BBIA Position Paper on Standards for Biodegradable, Compostable and Bio-based Plastics

About the BBIA

The BBIA represents UK and non UK manufacturers, developers and distributors of products, chemicals and materials that have a common identity in their sourcing (partially or totally bio-based which means derived from plant-based, renewable sources) and in their end-of-waste performance (biodegradable or compostable in various environments which could be natural – in the case of bio lubricants, in soil in the case of soil mulch films - or in industrial composting, in the case of packaging).

The BBIA was established by seven founder members in June 2015 and in 2019 comprises 24 companies which produce: biopolymers for onward conversion into products; building blocks for the chemical industry from bio-based sources that may be used in pharma, cosmetics, paints and coatings, as well as lubricants, packaging, pesticides; members also distribute and sell products in the UK market; and include associations, consultants and the Scottish IBIOIC. BBIA members represent most of the value chain in the production, conversion and treatment of compostable packaging materials.

More details about the BBIA can be found on www.bbia.org.uk including reports and research[1] undertaken on compostable packaging, bioplastics, biodegradability and bio-based feedstocks.

BBIA members participate in numerous British Standards Institute groups related to current packaging and waste strategy discussions, notably:

1. Committee MI/002 Bio-based products
2. Committee SDS/003/04 Sustainable Resource Management
3. Committee PKW/000/0-/01 Packaging - Biodegradability
4. Committee PKW/000/0X Packaging

Furthermore, BBIA members are represented on the following non UK standards committees:

At international level:

5. ISO TC 61 "Plastics"

At European level:

6. CEN TC 261 "Packaging"
7. CEN TC 249 "Plastics"
8. CEN TC 411 "bio-based products"

We therefore believe that BBIA through its direct participation and through its members, is well qualified to respond to the questions raised in this call for evidence.

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[1] BBIA is also a partner in 2 EU financed research projects: under the Horizon 2020 grant for the Res Urbis project which researches into producing compostable materials using food waste as a feedstock, ending in December 2019; and in the BBI JU funding grant for Usable Packaging, a research project that began in June 2019 lasting for three years researching into producing compostable materials from industrial food waste such as from bakeries, wineries, pasta producers.

It is of primary importance to BBIA members that internationally recognised standards for biodegradable, compostable and bio-based plastics are applied in the UK and that UK government and organisations take a leading role in developing and promoting such standards. The enforcement of such standards through legislation and through legal recourse (the Courts, the Advertising Standards Authority) is essential to ensure that there is certainty about the claims producers make for their products and materials.

False claims for products and materials damage reputable producers, create uncertainty among consumers, and complicate end-of-life solutions. For example, a plastic bag labelled "biodegradable" but not certified to any recognised standard will not biodegrade in a known and identifiable time frame or a known and identifiable place, nullifying its claim and creating confusion for the whole supply chain, from consumer to waste management.

Biodegradable soil mulch used in agriculture can be labelled as such but only if it adheres to the internationally recognised testing standard, in this case BSI EN 17033. If a producer uses the terminology "biodegradable" for soil mulch that is not tested to such a standard, it creates an un-level playing field. As well as harming the reputation of certified producers and damaging their market, it also potentially damages the soil in which these plastics will accumulate.

We hope that the recent consultation will lead to greater enforcement and elimination of false claims in the bio-based and biodegradable industries sectors; it is the hope of the BBIA that recent consultations are a first step to ensuring a market in which only verified and certified materials and products are lawfully commercialised.

A recent example from the USA (where consumer protection on these false claims has long been established) shows the way: Amazon was fined $1.5 million for incorrectly claiming compostability and biodegradability of products they sold[2].

We would add the need for the UK to adhere to standards applied in a wider number of markets. This is due to the nature of the industry producing, developing, supplying and using materials which can be classified "compostable" or "biodegradable". As suppliers, traders, converters, packers and retailers are operating across borders, it is essential the standards used in the UK apply to and are accepted in wider markets. For this reason we believe that the process for revising standards must necessarily pass through the BSI-CEN system to ensure compliance with the EU, a market to and from which 40%+ of our trade derives. BSI has confirmed it will remain within the CEN system post-Brexit. [3]

Finally, BBIA has responded to the May 2019 Consultations on Resources and Waste Management launched by DEFRA and our positions on those consultations can be read as supporting evidence for the responses given to the most recent call for evidence for compostable, biodegradable and bio-based plastics.[4]

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[2] https://resource-recycling.com/plastics/2018/08/15/amazon-settles-biodegradable-claims-case/

[3] https://www.bsigroup.com/en-GB/about-bsi/uk-national-standards-body/standards-policy-on-the-uk-leaving-the-eu/Archive/

[4] https://bbia.org.uk/reports/ See: BBIA Position Paper on the Resources and Waste Strategy

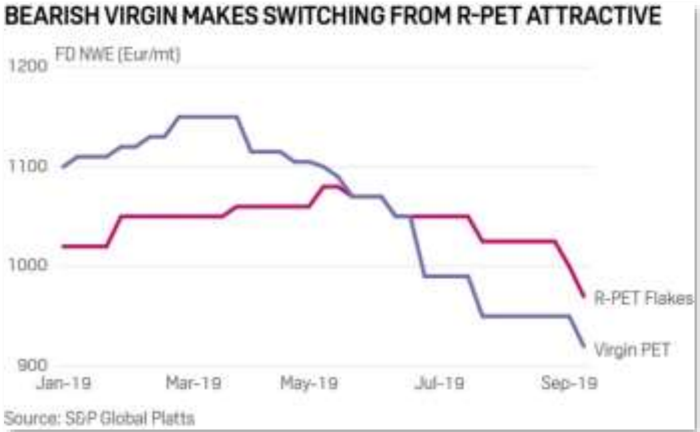
1. The role of bio-based plastics in eliminating all avoidable plastics and moving towards a circular economy. How the circularity of these materials are reflected or measured and the evidence in support of our view

Renewable energy, electric vehicles, bio-fuels; the global economy has begun taking steps towards a low carbon future. Over the last decades, outlines of global transition pathways have emerged in the buildings, power and transport sectors. These have been driven by legislation, technological breakthroughs and cost reduction. However, for industrial processes, such pathways are less well-defined. McKinsey & Company have called the decarbonization[5] of industrial sectors "the next frontier"[6].

Globally, recent demand for plastics has outpaced all other bulk materials (such as steel, aluminium or cement), nearly doubling since the start of the millennium. The United States, Europe, and other advanced economies currently use up to 20 times as much plastic as India, Indonesia, and other developing economies on a per capita basis, underscoring the huge potential for further worldwide growth and risk in environmental damage.

The petrochemical feedstocks that underpin this growth are rapidly becoming the largest driver of global oil consumption. They are set to account for more than a third of the growth in oil demand to 2030, and nearly half to 2050, ahead of lorry freight, aviation and shipping[7]. Assuming this trend continues; the greenhouse gas emissions from plastics will reach 15% of the global carbon budget by 2050[8], up from ~5% in 2017.

Whilst emissions from plastics are destined to rise, so conversely will the costs fall (assuming fossil fuel prices remain stable) as increasing scale and volumes will lead to prices falling for virgin plastics with evident repercussions upon recycling markets for used plastics and for materials competing in certain sectors with plastics.[9] Increased collection for recycling of plastics will also lead to falling values of the recycled material as these volumes will struggle to find markets. [10]



The scientific and policy development of strategies that can, on a global scale, mitigate the life-cycle GHG emissions of plastics are in their infancy. It is clear that a multi-factorial

[5] By decarbonisation we intend the substitution of fossil carbon with renewable carbon from biomass
[6] Mckinsey&Company (2018): Decarbonization of industrial sectors: the next frontier
[7] IEA (2018): The Future of Petrochemicals Towards more sustainable plastics and fertilisers
[8] Ellen MacArthur Foundation, McKinsey & Company (2016) World Economic Forum: The New Plastics Economy—Rethinking the Future of Plastics
[9] https://blogs.platts.com/2019/10/09/europe-plastic-recycling-consumer-demand/
[10] https://www.boell.de/sites/default/files/2019-11/Plastic%20Atlas%202019.pdf?dimension1=ds_plastic_atlas

approach will be required, given the integration of plastics into global economies. The most compelling recent work on this using a dataset covering ten conventional plastics and five bio-based plastics and their life-cycle GHG emissions under various mitigation strategies concludes that aggressive application of demand-management strategies, renewable energy, recycling and (importantly in the context of this consultation) the use of biogenic feedstocks as well as Co2 itself is required to ensure an absolute reduction from current levels by 2050[11].

On the 27th of June 2019, The UK passed into law a target for zero net carbon emissions by 2050, the first major economy to do so. This target shows Britain's ambition to be a global leader in the area of reducing CO_2 emissions and climate change abatement. To achieve this will require the switch from fossil to renewable carbon sources across the entire UK economy. In some areas the approach is becoming clear, but in terms of materials and specifically plastics there is much work to do; delivery will require decarbonisation[12] of feedstocks, production processes and a transition from a linear to a circular economy.

Considering the policy interests and the wider environmental landscape of the consultation in this context:

Clean Growth, including growing the bioeconomy *– the plastic sector is important for the UK with 2015 data demonstrating that the plastics industry supported 6,200 companies, employing 170,000 people, turning over £23.5 billion and generating £7.5 billion in exports[1]. In this sector, the UK produced 0.5% of the world's plastic by weight but 6.7% by value, underlining its importance to our economy[1]. By virtue of this activity, there is a UK bio-economy growth opportunity in ensuring that UK plastics industry transitions to a low carbon future and, arguably, a more significant export opportunity in ensuring that the bio-based plastic technologies of the future are first developed and then scaled-up in the UK. The UK Governments bioeconomy strategy[1] identifies the importance of producing smarter, cheaper materials such as bio-based plastics as part of a low-carbon economy. The UK has a small foot-print of bio-based plastics businesses but recent demonstration and commercialisation of such technology at larger scale has occurred overseas [e.g. bio-polyethylene by Braskem(Brasil), PLA by Natureworks (USA) and Corbion (Thailand), PBAT by Novamont (Italy) and BASF(Germany), PBS by PTT(Thailand)], NESTE & LyondelBasell in Germany making PP and PE from used cooking oil and animal fats (via Bio-Naphtha).*

Such investment is illustrative of the potential for global growth in this sector. The challenge is the alignment of regulatory, innovation and commercial drivers to ensure that the UK has a dominant role in this emerging space.

Two reports available on the BBIA website underline the potential for the use of bio-based and compostable plastics in the UK economy. [13,14] They measure the potential for new products as well as substitution of plastic packaging with bio-based and compostable materials, as well as the potential for the creation of new jobs and GVA for the UK economy. CEBR's report from 2015 states that the potential for the UK from such new materials is 30,000+ new jobs and; "*Cebr predicts that the gross output impacts of the bio-plastics sector will amount to £4.2 billion. From this, approximately 35,000 jobs are expected to be supported, and roughly £1.92 billion of gross value added is predicted to be contributed to*

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[11] Nature Climate Change, Zheng and Suh: Strategies to reduce the global carbon footprint of plastics

[12] see footnote 5

[13] https://bbia.org.uk/reports/ See: Plastics in the Bioeconomy report published in 2019 by Ricardo E&E

[14] https://bbia.org.uk/reports/ See: The future potential economic impacts of a bio-plastics industry in the UK, published in 2015 by CEBR

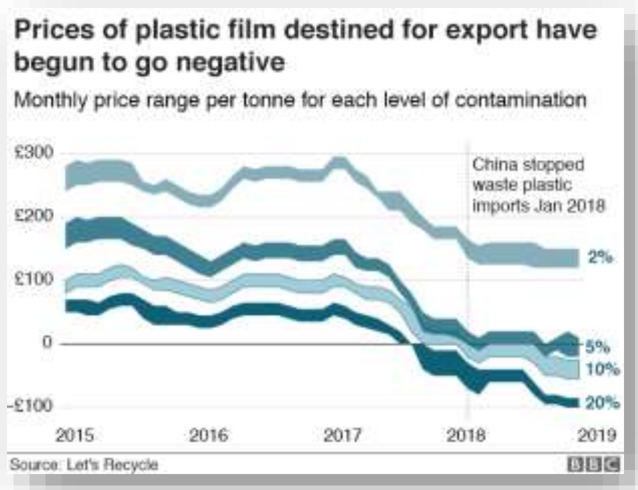
the UK economy. Further, we estimate that the bio-plastics sector will pay around £1.01 billion in gross employment compensation". [15] Both reports concur (at four years from one to the other) that the potential market for bio-based and compostable packaging in the UK is around 130,000 tons by 2025.

