Researchers evaluated five compostable packaging films for tensile properties, tear propagation and penetration resistance, seal strength, radiometric properties, water vapour transmittance, and contact angle-wetting tension. ‘Overall, the functionalities of bio-based films were found to be satisfactory. The characteristics of the bio-based food packaging films offer new design possibilities for targeted food packaging applications. Bio-based packaging films allow, for example, for achieving optimised [Equilibrium Modified Atmosphere (EMA)] packaging conditions for fresh produce because of their high [water vapour (WV)] permeability combined with their barrier function to CO_2 and O_2 gases.’
Abdul Khalil, H.P.S., Y. Davoudpour, Chaturbhuj K. Saurah, Md. S. Hossain, A. S Adnan, R. Dunagani, M.T. Paridah, Md. Z. Islam Sarker, and M.R. Nurul Fazita. ‘A review on nanocellulosic fibres as new material for sustainable packaging:	Review	Summarises packaging applications of cellulosic nanofiber and recommends additional research to understand how to make it commercially viable. For food packaging, cellulosic fibres are used in cellophane and other films. Cellulosic fibres can also be used to package liquids. Nanotechnology for packaging is still in early stages of research. Cellulose

Process and applications'. *Renewable and Sustainable Energy Reviews* 64 (2016): 823-836.		nanofibers are abundant and renewable, so they have a lot of potential.
Brodin, Malin, Maria Vallejos, Mihaela Tanase Opedal, Maria Cristina Area, and Gary Chinga-Carrasco. 'Lignocellulosics as sustainable resources for production of bioplastics—A review'. *Journal of Cleaner Production* 162 (2017): 646-664.	Review	'We have considered the production of conventional bioplastics such as PLA, PHA, [bio-polyethylene (BioPE)] and discussed its production in relation to the potential production from forestry biomass. One aspect to consider is the production of novel and dedicated bioplastics instead of focusing on drop-in polymers. Additionally, wood-based platform molecules such as [hydroxymethylfurfural (HMF)] are another example of a platform chemical that can be produced from carbohydrates….However, a viable utilisation of HMF as a platform molecule requires processes to convert cellulose into HMF at good yields….'
Geueke, Birgit, Ksenia Groh, and Jane Muncke. 'Food packaging in the circular economy: Overview of chemical safety aspects for commonly used materials'. *Journal of Cleaner Production* 193 (2018): 491-505.	Review	Reviews recycled food packaging safety. Recycling raises the risk of levels of potentially dangerous chemicals in packaging and in food via migration. Types of materials reviewed are largely out of the scope of this report (*e.g.,* paper/board, aluminium). Bioplastics, some of which are recyclable, are discussed with other plastics. Cross-contamination is a risk with recycling plastic for use in food contact applications: 'it may not only contain degradation products of polymer and additives, but also incidental contaminants arising from previous use and misuse by consumers, cross-contaminations from waste disposal, and environmental contaminants. Furthermore, polymers of the same type, but not of food-grade quality, may also enter the recycling stream and increase the level of possible contaminants.'

Zhao, Xiaoying, Kuihao Ji, Koellng Kurt, Katrina Cornish, and Yael Vodovotz. 'Optimal mechanical properties of biodegradable natural rubber-toughened PHBV bioplastics intended for food packaging applications'. *Food Packaging and Shelf Life* 21 (2019).	Research	Adding natural rubber to a [polyhydroxy-co-3-butyrate-co-3-valerate (PHBV)] bioplastic can improve flexibility and toughness but reduces ability to stand up to pressure. Trays from a certain blend of PHBV and natural rubber performed similarly to polypropylene in terms of vapor permeability and sealability, and they were deemed safe for food contact. The blend is also compostable under industrial conditions, though more slowly than pure PHBV.
Enescu, Daniela, Miguel A. Cerqueira, Pablo Fucinos, and Lorenzo M. Pastrana. 'Recent advances and challenges on applications of nanotechnology in food packaging. A literature review'. *Food and Chemical Toxicology* 137 (2019).	Review	Looks at the use of engineered nanoparticles in food contact. There is a risk of migration from added nanoparticles into food. A number of types of nanoparticles are approved by the European Commission for use in food contact materials, and the authors examine the state of the science for safety for each of these types of substances: nano-silver, nano-clay, titanium nitride, silanated silicon dioxide, titanium oxide, zinc oxide, iron oxide. Examples: Nano-silver: antimicrobial, migration limit. Nano-clay: can make packaging less permeable and generally recognised as safe. Zinc oxide: antimicrobial and absorbs UV light without threatening the container's stability; migration limit established. Article reviews analytical techniques for identifying engineered nanoparticles and migration. Primary concern for nanoparticles is health risks to humans from migration from the packaging into the food. Silver nanoparticles can be toxic, though the findings are mixed on how they affect the system when absorbed orally. The health risks of titanium nanoparticles are unclear; conflicting results. Some materials (such as zinc oxides) are toxic only at certain particle sizes.

Vinod, A, M. R. Sanjay, Siengchin Suchart, Parameswaranpillai Jyotishkumar. 'Renewable and sustainable biobased materials: An assessment on biofibers, biofilms, biopolymers and biocomposites'. *Journal of Cleaner Production* 258 (2020).	Review	Looks at bio-based materials for a range of applications, including food packaging. Biopolymers are biocompatible and biodegradable, but antimicrobial and antifungal additives may be needed for certain applications. They are also permeable to gases, and starch-based polymers can be affected by exposure to water, so adding plasticisers is necessary. High manufacturing costs. Insufficient research to date on antibacterial biofilms (biofilms with additives such as silver to enhance antimicrobial properties). Biofilms are biodegradable and often biocompatible, but they are not as effective for shelf life, and they do not hold up through recycling. Certain biofilms have limited food packaging applications due to not responding well to temperature changes and being permeable to water and oxygen. Some of the drawbacks can be addressed through the addition of plasticisers and nanomaterials, though such additions risk new health hazards.