Circular economy – new bio-based materials that enter the marketplace can be engineered to be biodegradable or they can be made to function exactly like conventional fossil-based plastic (i.e. to have the same durability). Where biodegradation/compostability is designed into the materials, they can be organically recycled through AD/composting in specific conditions and the (often biogenic) carbon returned to the atmosphere or soil. In the case of the bio-based facsimiles of existing fossil-based plastics (e.g. bio-polyethylene), they have the same potential to be mechanically or chemically recycled as the materials they substitute. Estimations of global plastic waste that is currently reused or recycled vary from 9%[16,17] to 18%[18]. Recent McKinsey and Company work on circularity has considered global scenarios of a "high" adoption model of both existing and novel mechanical/chemical recycling technologies reaching 50% rates by 2030 and 60% by 2050 but, despite these aggressive changes, still concludes that underlying global virgin plastics production will grow from the current 370mtpa to ~450mtpa[19] in the period. At the same time global plastic recycling values are falling as Far East markets close to imports of OECD countries waste and due to falling costs of virgin plastics.

This underlines the hypothesis that materials derived from non-fossilised living organisms are required, in addition to recycling, if the global plastics resource flows are to be made circular.

For completeness, it is worth noting that there is a third class of materials that are novel, bio-based but not facsimiles of fossil-based plastics (e.g. PEF as a replacement to PET).

Figure 1, Trends in Export Prices for UK Plastic Film Waste



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[15] ibid

[16] https://www.nationalgeographic.com/news/2017/07/plastic-produced-recycling-waste-ocean-trash-debris-environment/

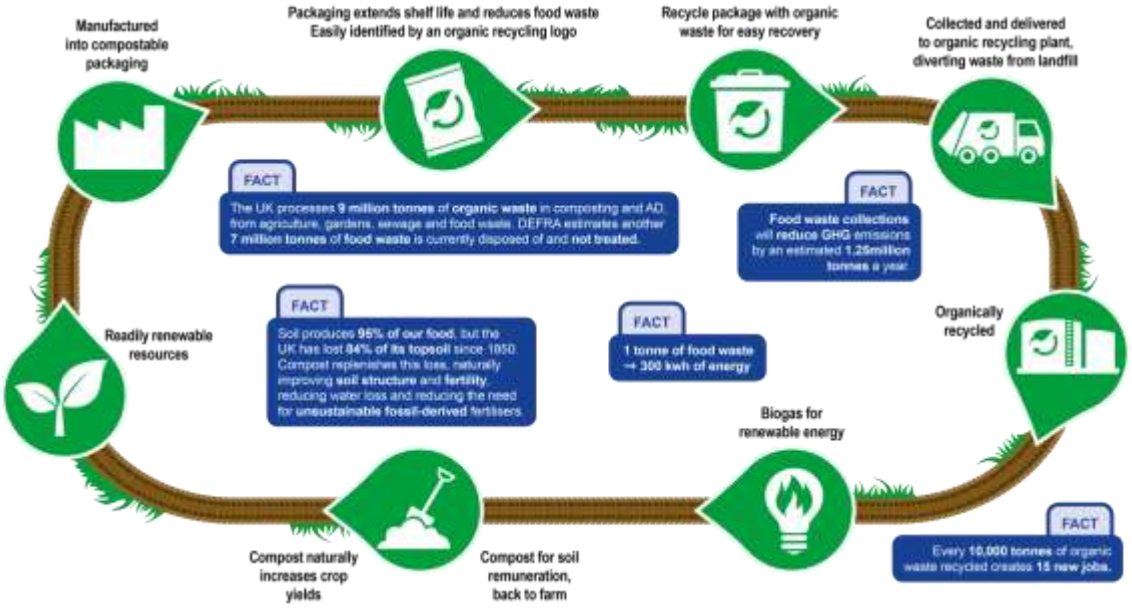
[17] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data

[18] www.oecd.org/environment/waste/policy-highlights-improving-plastics-management.pdf+&cd=13&hl=en&ct=clnk&gl=jo&client=firefox-b-d

[19] Mckinsey&Company (2018): How plastics waste recycling could transform the chemical industry

Here, some mixed approached to circularity maybe required; for example by allowing small and understood, percentages of these materials into existing recycling steams until critical mass for dedicated recycling is reached[20].

Representation of BBIA vision for a circular economy



Environmental protection - bio-based plastics have a role in environmental protection in that the production of their underlying inputs change from an extractive model of oil and gas, often implicated in environmental damage on land and sea in their extraction and transportation, to a renewable model of using materials derived from non-fossilised living organisms. In the case of bio-based facsimiles of current plastics the consequences of deliberate or unintended release to both terrestrial and marine environment has the same impact as fossil-based plastics. In the case where bio-based and biodegradable properties are combined in individual materials (already exemplified by a number of commercial polymers such as PHAs[21], cellulose acetates and PBAT) such materials will degrade biologically in many environments[22]. It is to be noted that where such materials are biodegradable the embedded carbon turns to CO2 or microbial biomass and not persistent microplastics (exemplified by research work on biodegradation of PBAT in soil conditions[23]). Research published in 2019 by the University of Plymouth confirmed these findings, showing that certified compostable carrier bags degraded completely in marine and open environments in less than three months and disintegrated after being buried in soil. Conversely, those marked "biodegradable" or "oxo degradable" resisted biodegradation in both the soil and marine environments after three years. [24] Accordingly, the research confirms the need for a certification of a material's biodegradability in a specific environment,

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[20] Waste Management World: EPBP Approval for Synvina's PEF Plastic Packaging Material as Recyclable in Existing Systems

[21] Global production of PHA is still very small, circa 5000 tonnes.

[22] https://pubs.acs.org › doi › 10.1021 › acs.est.8b02963

[23] Zumstein et al (2018): Biodegradation of synthetic polymers in soils: Tracking carbon into CO2 and microbial biomass

[24] https://www.plymouth.ac.uk/news/biodegradable-bags-can-hold-a-full-load-of-shopping-three-years-after-being-discarded-in-the-environment

before claims related to biodegradability may be made. Furthermore, the study illustrates the need to follow existing test methods for assessing biodegradation of plastics in soil, such as ISO 17556 and ASTM D 5988 in order to gain results that can be replicated by other researchers[25].

Citizen clarity – the BBIA recognises that there is demand from citizens for bio-based materials often on the perceived basis that "bio" may be better without apparent quantification at point of use. There are standards for bio-based content of products (e.g. European Standard EN 16785-1 and ASTM D6866 – 18) where analysis is determined by carbon-14 radioactive analysis. Such standards underpin some independent assessment and certification services; for example, the TÜV Austria OK bio-based certification which licences the use of "on-pack" certification marks that include a star rating (e.g. certified bio-based content of 60% to 80% is awarded 4 stars[26]).

BBIA is aware of the need to reform all packaging labelling including making bio-based and compostable packaging more easily identifiable to consumers and the waste management stream.

Standards for bio-based products covering horizontal aspects were developed by CEN TC 411 "bio-based products". CEN TC 411 developed consistent terminology, sampling, certification tools, bio-based content, application of and correlation towards life cycle analysis, sustainability criteria for biomass used, and communication: **Published European standards**.[27]

With regard to measuring circularity of materials we are not aware of metrics that have seen widespread adoption for either conventional plastics or bio-based plastics. The Ellen MacArthur Foundation has undertaken work to develop tools and methodologies to assess both product and company performance in the circular economy. Inputs cover where raw materials are virgin or recycled, how long the material is used for, destination after use and efficiency of recycling. The development and use of such circularity indicators are in their infancy[28].

2. Quantitative evidence on the environmental impacts (particularly greenhouse gas) of producing bio-based plastics and managing them at end of life, compared to conventional fossil-based plastics

(End of life of bioplastics is covered in the waste management section.)

For all the angst about the role of global air travel in global carbon emissions, at 2%[29] of the global releases they are less than half of global emissions from plastics at ~5% which are measured at 850 million tons in 2019[30].

[25] Zumstein, M. T., Narayan, R., Kohler, H. P. E., McNeill, K., & Sander, M. (2019). Dos and do nots when assessing the biodegradation of plastics.

[26] TUV Austria: http://www.tuv-at.be/ok-compost/certifications/ok-bio-based/

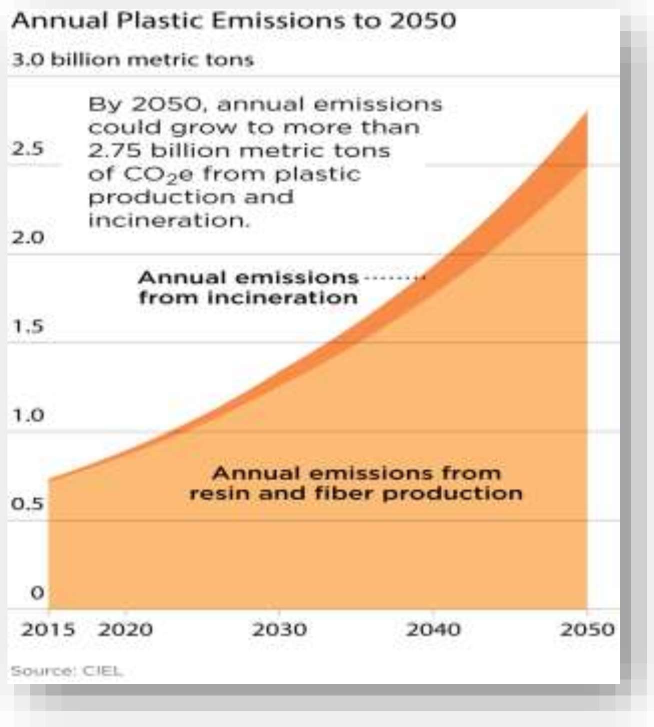
[27] https://standards.cen.eu/dyn/www/f?p=204:32:0::::FSP_ORG_ID,FSP_LANG_ID:874780,25&cs=1D63BAA7EABE56EB230DDAA05D6F2CE70

[28] EMF: https://www.ellenmacarthurfoundation.org/resources/apply/circularity-indicators

[29] Aviation IEA, Lee (2019), Flemming and Ziegler (2016)

[30] https://www.ciel.org/plasticandclimate/

Figure 2. Annual Estimated Plastic GHG Emissions through to 2050 given by CIEL[31]



BBIA contend that the mitigation of GHG emissions from the production and management of plastics after they are discarded is essential alongside the prevention of environmental damage from accidental release and that bio-based plastics have a significant role to play.

In 2016 work by the Ellen MacArthur Foundation, and McKinsey & Company in the *The New Plastics Economy: Rethinking the future of plastics* a world was envisaged with much higher recycling rates and where the remaining requirement for virgin feedstocks is supplied by renewable resources. Whilst this work appeared somewhat aspirational, encouragingly, quantitative scientific analysis on how the role of bio-based plastics might enable trajectories to a low carbon economy is now beginning to emerge. Work by Spierling et al. (2018)[32] reviewed 29 different academic papers to analyse the cradle-to-gate life cycle analysis of 10 different bio-based plastics (including durable and biodegradable materials). This concluded:

Bio-based plastics generally show lower life-cycle GHG emissions than their fossil-fuel based counterparts. The paper went further to estimate that substituting 66% of the world's conventional plastics with bio-based plastics would avoid 241–316 MtCO₂-equivalent (CO₂e) yr–1, approximately 20% of global GHG emissions associated the lifecycle of plastics.

More recently in *Strategies to reduce the global footprint of plastics*[33], for the first time in a published paper that BBIA has reviewed, the impact on GHG emissions from the whole 380

[31] idem

[32] Spierling et al. (2018): Bio-based plastics - A review of environmental, social and economic impact assessments

[33] J Zheng and S Suh (2019): Nature Climate Change - Strategies to reduce the global carbon footprint of plastics

million tonne global plastics supply chain has been modelled in a comprehensive manner. Based on a data set of ten fossil-fuel based and five bio-based plastics the authors have considered future roadmaps for:

- the initial manufacture of plastic polymers from petrochemicals and bio-based inputs
- the energy consumed in the conversion of such polymer to products
- the benefits and dis-benefits in energy and CO_2 release of various end-of-life disposal routes encompassing landfill, recycling, composting and incineration.

Scenarios are considered that envisage decarbonisation of electricity grids to reach 100% by 2050, significant changes in recycling rates, a reduction in the global rate of plastic growth from 4% to 2% and a gradual substitution of fossil-derived plastics by bio-based plastics.

The results of this work indicate that if the much needed absolute reduction in life-cycle GHG emissions of plastics by 2050 is to be achieved, it requires not just one action but rather a combination of all in concert including demand management, the decarbonization of energy infrastructure, vast improvement of recycling capability (including both mechanical and chemical recycling) and, importantly, large-scale adoption of bio-based plastics.

More data describing individual bio-based polymers is now in the public domain. One notable example is available on bio-based high-density polyethylene (HDPE) by UK firms E4tech and LCAworks and is commercially marketed by Braskem[34]. This assessment encompasses two product systems: HDPE from renewable agricultural resources (Brazilian sugarcane derived ethanol) and HDPE from fossil resources (Naptha) and is conducted on a cradle-to-gate basis (the finished polymers are identical in performance). The assessment includes both the production of High Density Polyethylene (HDPE) and co-produced electricity so as to avoid allocation between these co-products as recommended by ISO 14044. The net conclusion is that each kilogram of bio-based HDPE produced absorbs ~3kg of CO_2e of emissions whilst Naptha -based HDPE production is assessed to release ~2.2kg of CO_2e. Three quarters of the bio-based benefit comes from CO_2 uptake in the growing of sugarcane and one quarter from the bio-based power provided from bagasse burning. Clearly, there will be subsequent emissions from transport, product manufacture and end-of-life disposal but these will be identical to fossil-based materials. This initial sequestration of CO_2 provides a useful insight to the positive role that bio-based plastics might play in the future bio-economy.

Specific PLA manufacturers have published LCAs such as Corbion[35], and NatureWorks[36], showing lower carbon impacts than conventional oil-based plastics. Corbion has also published a White Paper[37] entitled *'Sustainable sourcing of feedstocks for bioplastics'* which highlights feedstock efficiency: '*PLA is one of the most efficient biopolymers: yielding 1kg of PLA polymer for 1.6 kg of fermentable sugar feedstock*'.

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[34] http://plasticoverde.braskem.com.br/Portal/Principal/Arquivos/ModuloHTML/Documentos/1191/Life-Cycle-Assessment-v02.pdf

[35] https://www.corbion.com/about-corbion/sustainability/life-cycle-assessment and https://www.total-corbion.com/downloads/

[36] https://www.natureworksllc.com/What-is-Ingeo/Why-it-Matters

[37] https://www.total-corbion.com/media/1082/170822_totalcorbionpla_whitepaper_12-web.pdf

Whilst still under development, another interesting bio-based plastic is polyethylenefuranoate (PEF), being developed by a number of parties as a potential drop-in replacement for PET (used in fibres and bottles). Even though the emergent PEF production process from fructose is still under development, academic modelling[38] of GHG emission results demonstrate the process is likely to offer reductions between 46% to 54% vs oil-derived PET.

The authors further postulate that based on the global PET bottle market, complete substitution of PET by PEF would result in savings of up to 35 Mt of CO_2e. To put these absolute savings in perspective, they can be compared to the annual GHG emissions of Denmark[39] (entire country covering emissions from all sectors of the economy).

Turning to a UK specific example; Ricardo Energy and Environment[40] conducted a comparison of fossil-based low density polyethylene (LDPE) versus bio-based (and biodegradable) polylactic acid (PLA), based on the latter being (theoretically) manufactured in the UK from local biogenic waste inputs, and encompassed a cradle-to-grave review considering recycling and composting. This study uses the IPCC 2013 GWP method, developed by the Intergovernmental Panel on Climate Change. The modelling highlighted the significant dependence on grid decarbonisation (Scottish renewable grid versus UK mixed grid making a significant difference). The report concluded that even when 90% LDPE plastic films are segregated from general waste and recycled (a near impossible ambition given only trace quantities of plastic films are currently recycled in the UK); PLA using the Scottish grid mix is preferable to LDPE in GHG emissions terms. Indeed, based on the current end of life assumptions it is not possible for LDPE to outperform PLA using the Scottish electricity grid mix. To put this into context, the analysis suggests that per tonne of LDPE produced, ~1.5 tonnes would need to be recycled before LDPE has a lower carbon footprint to PLA produced using a Scottish grid mix.

The examples cited above provide supportive evidence that there is good reason to believe that bio-based plastics have a role in the decarbonisation of the global plastic economy. Whilst there is more to understand about the GHG emissions of bio-based plastics for both their biogenic inputs and production processes, it seems difficult to believe that the continued reliance on fossil-based carbon, much of which will inevitably be released to atmosphere despite improved recycling rates, is a model on which humanity can rest.

[38] A. J. J. E. Eerhart et al (2012) Replacing fossil based PET with bio-based PEF; process analysis, energy and GHG balance https://www.researchgate.net/profile/AJJE_Eerhart/publication/241881454_Replacing_fossil_based_PET_with_bio-based_PEF_Process_analysis_energy_and_GHG_balance/links/0f317533bf413ba144000000.pdf

[39] https://www.statista.com/statistics/449517/co2-emissions-denmark/

[40] Ricardo Energy and Environment (2019): Plastics in the Bioeconomy https://d1v9sz08rbysvx.cloudfront.net/ee/media/downloads/ed12430-bb-net-report-final-issue-2.pdf

3. If an accurate comparison between the environmental impacts of bio-based and conventional fossil-based plastics cannot be made, what barriers exist to making this comparison and what knowledge gaps need to be addressed to enable it.

Notwithstanding the evidence presented in chapter 2 above, which supports the case for bio-based plastics in the route to material decarbonisation, there are a number of barriers to the comparison between the environmental impacts of bio-based and conventional fossil-based plastics.

We refer to the report commissioned by BBIA from the Bangor University Biocomposite Centre, titled: *Factors Affecting the Life Cycle Assessment of Biopolymers* (see appendix)

In principle, there are published standards for life cycle assessments (LCA) that provide guidance on how to compare different polymers fairly with regard to their environmental impacts. However, the rules still leave sufficient room for manoeuvre to specify the methods by which such comparisons are to be carried out in LCA1[41]. Moreover, there are rather fundamental problems that make a fair comparison difficult, and which can only be solved with difficulty and incompletely, both methodologically and technically.

Let's consider a few of these fundamental matters in turn (drawing on work by the Nova Institute[42]):

Scale - new bio-based polymers that are produced today are usually produced in much smaller plants (typically ~50ktpa) than petrochemical polymers (typically >500ktpa). The bio-based process chains and system integrations are far from being at the elaborated level of petro-chemistry.

Process development – the bio-based polymer industry is in its infancy with small commercial scale facilities only emerging in the last 10 years. In comparison, manufacture of fossil-based plastics has enjoyed some 60 years of process development and operation to bring them to current standards of operating efficiency. Whereas the environmental impact of oil production will increase by 2050 because larger proportions of shale gas and oil sands will be in the petrochemical mix, the environmental impact of biomass production, on the other hand, will be significantly reduced by 2050: digital and precision farming as well as bio-stimulation will reduce fertiliser use and minimise the use of pesticides as well as increase yields (for local context, in the UK the NFU now has a net zero target for agricultural GHG emissions by 2040[43]).

Raw materials – whilst individual biomass inputs are suitably investigated and required to provide detailed analysis of both direct and indirect impacts (such as land-use change or impact on biodiversity), when it comes to crude oil there are large gaps in transparency

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[41] "Although there are published standards for LCAs (ISO 14040/44, and the International Reference Life Cycle Data System (ILCD) handbook), these do not give fixed rules for calculating GHG reductions: much is left to users to select what they consider the most appropriate method in particular cases. The results often depend strongly on these choices. This is why the LCA guidelines do not offer a consistent or unambiguous way of determining carbon intensities by economic operators or by national authorities." https://ec.europa.eu/clima/sites/clima/files/transport/fuel/docs/novel_transport_fuels_default_values_en.pdf

[42] Nova Institute open letter to JRC (2019): How can the environmental effects of bio-based polymers be compared with those of petrochemical polymers on equal footing?

[43] https://www.nfuonline.com/news/latest-news/nfu-reiterates-its-net-zero-aims-for-agriculture/

when it comes to analysing all the effects (such as the land/water footprint of crude-oil production, impact on terrestrial and marine diversity, transport accidents). Whilst there are detailed sustainability certifications for biomass, for petroleum there are no certifications to differentiate the impact of the oil industry and to prefer specific origins.

Geographic/age selection - The default values used for petrochemical polymers in LCA modelling favour more modern installations than older ones (simply because operators do not provide data for the latter), so that the values used are not averages that fairly reflect the whole spectrum of petrochemical polymer manufacturing installations. Also, the data covers only the environmental footprint of European manufacturing sides – the majority of polymers used in European industry are produced outside Europe.[44] Additional data sources including country specific data should, therefore, also be taken into account.

Storage - storage of biogenic carbon is generally not taken into account in life cycle assessment, (although new dynamic models exist to integrate storage into an LCA), all emissions are considered to happen at the same point in time. As our time-horizon to mitigate carbon emissions shortens, the impact of storing carbon derived biogenically from the atmosphere in the goods that we use will be important.

Decarbonisation of electricity grids - By 2050, electricity production in the UK and many other countries will be mainly from renewable energy and therefore, much cleaner than today with a very low carbon footprint. This alone has a considerable influence on life cycle assessments of facilities that may be built now to last another 20-30 years. Fossil derived plastics are high in calorific value for electricity production through Waste to Energy plants and in many countries incentives exist for them to be burnt in preference to virgin fuels. From a GHG perspective there is no difference and with a decarbonised grid no such incentives can remain by 2050. Alternatively, burning sustainably sourced bio-based polymers, whilst not optimal (e.g. the compostable ones would better have been composted than combusted), is akin to a bio-mass power station.[45]

The average lifespan of an ethylene facility (feedstock for polyethylene) in Europe/North America is 30 years[46]. By way of illustration, ExxonMobil has recently commissioned a new 650ktpa polyethylene expansion in Texas[47] taking the site production to more than 1.7mtpa (in context, the amount of plastic packaging consumed in the UK is circa 2.7 million tons p.a.)[48] One might expect this asset to have a similar life to previous facilities and still be producing from shale-gas derived feedstock up until 2050.

The broader point here is that there are decisions being made right now in the global plastics market that will impact the next three decades of emissions. It is not enough just to be evaluating emerging bio-based technologies in the context of now, but rather in how they can play a meaningful role in changing this trajectory.

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[44] https://www.euractiv.com/section/energy-environment/news/while-global-plastic-production-is-increasing-worldwide-it-is-slowin-down-in-europe/

[45] See below Question 27

[46] John Pearson (2010): Comparing petrochemical plant ageing https://www.chemengonline.com/comparing-petrochemical-plant-aging/?printmode=1

[47] https://www.nsenergybusiness.com/news/exxonmobil-beaumont-polyethylene/

[48] http://www.wrap.org.uk/sites/files/wrap/PlasFlow%202017%20Report.pdf.

In conclusion, we believe that the tools academics, industry and policymakers are using to evaluate the opportunities and risks in the large-scale deployment are rooted in models of the "now" with varying levels of information and transparency. What is also required is the development of plausible future scenarios with which a quasi-standardised life cycle assessment for the year 2050 can be conducted in addition to today's situation. A comparison between bio- and petro-based polymers and their impact on GHG emission through the next 30 years can then be made on an informed basis.

4. Bio-based plastics currently make up a relatively small proportion of the market, representing around £50m GVA. What are the potential barriers preventing innovative bio-based products from succeeding in the marketplace?

The bio-based plastics industry is a small but growing section of the plastics industry. Estimates for 2019 suggest bio-based plastics represented around one percent of plastic produced annually in the world[49]. Demand is rising and with more sophisticated bio-based polymers, applications, and products emerging. However, there are currently limited comprehensive policy frameworks in place to support bio-based plastics (such as mandatory targets, tax incentives, etc.), and, as a result, these products are hindered by low investment security on the global stage.

Below we consider various barriers limiting the success of bio-based plastics in the marketplace both globally and in the UK:

Cost

The challenge for bio-based plastics lies throughout their fast-emerging supply chains:

I. The non-fossilised, living-organism derived materials currently in use are typically first generation crop inputs and provide starting points for cost far higher than the crude-oil comparative materials. Whilst there is much research work being undertaken on second generation materials, including non-edible by-product of food production, such as wheat straw, the technologies for use of these materials remain prohibitively expensive.[50] It's worth considering the parallel to biofuels here, where despite significant research efforts and legislative incentives on fuels, worldwide there are currently only 6 major plants[51] producing second generation biofuels (ethanol). Locally, the UK has had two second generation ethanol plants at demonstrator scale, neither of which is currently operational[52].

II. The manufacture of bio-based building block chemicals (monomers) is then conducted at limited scale (typically <50kt), often in fermentation type processes that

[49] https://www.european-bioplastics.org/market/.
[50] See for example www.resurbis.eu and www.usable-packaging.eu research projects using waste as feedstocks
[51] Journal of Cleaner Production (2018): Business models for commercial scale second-generation bioethanol production
[52] Q Nguyen et al (2017): Global production of second generation biofuels

are less intensive than their petro-based competitors.[53] Globally, a number of these processes emerged following the 2004 US Department of Energy study on "Top Value Added Chemicals from Biomass"[54] as this was seminal in attracting interest to the sector and steering academic and industrial activities. Recently, the UK has begun is own path towards coordinating activities in this area with the publication of the UKBiochem10[55] in 2017.

III. The polymerisation production stage suffers from both the same limited scale and the cost of aggregating monomers from disparate facilities around the world (few countries have yet developed suitable clusters of monomer production at scale).

IV. Where we have seen regulatory stimulus of the market for bio-based plastics as in the USA[56], France[57] and Italy[58],[59] these pull factors have determined growth in the local development of bio-based industries. In the UK no such stimuli exist to date.

This is an industry in its infancy and there is much to do to develop processes and infrastructure of scale.

Regulatory clarity

The real cost of GHG emissions are not priced into petro-chemical based plastics just as the externalities caused by plastic pollution are not accounted for in the price of plastics. Further, stimuli are still given globally to the production of fossil fuels, (including through tax incentives on exploration in the UK) lowering the real price of these sources and making it harder for materials from non-fossil sources to compete with them. The IMF working paper of 2019 judges such subsidies to be circa $5.3 trillion annually or 6.5% of global GDP.[60] 99% of plastics derive from artificially under-priced fossil fuels.

Unless the regulatory regimes change, it is unlikely that bio-based plastics will secure a substantial share of the commodity market. The introduction of a pan-European Emission Trading Scheme from 2020 and a Plastic Tax[61] in the UK from 2021 may help create a more level playing field. The introduction of Carbon Taxes across the globe is also encouraging.[62]

Globally, the regulatory support for bioplastics has been very limited compared to, say, biofuels or renewable energies. And yet both categories of bio-based products aim to fulfil the common goal of decarbonisation and development of a vibrant renewably based bioeconomy. Indeed, there is evidence that bioplastics offer greater job creation and value-added than biofuels[63].

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[53] One of the world's largest plants in Italy will produce 150,000 t/pa biopolymers c.f. https://packagingeurope.com/novamont-boosts-production-capacity-with-new-bio-plastic-plastic-plant/
[54] https://www.nrel.gov/docs/fy04osti/35523.pdf
[55] http://ukbiochem10.co.uk/
[56] https://www.usda.gov/media/press-releases/2016/02/18/fact-sheet-overview-usdas-biopreferred-program
[57] https://www.european-bioplastics.org/pr_150723/.
[58] http://www.edizioniambiente.it/libri/923/bioplastics-a-case-study-of-bioeconomy-in-italy/
[59] http://www.kyotoclub.org/docs/bruxelles_060313_bioplastics_bastioli.pdf.
[60] https://www.imf.org/~/media/Files/Publications/WP/2019/WPIEA2019089.ashx
[61] https://www.gov.uk/government/consultations/plastic-packaging-tax.
[62] https://www.worldbank.org/en/programs/pricing-carbon
[63] OECD (2013): Policies for bioplastics in the context of a bioeconomy

There is no international pattern of support for bio-based plastics. Major policies have been applied to biofuels and without similar for bio-based plastics the investments needed for large-scale production and market uptake are unlikely.

A perverse incentive against bio-based plastics is in play. Strong policy support exists for biofuels/bioenergy in R&D and pilot plants, but also strong ongoing support during commercial production (quotas, tax incentives, and green electricity regulations). This policy leads to a market distortion regarding feedstock availability and costs. If the energy market is more attractive because of related incentives and support, bio-refinery development will be disproportionately focused on energy as the main output rather than building blocks (monomers) for bio-based plastics.

In the same manner that there are GHG emissions savings targets along with volumetric mandates for biofuels[64], then environmental targets for bioplastics may be possible. This might have the effect of not only encouraging the development of the most effective bioplastics but would also deter early investment in bioplastics with poorer environmental performance. It would also drive the need for LCA harmonisation.

Yet if we are to decarbonise the economy as Government policy declares, we have to decarbonise the production of those materials that can possibly be converted to biomass. So, the importance of biomass use for material production rather than just for energy production, and stimulus to that use in a similar way to that we have seen for energy, are issues which need to be addressed.

Technology development

There is considerable technology development required before the functionality of bio-based plastics and the cost effectiveness of their production processes are optimised.

The investments in recent years, in particularly building UK capability in industrial biotechnology, puts UK academics and companies in a strong position to begin to tackle these challenges at a research level. However, the infrastructure and support for translational development activity to enable emerging technologies for the production of bio-based monomers and polymers to be prototyped and developed to industrial scale is lacking.

Public resistance to synthetic biology

It is likely that a number of the new technologies for the production of bio-based plastics (particularly monomers) will rely on the use of the use of synthetic biology in the preparation of bacteria, yeasts and enzymes. Although use of such gene edited materials will be undertaken in closed vessels, the commercialisation of such new technologies requires careful management to ensure public acceptance.

Standards

Companies, governments and consumers are confronted with numerous uncertainties. These may limit bio-based plastic technologies from growing into full-scale commercial applications. In this context, standards are essential elements in aggregating demand of existing and new bio-based products. Definition and harmonisation of standards related to concepts such as sustainability in order to avoid creating barriers to the international trade of bio-based plastics are required. This is one reason BBIA welcomes the recent Call for

[64] https://www.gov.uk/government/news/new-regulations-to-double-the-use-of-sustainable-renewable-fuels-by-2020

Evidence and supports the unambiguous implementation and enforcement of internationally harmonised standards.

5. What potential unintended consequences could arise as a result of a growth in use of bio-based plastics? *(The potential impacts of bio-based plastics on waste processing are covered in Chapter 7.)*

The BBIA has set out below a number of potential consequences that could arise as a result of a growth in the use of bio-based plastics:

Competition for land use

Both petro-based and bio-based plastics are based on carbon chemistry. Accepting that plastics are essential to modern life, there is a choice to make as to whether humanity continues to obtain the required carbon for plastics from underground deposits of oil and gas formed some 200 million years ago, or whether a transition towards obtaining this necessary carbon from the atmosphere (captured by plants and other living organisms such as algae and fungi) is not just desirable, but essential.

The move to renewable carbon is required because CO_2 will continue to be released from the global plastics ecosystem system in perpetuity. The ambitious global targets for improvements in recycling will not deliver an entirely closed system, unintended losses to the environment will continue to occur, there will remain an imperative for incineration for some applications (e.g. medical waste) and the case for compostable plastics in the collection of food-waste (made elsewhere in this document) is compelling.

Today, bio-based plastics are either produced from agro-based feedstock, i.e. plants that are rich in carbohydrates, such as corn or sugarcane, or from farmed sustainable forestry. The former are far more efficient than non-food crops due to highly efficient processes of cultivation, harvesting and transportation. The bioplastics industry is investing in research and development to diversify the availability of non-fossilised, living-organism-derived materials for the production of bio-based plastics. The industry particularly aims to further develop fermentation technologies that enable the utilisation of ligno-cellulosic feedstock sources, for example non-food crops but also agricultural/municipal waste materials

Putting the current usage of non-fossilised, living-organism-derived materials into context of today's global land-use, some 92% of global cultivated land is used for food, 6% for industrial materials, 2% for bio-fuels and 0.016% for bioplastics (latter being anticipated to rise to 0.021% by 2022)[65].

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[65] Nova-Institut GmbH: Land use for Bioplastics https://www.bioplasticsmagazine.com/bioplasticsmagazine-wAssets/docs/article/0904_p46_bioplasticsMAGAZINE.pdf

In a local context, recent research by Ricardo Energy and Environment[66] examined the UK's availability of agricultural products including the major cereal and root vegetable crops in the UK and their potential for producing residues that could be used for bio-plastics. The report confirmed that the UK has an abundance of renewable bioresources to supply the biochemicals needed to produce the envisaged growth in markets for bio-based and compostable materials and final products.

The report's data highlighted that if the bio-based and compostable materials market grew to [say] 120kt in the next decade (5% of UK plastic packaging), this would require ~1.3% of the UK wheat crop (based on a PLA type material). Similar work by UKBiochem10 suggested ~4% of the UK sugar crop would be required for 100kt of a PET/PEF type material.

Research funded above all by the European Union into sourcing bio-materials from waste feedstocks has reached a critical level. The BBIA is itself involved in two such funded projects[67], whilst at least another ten projects have similar aims.[68] We can predict that with the right policy environment, by 2030 waste feedstocks will have substituted certain crop feedstocks.

Moreover, technology using Co2 as a primary feedstock for PHA is in the start-up phase and depending upon its viability could provide an interesting source for the production of bioplastics.

The BBIA contends that the land use need for bio-based plastics is limited (and certainly modest in the context of bio-fuels) and that it is appropriate to use crop-based inputs for now, whilst the industry gains traction and whilst investment in second generation technologies continues.

Increase in price of bio-based plastic products

The relatively high costs of biogenic materials (i.e. from living, non-fossilised organisms), their limited scale of use and the cost of research and development have an impact on bio-based plastics prices. However, prices of existing products have been decreasing over the past decade as more companies and brands are switching to bio-based plastics, as production capacities are rising and supply chains and processes are becoming more efficient. With rising demand and more efficient production processes, increasing volumes of bio-based plastics on the market and prices will continue to fall.

Nevertheless a large-scale switch to bio-based plastics is likely to increase the cost of materials in the short to medium term. BBIA would argue that this is an intended rather than an unintended consequence and effectively this is the pricing in of the externality of GHG emissions that the petrochemical industry does not take-on at present.

Orphaning of existing petro-based refining and downstream assets

It could be argued that a significant move to bio-based plastics could prematurely orphan or reduce returns on existing assets that support the plastics economy.

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[66] Ricardo Energy & Environment (2019): Plastics in the Bioeconomy

[67] www.usable-packaging.eu and www.resurbis.eu

[68] https://www.bbi-europe.eu/news/bbi-ju-announces-further-%E2%82%AC-135-million-funding-boost-development-eu%E2%80%99s-bio-based-industries

Given the continued global growth of plastics, this is unlikely for refining and large-scale petro-chemical assets in the short/medium term.

Bio-based plastics are generally designed to "drop-in" to existing conversion technology resulting in no orphaning of such assets at the product/packaging level of the supply-chain.

Consumer confusion

There are various bio-based content standards and certification schemes that independently assess and certify conformance to a bio-based content standard, but appropriate labelling is not yet either universally used, or understood by consumers.

There is some risk that consumers might mistake bio-based materials for natural materials, or biodegradable or compostable plastics, and dispose of them or litter them inappropriately.

Appropriate labelling and education will be required throughout the supply chains as bio-based plastics grow. Indeed bio-based certification could be a tool that is used by supply chain decision makers. Potential for customer confusion on what bio-based certification marking means needs to be avoided. We do not know enough about consumer behaviour and BBIA suggests research into how consumers are likely to correctly dispose of the final product types according to the markings and certifications used.

6. The role of biodegradable plastics in eliminating all avoidable plastic waste and moving towards a more circular economy. How the circularity of these materials are reflected / measured and supporting evidence

Please also refer to answers below and in Chapter 7 on waste management.

7. With existing technology and materials, what's the minimum timeframe for complete biodegradation (breaking down to nothing but water, biomass, and gasses, such as carbon dioxide or methane) for plastics designed to biodegrade in the following environments? *Deep Sea - Surface of the Sea - Freshwater - Beach - Soil surface - Soil - lightly buried - Landfill - Industrial composting - Home composting*

The question is equivocal. It is not clear whether the interest is towards the **intrinsic biodegradability** of plastic materials or the **environmental fate** of any specific consumer or professional product made with a biodegradable plastic material. These two aspects shall not be confused because they must be treated using different methodologies.

The timeframe for biodegradation of a product depends on

- **(i)** **The intrinsic biodegradability of the materials it is manufactured from,**
- **(ii)** **Dimensions of the products,**
- **(iii)** **Environmental conditions.**

(i) **The intrinsic biodegradability** is a specific characteristic of the material and it refers to the ability of the material to be depolymerised and assimilated by microorganisms present in the biosphere and in particular in the environment of interest. The assessment of biodegradation of any chemical/material is carried out under optimised and controlled conditions in order not to limit the microbial development[69]. This type of approach aims at finding whether the material under testing is intrinsically biodegradable, i.e. microbes can break it down to carbon dioxide, water, as it is used to grow their own biomass.
Achieving high levels of conversion to CO2, comparable to those achieved by GRAB (Generally Recognized As Biodegradable) substances, is a strong indication that plastic is biodegradable[70].

Relevant standard for biodegradability in soil is EN 17033:2018 Plastics - Biodegradable mulch films for use in agriculture and horticulture - Requirements and test methods.

Relevant standard for biodegradability when assessed by using marine microorganisms:
ISO/DIS 22403 Plastics -- Assessment of the inherent aerobic biodegradability and environmental safety of non-floating materials exposed to marine inocula under laboratory and mesophilic conditions -- Test methods and requirements

(ii) Plastics are solid materials and thus dimensions make a difference.
It is intuitive that the time necessary to degrade a one-meter diameter fully biodegradable redwood block will be extremely long when compared to a leaf or thin straw even if the basic material is the same.

(iii) Most biodegradable plastics are solid non-water soluble materials Biodegradation happens at the surface of solid materials and it can be quantified as (for example) mol C s^{-1} cm^{-2} i.e. amount of Carbon (moles) converted into CO2 per unit time (seconds) per unit surface (cm2). Thus, the complete biodegradation of a product will depend on the mass and on the available surface area.[71]

Environmental conditions will affect the biodegradation rate. Here the main factor is temperature. It has been shown that the biodegradation reaction obeys the Arrhenius curve similarly to most chemical reactions. This enables the development of a methodology to predict field dissipation kinetics taking into account the effects of temperature.[72]

Additionally, the prevalence of microorganisms in a given habitat affects the biodegradation speed. In an environment that is rich in food for microorganisms, there will be more microorganisms at a given temperature and a certified compostable plastic will biodegrade faster in such an environment than in a habitat with no food for microorganisms. Accordingly,

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[69] Hemond, H. F., Fechner E.J. (2015) Chemical Fate and Transport in the Environment 3rd Edition; San Diego, CA: Elsevier/Academic Press

[70] De Wilde, B. (2012). "Biodegradation Testing Protocols" in Degradable Polymers and Materials: Principles and Practice (2nd Edition), ACS Symposium Series Vol. 1114, ed. K. Khemani, and C.Scholz (Washington, DC: ACS) 33-43. doi:10.1021/bk-2012-1114.ch003

[71] https://www.sciencedirect.com/science/article/pii/S0141391017303816
https://www.sciencedirect.com/science/article/pii/S0141391019301934

[72] Pischedda et al. submitted to Polymer Degradation and Stability.

the most robust results on questions of marine biodegradability are gained, if biodegradation is compared in marine environments that differ in the prevalence of microorganisms.

If the interest is about ecological risk of littering of products (including the biodegradable ones); then proper tools must be developed. Interesting ongoing projects are:
"The Plastic leak project" by Quantis[73] and the MariLCA project[74]

8. Is there any evidence on the direct impact of biodegradable waste plastics on biodiversity, ecosystems, and the natural environment in the short-term (over the degradation period of the item), and in the long term (including cumulative effects)?

To answer this question, it is important to know what the specific methodological framework is that should be used to measure such impacts. To our knowledge, there is no methodology ready for measuring the impacts of waste (whether biodegradable or not; whether plastic-based or ligno-cellulosic, or whatever).

The above-mentioned studies in Chapter 7 are the first attempts to determine the environment impact of littering. It has to be emphasized that application of biodegradable plastics in agriculture ("plasticulture") is not strictly speaking an application on a "natural" environment. Biodegradable mulch films are for professional use. Agricultural fields are not a "natural environment". Requirements for biodegradable mulch films are present in the European standard: EN 17033:2018[75]. Plastics - Biodegradable mulch films for use in agriculture and horticulture - requirements and test methods.

9. To what extent, if at all, can the existing evidence be used to extrapolate the degradation rate of plastics in different environments (e.g. in surface water vs deep sea, etc.)?

The existing evidence shows that (at least some) biodegradable plastics display biodegradation behaviour comparable to cellulose-based products. Cellulose is used as a benchmark in all the standard specifications to set the level of biodegradation to be reached. Thus, biodegradability in EN 13432, EN 17033, ISO 18606, ISO 17088, ISO/DIS 22403 is ascertained by comparing the behaviour of the considered material toward cellulose. According to all these standard specifications, intrinsic biodegradability of plastics (and other materials) is shown by showing biodegradation levels analogous to that obtained by cellulose.

All the knowledge available on the biodegradation behaviour of cellulose can then be reasonably applied to predict the behaviour of the materials under study[76][77]. The biodegradation speed will then depend upon the temperature in an environment as well as

[73] https://quantis-intl.com/metrics/initiatives/plastic-leak-project/
[74] http://marilca.org/
[75] https://www.european-bioplastics.org/new-eu-standard-for-biodegradable-mulch-films-in-agriculture-published/.
[76] Bengt V. Hofsten and Nils Edberg Estimating the Rate of Degradation of Cellulose Fibers in Water Oikos Vol. 23, No. 1 (1972), pp. 29-34
[77] Chung Hee ParkYun Kyung KangSeung-Soon Im, Biodegradability of cellulose fabrics 2004 Journal of Applied Polymer Science 94(1):248 – 253

the prevalence of food for microorganisms which is different from environment to environment.

10. Testing regimes/methodologies that can verify biodegradable plastics completely degrade (breaking down to just water, biomass, and gasses, such as carbon dioxide or methane) in the open environment instead of fragmenting into microplastics and key challenges

EN 17033:2018 Plastics - Biodegradable mulch films for use in agriculture and horticulture - Requirements and test methods

ISO/DIS 22403 Plastics - Assessment of the inherent aerobic biodegradability and environmental safety of non-floating materials exposed to marine inocula under laboratory and mesophilic conditions - Test methods and requirements

The applied test methods show intrinsic biodegradability, i.e. complete transformation into CO2 and biomass using cellulose as the benchmark in specific environments. Thus, the materials satisfying these specifications can be equated with cellulose-based materials in these environments. Behaviour in the open environment will be similar. To illustrate this point, if the open environment is humid, warm and rich in microorganisms, the biodegradable plastic may biodegrade at similar rates as cellulose. In a dry open environment, and in the absence of a rich microorganism community (e.g. concrete in a dry area), slow biodegradation will be observed. BBIA believes that products should be certified according to their intended end of life, not to the specific product's intrinsic level of biodegradability (cf. also ref to Chapters 13 and 21).

Microbial lifeforms are present in most locations on Earth so the question about the biodegradation of such materials is more about the environment they are in and, therefore, the rate of biodegradation. If the surface area of such materials is increased by (say) mechanical action, it is more likely to lead to a higher rate of biodegradation.

11. Do these testing regimes/methodologies apply to plastics which contain prodegradant agents intended to aid the biodegradation process?

Plastics which contain prodegradant are applied to non-biodegradable conventional polyolefins. Normal polyolefins undergo oxidation and degradation with time. This leads to fragmentation. Prodegradants accelerate the oxidation of polyolefins. As a matter of fact, "prodegradants" are catalysts, which decrease the activation energy for oxidation of polyolefin to happen. Energy comes as UV light or heat. **We can therefore define prodegradant agents as substances that accelerate the formation of microplastics from polyolefin.** [78] [79]

[78] UNI/TR 11605:2015 (Plastics- Additives intended to promote the degradation of polyolefin-based thermoplastic materials)

[79] The technical report provides information on additives intended for promoting the degradation of thermoplastic materials based on polyolefins. It identifies the different original technologies of the products, it characterizes the mechanisms of action, it describes the environmental claims generally used, and it clarifies the differences between the terms "degradation" and "degradability". The technical report deals with technologies based on the use of additives only. It doesn't therefore apply

The question itself raises an issue in that under the Single Use Plastics Directive and indeed through the DEFRA-led Plastics Pact, the use of oxo-degradables is banned or listed for elimination.

The Ellen MacArthur Foundation's New Plastics Economy, which developed the Global Commitment on plastics, to which DEFRA is a signatory, has issued a statement summarised as; "since oxo-degradables *and similar additives designed to encourage degradation* hinder the circular economy for plastics and do not bring any benefit to leakage and so should be banned."[80]

12. What evidence is available to quantify the differing environmental impacts of compostable plastics when they "escape" and then degrade in the open environment?

This is about littering of products.

The tools for quantifying the environmental impact of littering are under development (ref chapter 18)

13. What other potential unintended consequences could arise as a result of a growth in use of biodegradable plastics? *(The potential impacts of biodegradable plastics on waste processing are covered in Chapter 7.)*

It is essential that the deployment of biodegradable plastics is done at an application level where the systemic impacts are considered. Much noise is currently being made in relation to the impact of alternatives to traditional plastics, most often these complaints come without understanding the final goal – in the case of the UK, and with regard to this consultation, the principle aim is to achieve net zero emissions by 2050. It is interesting to note that from our understanding, the Government is looking at a future EPR system which is fixated on material recycling, with little consideration for the wider sustainability or even reality that most plastic material cannot be recycled more than once or twice.

Under the current proposal for a new EPR system and fee calculation, innovation is not accounted for. The system intends to be 'simple', binary - packaging will be recyclable or not, and is based on today's infrastructure. So, even where your packaging can bring co-benefits e.g. through the secondary use of compostable carrier bags to collect additional food waste, whilst removing the need for a bespoke waste bag, or where the presence of food and grease will impede material recycling; the system will still penalise the innovation since higher fees will be required due to the overarching principles. Furthermore, there appears little in terms of a vision of a future system which works for all but the incumbent, dominant materials of today.

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to degradable copolymers such as, for example, copolymers of ethylene and carbon monoxide or copolymers based of ethylene and / or propylene and alkyl vinyl ketones (commonly methylvinyl ketone).

[80] https://www.newplasticseconomy.org/about/publications/oxo-statement

So, one unintended consequence is that companies placing compostable plastic packaging on the market will potentially be charged at the highest fee rate (non-recyclable) and the composters, where the packaging is recycled, will not receive any credit for the actual recycling. One often cited concern is that biodegradable plastics do not solve littering, in fact they exasperate it. To the best of our knowledge, biodegradable (compostable) plastic packaging is not flagged as litter concern; no biodegradable (compostable) option has been cited in any of the work the EC has done prior to the implementation of the SUP. In fact, the only area where so-called biodegradables were deemed a concern, i.e. oxo-degradables (defined as plastics which contain additives designed to enhance fragmentation) the SUP has moved to ban them whilst at the same time, defining biodegradable plastics as those which meet EU standards for biodegradable packaging i.e. the biodegradation and composting standard, EN13432.

To the best of our knowledge, none of the claims of biodegradability will increase litter are backed up with any actual evidence. The much cited UNEP report is a point in case[81]. The only reference to research cited in that "landmark" report, comes from a small piece of research into youth behaviour undertaken by the municipality of Los Angeles. The link to this work – which is just a presentation at a conference – is no longer available (see Keep Los Angeles Beautiful (2009) "Littering and the iGeneration: City-wide intercept study of youth litter behaviour in Los Angeles." Session paper at XIII Environmental Psychology Conference Granada, June 23-26, 2015 http://www.congresopsicamb2015.com, which is no longer online.

Having said this, it is clear to BBIA that the branding/labelling/marking of products made from biodegradable materials is key to informing consumers about how to dispose of the product once used. Making products that can biodegrade in specific environments defined in standards (as we have seen with compostable films) is not an excuse for incorrect disposal or behaviour. This applies for all materials, not just biodegradables.

14. What evidence, if any, is available regarding the suitability of the existing industrial and home composting standards? We welcome any suggestions on how these standards could be adapted to current and future needs, if necessary.

Packaging and products that comply with the current standard on composting (EN 13432) can be defined as "organically recyclable", i.e. are biodegradable, disintegrate in a composting plant, do not release harmful substances and are non-toxic for soil and plant life. This is a general, basic prerequisite for a packaging to be recovered in a composting plant.

[81] http://wedocs.unep.org/handle/20.500.11822/7468

Then, specific composting plants have adopted operating systems that can result in not being able to treat "compostable" packaging and products because, for instance, of screening systems rejecting the packaging in a pre-treatment phase. Thus, compostable packaging may be discarded even before entering the composting plant. It is "compostable" but not compatible with a specific composting plant.

Industrial composting

Pre-treatments do not allow composting

Note on Rejection: Biological treatment plants can be installed with screening systems that are meant to sieve the incoming biowaste and reject all materials that can contaminate the final product or interfere with the process (glass, metals, plastics, etc.). Biodegradable packaging is no different to conventional packaging in mechanical properties and, therefore, is rejected whenever a sieving is applied.

A standard cannot solve these incompatibilities that must be solved by the local waste management systems and by the operational standards adopted in each treatment plant. National BREFs can be adopted giving minimum treatment time to ensure products spread to soil are stable and thus reduce ammonia emissions and nitrate leaching (for example, in Italy 90 days composting is legally required for food waste to reach end of waste criteria including that derived from AD plants).[82]

Short composting cycle

Most plants sieve the final compost for refining. At this stage compostable packaging is normally fully disintegrated and part of compost. However, some composting plants anticipate the screening phase. Sometimes, sieving is carried out between the thermophilic phase and the maturation phase. Any early sieving is potentially a step where the plant rejects packaging if not completely disintegrated yet. If sieving is done early, like much organic material, ranging from orange peel to lingo-cellulosics, the packaging may not be totally disintegrated yet and, therefore, sorted out. This event is especially possible with bulkier and thicker items. That happens also with logs, branches and in general with ligno-cellulosic materials. Composting plants generally recycle these materials at the beginning of the process (internal recycling), so that the disintegration can be finished. This could also be applied to compostable packaging.

The standard EN 13432 defines the maximum allowed thickness of compostable packaging by means of a specific laboratory test. In order to cope with the real-life conditions in certain composting plants that operate an early-sieving composting process, the EN 13432 should consider some factor to decrease the maximum allowed thickness to satisfy this type of plant, whilst considering the use of internal recycling within the process time.

[82] www.isprambiente.gov.it › contentfiles › 3526-manuali-2002-07

With reference to home composting the current reference is: prEN 17427 Packaging — Requirements and test scheme for carrier bags suitable for treatment in well-managed home composting installations.

Home composting

Is a gardening activity, which can also treat bio-waste (kitchen waste). It can also be used to some specific packaging such as coffee pods, tea bags, specific packaging and lightweight carrier bags.

Two thirds of UK households have some form of outside space/garden which could be potentially used for installing a home composting unit[83]. The OK Compost certification scheme adopted for home composting, (see below Question 25a) has been widely accepted and demonstrates the functionality of compostable materials in well managed domestic composting.

15. To what extent, if at all, would a home composting standard that covers all home composting techniques, equipment and environments in the UK be possible? If so, would it be a desirable system to adopt?

The term **"composting"** is used to designate very different practices:

It refers to the treatment of biodegradable organic waste in large-scale installations run by professionals. These installations are true waste treatment plants, i.e. they need authorisation to accept waste, treat it, and produce compost, a product subjected to quality controls following specific regional or national regulations. The centralised treatment of biodegradable organic waste is better identified as "industrial (or professional) composting".

The same term "composting" is also used to describe the gardening activity carried out by householders in small installations normally located in the backyard (called "composters"). Grass clippings, leaves, and potentially food waste are decomposed to make compost that is used as a supplement to the garden soil. The compost produced by householders is not the result of an economic activity and it is not a commercial product, lacking the required analysis and authorizations needed to place on the market fertilizers and soil improvers. The compost can only be used for gardening as a hobby activity. The autonomous management of biodegradable organic waste carried out at home is better identified as "home composting".

In spite of both being identified as "composting", **professional composting** and **home composting** are two very different processes.

Professional composting treats large masses of organic waste which are managed in order to get a final optimised composition (e.g. with a proper carbon/nitrogen ratio, optimised water content, texture),

[83] http://www.prestonbaker.co.uk/explore/property-journal/third-homes-no-back-garden/

and assure proper environmental conditions (e.g. aeration, mixing), in a controlled process. This management enables the waste to go through a spontaneous thermophilic phase, where the evolved microbial heat is trapped by the large mass and increases temperatures up to 60-70°C. Under these conditions, the microbial population shifts towards species adapted to high temperature (thermophilic) and the overall metabolism is highly accelerated.

Home composting deals with small amounts of organic waste discontinuously added into the composters. The feeding of the composters may or may not be continually managed i.e. the amount, quality, and intervals of addition are not predefined but based on the activity of a single kitchen. This can make the establishment of thermophilic conditions rather difficult, for lack of available energy and insufficient volume (little heat and high dispersion = low temperature). Unless properly managed it is possible that the establishment of local micro-imbalances (e.g. C/N ratio, water content, texture, oxygen availability) will occur. Under these conditions, the temperature of the mass under composting is generally simply controlled by the seasonal climate. For all these reasons, the degradation rate of home composting is much slower than professional composting and basically unpredictable being home composting a personal activity autonomously carried out by independent householders.

Nevertheless, the treatment of some packaging waste through home composting is clearly an opportunity. Indeed the European standard on home composting being discussed in CEN at the time of writing[84], currently only considers lightweight bags and the title specifically mentions the scope of the standard to **"well-managed home composting installations"** to indicate that the positive outcome of the process depends both on the biodegradability characteristics of the "home-compostable" bags and the way the process is performed. However, it is a step forward and the establishment of a specific UK standard (given our own climatic conditions) could help develop the use of home composting of compostable materials here. Belgium and France both have home composting standards.

Finally, we also have to establish the indicators needed to measure how much home composting contributes to waste prevention targets, because we cannot define the practice as recycling. DEFRA has established a waste prevention programme within the Environment Bill that will be put before Parliament in 2020 and in this legislation home composting can be better defined.

16. What potential unintended consequences could arise as a result of a growth in use of compostable plastics? (*The potential impacts of compostable plastics on waste processing are covered in Chapter 7.)*

Compostable packaging (including plastics packaging) should be easily recognisable by consumers so as to facilitate the proper separation of wastes of different natures. However,

[84] https://www.european-bioplastics.org/revised-mandate-for-home-composting-standard/

mis-sorting can happen so that compostable plastics can end into the waste bin for non-biodegradable plastics and vice-versa. Mis-sorting can decrease the quality of both mechanical and organic recycling. To reduce the negative effects of mis-sorting, the application of markers would be beneficial, when for example, the number of compostable bags increases. For example, substances imbedded in the carrier bags which are recognised by IR-based automatic sorting machines can be used to remove extraneous bags from the different waste flows before recycling.[85] [86]

17. Other relevant standards or test methods for biodegradability for all plastic materials in soil, marine and waste water environments that are not included in the report 'A Review of Standards for Biodegradable Plastics'

ISO 22404:2019 Plastics — Determination of the aerobic biodegradation of non-floating materials exposed to marine sediment — Method by analysis of evolved carbon dioxide https://www.iso.org/standard/73123.html

ISO/DIS 22403 Plastics — Assessment of the inherent aerobic biodegradability and environmental safety of non-floating materials exposed to marine inocula under laboratory and mesophilic conditions — Test methods and requirements
https://www.iso.org/standard/73121.html

EN 17033:2018 Plastics - Biodegradable mulch films for use in agriculture and horticulture - Requirements and test methods
https://standards.cen.eu/dyn/www/f?p=204:110:0::::FSP_PROJECT,FSP_ORG_ID:41401,6230&cs=19E53F436D5E8A6FF49358DA8C195A6E2

18. Improvement and developments needed for existing biodegradability standards to strengthen their effectiveness

The interest towards the effects of plastic littering on the environment requires the development of tools suitable to be used to assess the risk associated with uncontrolled release of waste. Standards on how to track the environmental fate of plastic waste must be developed. Proper methodologies, where input sources, sinks, pathways, and biodegradation rate are factors to be evaluated need to be developed. In this regard, it is important to mention two important ongoing projects that aim at integrating potential environmental impacts of marine litter, especially plastics, in LCA results:
The Plastic Leak Project of Quantis [87] and **Marine Impacts in LCA (MariLCA)**[88]

19. Advantages and disadvantages of producing national and international biodegradation standards

Standards are needed to characterise the properties of materials and thus the behaviour of different products for purposes of recovery and recycling. This area has been deeply studied in the last three decades and many standards on organic recycling of plastic products and packaging do exist. This activity was relevant in order to promote the development of certification schemes and labels needed to allow the development of a controlled market.

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[85] https://packagingeurope.com/sorting-plastic-recycling-tracers-digital-watermarks-tomra-procter-gamble/
[86] https://global-recycling.info/archives/3142
[87] https://quantis-intl.com/metrics/initiatives/plastic-leak-project/
[88] https://www.lifecycleinitiative.org/new-project-marine-impacts-in-lca-marilca/

When littering is concerned, then a specific methodological approach is needed to take into consideration amount of litter, migration among different environmental compartments, environmental sink, exposure, damage, risk assessment. Biodegradability is just one factor relevant to understand the environmental fate of products. The assessment of risk associated with waste leakage cannot be solved with one standard. A broader approach is needed, similar to what has been done for chemicals released into the environment.

20. National, regional and /or international work to implement biodegradability standards

CEN TC 261 Packaging developed between 1994 and 2000 the standards for organic recycling of packaging

CEN TC 249 Plastics developed standards about bio-based plastics

ISO TC 61 developed, starting from early 90s several standards on biodegradability

ISO TC 122 Packaging developed standards on organic recycling of packaging

21. Can biodegradability standards be beneficial for specific products *(such as carrier bags)* or product forms *(for example those that with current technology are typically too contaminated to be mechanically recycled once disposed of)*?

BBIA believes that the standard should refer to the end of life of a product, not to the specific product's intrinsic level of biodegradability. This is because a product, when collected, will require an end of life treatment option. Products like carrier bags may not be collected separately or may be used for example for collecting food waste; in this case the product must be compatible with food waste treatment protocols for biodegradable packaging and in this case a standard already exists, the EN13432. So the standard should refer to the final treatment option, not to the specific product.

22. Standards, labelling and certification schemes currently in place to determine the level of bio-based content in bio-based plastics

ISO16620-2015 (equivalent to **ASTM D6866**) sets out globally recognised methodologies for determining the Bio-based content of materials. In the case of a product derived from mixed resources (fossil-fuel-derived and naturally-derived, the test methods allow the ratio of Bio-based to fossil-derived content to be determined).

The general principles are set out in **ISO16620** part 1,[89] and the following parts of **ISO16620** set out the methodologies that can be employed. BBIA fully endorses this standard.

We would point out that measurement of the Bio-based carbon content provides a relatively easy measure of bio-based to fossil-based content, which can be carried out by expert laboratories at a relatively low cost to industry. This is therefore easily quantifiable and represents a viable test-method in practice. Further, the cost of testing is in the range of hundreds of pounds sterling, making it accessible to even SMEs.

89 https://www.en-standard.eu/iso-16620-1-plastics-bio-based-content-part-1-general-principles/

However, total biomass content is much more difficult to ascertain, with no simple laboratory test methods that we know of and much of the calculation, therefore, relies on the supply of accurate data on raw material content from the suppliers of each component of a finished article.

23. Should current labelling requirements be changed to produce new suitable standards?

In the USA there is a formal USDA "Biopreferred" certification programme available based on the ISO16620/ASTM D6866 Biocarbon test method. Products can then carry a formal logo similar to that shown here to the right:

We are not aware of a formally 'government-promoted' identification programme yet in Europe, but would very much endorse the creation of a similar scheme in the UK (and indeed in the EU). However there are two fully independent and widely recognised certification programmes already in existence that certify based on performance to the same test methods:

DIN CERTCO Bio-based - which is administered locally in the UK by the Renewable Energy Association Ltd., (REAL Ltd) – provides a logo based choice of three levels depending on Bio-based percentage recorded for the material in question. Example:

TÜV Austria certifies to the OK Bio-based programme: This operates in a similar way to the DIN CERTCO scheme but awards a star rating according to Bio-based % achieved. Example:

between 20 and 40% biobased	between 40 and 60% biobased	between 60 and 80% biobased	more than 80% biobased

24. Should specific labelling rules apply to bio-based plastics to certify their proportion of bio content – either to better inform consumers or for any other reason?

One of the major goals of emerging sustainability programmes for plastic materials (e.g. Ellen MacArthur Foundation 'New Plastics Economy' and the 'UK Plastics Pact') is to decouple the manufacture of plastics from the use of finite resources. From a government, business and consumer point of view, the start-point needs to be to understand the current level of use of finite resources versus bio-derived sources and hence a simple, accurate test method and an equally effective labelling programme is essential. The adoption and wider communication of a similar approach to the USDA Bio-based product certification programme (or TÜV Austria and DIN CERTCO Bio-based schemes) would certainly facilitate this. To make progress, we first need the baselines (provided by the carbon tests listed earlier), and then we need to be able to track the progress away from finite resources. Such a programme would allow this.

Note: Chapter 6 is potentially confusing as it mixes 'Bio-based content certification' and 'biodegradability certification', however there are two different measurements.

The subject of certification types is covered elsewhere in this response to the Call for Evidence. Consumers are faced with a confusing plethora of green claims, and in recent years there have certainly been products on the market that have made false and/or unsubstantiated claims of biodegradability and/or compostability in some cases. BBIA and its industry members firmly believe that:

a) All claims of biodegradability (including those of industrial and home compostability) should be referenced only to standards or formally recognised certification programmes that set pass/fail criteria wherever these exist. (Some standards only specify test types and test methodologies for labs to use and we have experienced claims of oxo-degradable plastics claiming to be biodegradable after testing as per BS 8472; this standard sets no pass/fail criteria for any generic or specific biodegradation environments. A prime example of misleading environmental claims in our opinion.) In the case of the UK , USA and EU these are BS EN13432, BS EN 14995 or ASTM D6400 for industrial (municipal) composting and in the case of home composting, TÜV Austria's 'OK Compost Home' certification scheme criteria or TÜV Rheinland's (DIN CERTCO) home compostable certification schemes aligned to the French standard NF T51-800 and the Australian standard AS 5810.

b) A single recognisable certification marking system should be employed. This will provide a number of key advantages:
   a. Easy identification and, therefore, separation and sorting of certified compostable packaging from conventional plastic packaging, by both consumers and waste collection operators.
   b. Facilitate an 'effective' policing of the claims made on pack. This can be further enhanced by demanding a certified product reference number be placed by the certification mark. (Indeed this is already standard-practice by the BS EN13432 certifying bodies).
   c. Helps to eliminate companies who and/or products that carry dubious or false green claims

In the early 2000's pilot programmes such as the so-called 'Kassel project' in Germany were used to measure the effectiveness of an identification scheme and to demonstrate how it aided consumers to identify compostable packaging from conventional packaging even if the physical appearance of the packaging was very similar. The Kassel project demonstrated very high levels of consumer awareness, following in-store promotions of the concept. It also highlighted this minimised 'misthrows' by consumers. Moreover it demonstrated that a high proportion of consumers preferred to purchase packs that carried the logo versus packs that did not.

Given Defra's publicly declared intentions, by end 2023 separate food waste collection will have been rolled-out across England, substantially adding to the amount of food waste separately collected and composted or digested in the UK. It is also possible that separate garden waste collections will increase in England by 2023. This provides the practical vehicle to ensure that suitable compostable packaging can be collected and revalorised via the organic waste recovery schemes in the UK.

Ideally the certification mark on pack should also be licenced for use on the food waste collection 'caddies' to make identification as easy as possible for both consumers and waste collectors/processors accordingly.

Impacts on Waste Processing

We advise reading of the document produced by BBIA for the May 2019 consultations on the Resource and Waste Management legislative proposals issued by DEFRA. Reference should also be made to the document written and published by Ricardo E&E in May 2019 cited in this text illustrating the scope for compostable plastics in the UK packaging mix.[90]

In the BBIA policy document we lay out the role of compostable plastics in the packaging industry and how their use can benefit

- *a. Collection of food waste*
- *b. Quality of food waste*
- *c. Ease of treatment especially in composting thereby reducing waste outputs*
- *d. Quality of compost going to soil to reduce contamination by plastic*
- *e. Reducing plastic waste by making certain packaging materials and products compostable, ie effectively recoverable through organic recycling.*

In this document we lay out a concept for a waste management system in the future which sees AD and composting working together to ensure maximum recovery of food waste, maximum delivery of organic carbon to soil, a reduction in ammonia emissions from digestate storage, and a reduction in nitrate run-off to soil and water courses by spreading solid compost over a longer season rather than wet digestate over a very short spreading season.

Therefore, when answering the following questions we emphasise that compostable materials have a specified, designated use and purpose beyond their initial role as a packaging material. That role is relative to the improvement of the food waste collections and treatment system. Compostable materials achieve their purpose in improving food waste collections and treatment.

26. What evidence is available to demonstrate the impact that biodegradable (including compostable) plastics have on the current waste management system, including on the quality and safety of composts and digestates? Does existing evidence allow estimated monetary value of this impact?

Compostables currently play a tiny role in waste collections in the UK having a total market penetration in the region of 10,000 tons[91] out of 27 million tons of MSW arising. [92]

We can conjecture that this volume will increase, as per the cited Ricardo E&E report, to some 130,000 tons by 2025. This will represent 0.005% of all MSW arisings in the UK assuming that the arisings remain stable over the next five years. We can, therefore, assume that in terms of overall impact on the waste management system the potential cross contamination caused by compostable plastic will be immeasurably small

On the risk of compostable plastics contaminating conventional plastics, SUEZ UK have informed that, in UK MRFs they manage; “PET & HDPE are both positively sorted from the mixed 3D stream by near infrared, whilst the metals are pulled off separately.” (Quote Dr Adam Read to Vegware).

[90] Both can be downloaded from https://bbia.org.uk/reports/

[91] https://ee.ricardo.com/news/our-new-report-highlights-potential-tenfold-increase-for-uk-compostable-plastic-packaging-market-by-2025

[92] https://www.gov.uk/government/statistics/uk-waste-data

Therefore, there is little probability of other polymers going into the PET and HDPE streams the main two conventional plastics streams with significant recyclate value So, if a compostable polymer such as PLA was to go into the plastics recycling it would not contaminate those two valuable streams.

As for the possibility of compostable materials contaminating conventional plastics recycling, German and Italian researchers have found there was no reduction to quality, up to these levels:

- **Up to 3% PLA in post-consumer PP plastic recyclate (1)**
- **Up to 10% PLA in PS plastic re-granulates (1)**
- **Up to 1-2% PLA in recycled PET plastic short-spinning plant (2)**
- **Up to 10% MaterBi in the recycling of PE plastic shopping bags (2)**

Source: (1) the report PLA in the Waste Stream, a report initiated by the German Ministry of Food and Agriculture.

Source: (2) from CONAI, the National Packaging Consortium of Italy: Working Group Biodegradable Packaging Recovery Project report, 2012. (Compostable bioplastics are less than 1% of global plastics production at present.)

However, compostables are present in uses where the concentration of compostable plastics can play a positive role, and this refers to the use of compostables above all in food packaging, food waste collections and food waste treatment. Here they could potentially be put into collection systems where plastic packaging is currently collected, when at all.

REA ORG monitored a composting trial of 1.3 tonnes of used Vegware disposables conducted at Biogen's IVC, with REA's Technical Director Jeremy Jacobs, concluding in the trial report[93] that; "this trial provides robust evidence to demonstrate that under normal commercial conditions certified material does degrade successfully."

In the current waste management system in the UK (with the exception of Wales and increasingly Scotland) the quality of waste streams sent to separate collection is compromised by cross contamination and no more is this visible than in food waste collections.

Data relative to the contamination of food and garden waste by plastics and other non-compostable contaminants are scarce but some have been collected through surveys undertaken by BBIA member REA, whose membership includes many composting and AD facilities and to which we refer below.

[93] REA ORG Biogen IVC composting trial of 1.3 tonnes of Vegware disposables http://www.organics-recycling.org.uk/uploads/article3509/Vegware%20packaging%20trials%20at%20Biogen's%20Tempsford%20IVC-final.pdf

We also have data from Italy, where food waste collections have been established in the central and northern regions for 15 years or more. Since 2010 there has been a national obligation to use compostable bags for food waste collection. In April 2018 a compost association conference including Italians, Austrians, Swiss and Germans[94] presented data on the contamination of food waste collections by plastics. Whereas the Italian system on average has reduced overall contamination to 3.1% from non-compostable plastics, the data from the other associations (where compostable plastics are not used for collections) showed that some 26.7% of final compost samples and 50% of final digestate samples in Switzerland, did not reach the standard for elimination of plastics; whilst in Germany the figures were 8.7% and 10.8% respectively. (The data are not fully comparable due to different standards being applied). The lesson learnt is that where compostable plastics are used for collections, contamination of food waste and its outputs (compost and digestate) falls.

The percentage of contamination varies enormously among sites in the UK depending upon the quality of council collection programmes, enforcement of contractual obligations and the capacity of the receiving plant to handle contaminants. Moreover, as plastic is a lightweight material the percentage contamination in terms of weight may be small, while in terms of volume the percentage is much higher as food waste contains 70% water. Thus, we see and hear of figures from 1% to 10% contamination. They mean little unless we define whether this is by volume, weight and is pre or post process, i.e. in the finished compost/digestate

REA, in their response to the DEFRA Resources and Waste Strategy in May 2019, quoted the following evidence:
"Based on information the REA has gained from members and from surveys of the UK organics recycling industry, the concentration of non-compostable plastics in biodegradable wastes delivered for organic recycling / recovery is, conservatively, 1 % weight for weight [on a fresh matter basis]. Input tonnages to composting facilities totalled 5.92 million tonnes in the year 2014 and 'waste-fed' AD facilities reported treating 3.84 million tonnes that same year" (see http://www.wrap.org.uk/sites/files/wrap/asori%202015.pdf). Assuming 80 % of those 9.76 million tonnes of waste contained, on average, 1 % w/w plastic, the UK organics recycling sector incurs an annual cost of **£7.26 million** (excl VAT) for removing approx. **78,080 tonnes of plastic** and sending it for recovery at Energy from Waste facilities. This is a very conservative estimate which does not include all costs incurred by the organics recycling sector for dealing with non-compostable plastics.

Assumptions made in the calculation and exclusions;

a) extraction of 1 tonne of plastic waste costs approximately £10 / tonne of waste received at the organics treatment facility,

b) the cost of washing organic waste off the extracted plastic and managing the used wash water is excluded, or alternatively the extracted plastic is not washed and the value of the organic waste that sticks to it is lost at the organics treatment facility, [or the extracted plastic is dried before sending to other treatment/disposal and the cost of drying is excluded] and

c) the extracted plastic waste is sent to Energy from Waste facilities that charge a median gate fee of £83 / tonne excluding VAT (in reality an unknown percentage of the

[94] https://www.polimerica.it/articolo.asp?id=19763

extracted plastic waste goes to landfill (median gate fee of £107 / tonne incl landfill tax) instead of EfW; REA's perception is that the proportion of extracted plastic waste that goes to landfill is lower than the proportion that goes to EfW facilities).

Excluded from the calculation;

a) the costs of transporting the extracted plastic waste from the organics treatment facility to the EfW facility, and

b) the costs of managing plastics at concentrations above 1 % w/w in wastes delivered to those AD facilities that accept at least some of their organic waste - usually separately collected food waste - bagged in non-compostable plastic (some of them have estimated that plastic is approx. 10 % w/w in waste delivered for treatment).'

Given the exclusions quoted here it would not be an exaggeration to say that the organics system managing food/garden waste is bearing a cost of circa £10 million annually from having to handle plastic contamination. No compensation or even recognition is given to the organic recycling plants for having to handle and dispose of what is effectively the equivalent to 20% of all the plastic packaging sent to recovery in the UK. See figure 3.

As food waste collections, in particular, are destined to grow considerably (two or three times current levels), we could assume that in a future time, if the contamination levels remain unvaried, **the cost to food waste treatment facilities of handling plastic contamination could rise to <u>£20 or £30 million annually</u>.**

Figure 3: Plastic Packaging Waste Treatment in the UK 2016-2018

THE UK PLASTICS PACKAGING TREATMENT DATA	(1000 Metric Tonnes)		
	2016	**2017**	**2018 - From UK HMRC Govt Data**
Plastic Packaging Waste Arisings	2,260	2,350	2,444
Net Plastic Waste Exported Outside of EU (Net of Imports)	647	520	437
Plastic Waste Reprocessed in UK	331	358	343 (14%)
Total %: Exported & Reprocessed ("Recycled")	**43.3%**	**37.4%**	**31.9%**
Net Plastic Waste Dispatched to EU	59	55	89
Total %: Exported, Dispatched & Reprocessed ("Recycled")	**45.9%**	**39.7%**	**35.6%**
Plastic Waste Not Recovered	1,223	1,417	1,575
% Plastic Waste Not Recovered	**54.1%**	**60.3%**	**64.4%**

This figure may indeed be a gross under estimation. The below suggests that in 2014 the figure was already between £28 million and £108 million.

Data from a REA survey in 2014 suggest the following:

Excerpts from ORG document named **Organics Recycling Group proposal to other trade associations to improve the quality of biowastes,** dated 25/04/2014:

'Removing physical contaminants from source-segregated biodegradable wastes delivered to composting facilities (e.g. via picking lines, wind sifting etc.) is costing the industry an estimated £15.6 million to £78 million per annum. The cost of landfilling the process rejects is in the range of £12.8 to £19.1 million per annum.[95]'

Moreover, there is not just the financial element to consider, as the Call for Evidence asks. There is also the legal issue of what can be counted towards recycling. REA continues:

'…*the presence of physical contaminants in the feedstock materials may result in composts and digestates with a level of contaminants exceeding the PAS 100 and PAS 110 upper limits. This, in turn, will affect the amount of input materials that Local Authorities (LAs) ……. will be able to claim as 'recycled' in future. LAs will not be able to count towards their recycling performances input materials that are sent to composting and AD sites that [respectively] fail to comply with PAS 100 and PAS 110 specifications and [,where applicable,] the Compost Quality Protocol and the AD Quality Protocols…'*

The mandatory use of compostable carriers/bin liners, which need no extraction from food waste to be treated, would save the food waste treatment system a similar amount, whilst reducing the risk of non-compatible outputs going to soil and failing to reach PAS quality standards. Indeed, it was precisely for this reason that Italy, as noted above, in 2010 mandated the obligatory use of compostable bin liners for food waste collections and in 2012 the obligation for all single-use carrier bags to be compostable. Since then, in 2018, the French and Italians have mandated the use of compostable fruit and vegetable bags, having a dual purpose; as a food waste collection bag once brought home. Spain has discussed introducing a similar law taking effect in 2020.

27. What is the behaviour of bio-based plastics compared to conventional fossil-based plastics in the current waste management system?

There are three types of bio-based plastics used for packaging but we will focus upon two categories for simplicity: **bio-based but not compostable**, and **bio-based and compostable**. The first type acts in a similar way to traditional fossil-fuel based plastics and is known as a "drop-in". The most well-known article sold using a bio-based non compostable plastic for packaging is the Coca Cola Green PET bottle produced predominantly from raw materials derived from sugar cane in Brazil and whose properties are (for waste management purposes) identical to other PET products. These can be recycled through mechanical or in the future when available, chemical recycling but not through organic recycling. Their loss into the environment has exactly the same consequences of any fossil fuel plastic without biodegradation qualities.

Coca Cola bottle with its plant-based logo

[95] These figures have been provided by members of The ORG from a survey

The second type of bio-based plastic used for packaging is compostable. These materials are certified (as above, answers in Chapter 6) to the standard in the UK known as the ENBSI13432:2000 and have the characteristic of compostability in industrial composting plants where they decompose in a timeframe up to 180 days. Most films will decompose in a time frame of 20 to 40 days whilst thicker materials take longer.

Materials certified “Home Compostable“ (as above Chapter 6) will also compost in industrial facilities but are designed to compost in a well-managed home composting unit. The decomposition time can vary anywhere between several months and a year. From this we can understand that to ensure the correct treatment path for compostable plastics, they need to be delivered to composting facilities, or excluded from the waste management system upstream by being composted at home.

It is evident that in the current waste management system available in England sorting of materials (of various nature) is difficult and there are high levels of contamination between streams and falling levels of recycling. This applies to compostable materials too.

However there are clear signals that the commercial waste management sector is waking up to the opportunity offered by compostable plastics, organising collection where available in sufficient volumes in closed environments. The companies Vegware, Keenan’s, Forge Recycling, Paper Round and First Mile[96] have all introduced the separate collection of compostables where they are available in volumes, such as in offices, cafes, sites, events, buildings, where the stream can be controlled. The Parliamentary Estate[97] has adopted the use of compostable tableware and cups; during the transition from two to three waste streams, the compostables bin was contaminated and the first load was not of sufficient quality to be composted. Behaviour change activities proved successful and the second load has been sent to an industrial composting facility. According to Vegware,[98] today some 40% of UK post codes have access to a trade collection of Vegware compostables where they are derived from closed environments using them for catering.

Where compostables are used for drinks only, and only contain milk or cream residues, they may be composted in open windrow composting plants under conditions published in August 2018[99] and approved by the Animal and Plant Health Agency (APHA), Environment Agency and Scottish Environment Protection Agency.

- hot and cold drinks cups*,
- lids for hot and cold drinks cups*,
- drinks cup clutches / holders / sleeves*,
- drinks stirrers that consist of only untreated wood without any additives,
- drinks stirrers made of other compostable materials and/or include an additive*,
- straws*,
- coffee pods / capsules*,
- used coffee grounds,
- used loose leaf tea, and
- used tea in tea bags*,

Where identified with an asterisk the products must show a certification of compostability, as described in Chapter 6.

[96] https://thefirstmile.co.uk/service/compostables-recycling
[97] https://www.parliament.uk/mps-lords-and-offices/offices/commons/media-relations-group/news/uk-parliament-to-dramatically-reduce-plastic-use-through-new-compostable-products-/
[98] https://www.vegware.com/news/2019/04/10/uk-regions-with-tradecompostingcollections-for-vegwareclients/
[99] https://www.letsrecycle.com/news/latest-news/compostable-cups-green-light-composting/

Other compostable products used for food packaging and potentially contaminated with foodstuffs fall under the Animal By-Products Regulation and require composting in a facility that is approved for treating ABP materials. There are 53 industrial composting facilities in the UK with such a license.[100]

Currently these collection programmes regard the recovery of materials used for catering in business environments. Household collections of compostable packaging and materials are virtually inexistent throughout the UK. Consumers are likely to encounter and purchase compostable materials used as food packaging - primarily films, but also yoghurt pots and other rigid products such as trays made from PLA, coffee pods, tea bags, candy bar wrappers etc. Whilst these may be home compostable in certain cases, the more rigid, thicker materials require industrial composting to break them down. (In the same way a tree trunk is biodegradable, it requires years to effectively decompose, whilst a leaf, identical in biological terms, will decompose in weeks or days. So thicker, more rigid compostables require industrial processes to decompose.) It is unlikely at present that many of these are separately collected and sent to industrial composting but, like 65% of conventional plastics, are disposed of in landfills or incinerators (see Figure 2) in the UK.

One exception to this is the collection of food and garden waste with compostable bags or liners. These are widely accepted and used to bring organic material to composting and AD plants throughout the UK. Further, where retailers sell or supply compostable carrier bags with the purpose of using them also as bin liners for food waste collection, these bags are widely accepted as carriers for food waste in treatment facilities. The COOP Food Group has been especially progressive in this sense, supplying compostable carrier bags as a dual use bag in more than 1,000 stores.[101] The well-known case of Oldham in Lancashire demonstrates how the use of compostable carrier bags for food waste collections drives up participation rates among the public and reduces costs for the Council. A Council with a population of circa 230,000 people was able to demonstrate savings to the Council budget of £282,029 in avoided disposal costs and an increase in participation in food waste collections from 19% of the population to 96% (year of reference 2014/2015).[102]

Retailers are slowly introducing compostable bags for the collection of fruit and vegetables, such as Waitrose and Aldi, and we are expecting others to follow shortly. These may also be used to collect food waste and deliver that to treatment facilities.

One footnote, regarding disposal of compostable plastics that are not recovered in organic recycling but conversely are incinerated: in terms of end of life, PLA manufacturer NatureWorks conducted incineration testing at the optimum incineration temperature of approximately 1100°C (2000°F). The heat content of NatureWorks' PLA was determined to be 8,368 Btu/lb, which is higher than newspaper, wood, corrugated boxes, average MSW, garden waste or food waste. Further analysis showed no volatile gases and low residue, representing a significant advantage over oil-based plastics in incineration[103].

[100] https://www.gov.uk/government/publications/animal-by-product-operating-plants-approved-premises
[101] https://www.co-operative.coop/media/news-releases/shoppers-can-bag-compostable-carriers-at-co-op-as-retailer-ditches-single
[102] http://www.wrap.org.uk/sites/files/wrap/Oldham_Council_carrier_bag_case_study_Dec_2014.pdf.
[103] See page 765 for a table of results for VOCs from incinerating various plastic wastes: https://www.researchgate.net/publication/264141843_Analysis_of_VOCs_Produced_from_Incineration_of_Plastic_Wastes_Using_a_Small-_Electric_Furnace

28. How waste collection systems need to be adapted to accommodate the introduction of biodegradable plastics

The report published in May 2019 by Ricardo E&E on the scope of compostable packaging in the UK market[104] illustrates the potential for introduction of compostable packaging- some 138,000 tons in 2025 if certain conditions prevail. Given that overall plastic packaging represents some 2.5 million tons it is clear that the amount of compostables foreseen represent a niche in the market place, around 5% of current packaging. However, given the predominance of the use of compostables as films they could represent some 20 to 25% of plastic films used as primary consumer packaging.

Currently little or no plastic films are recycled. Data published by WRAP illustrate consumer films recycling to be around 4% of the annual volumes put onto the market[105].

There is an evident potential for compostable films to substitute the more difficult to recycle plastic films especially where food is packaged. By sending the film with waste food to composting, both the waste food and the packaging can be recovered, raising recycling levels and reducing plastic waste.

In order to achieve this potential, which (as the Ricardo E&E report illustrates) is around 138,000 tons, compostable packaging should be collected with food waste and destined to food waste treatment plants.

For this to happen, Councils and/or their licensed operators need to be authorised to collect compostable packaging with food and/or garden waste. Operators need to treat them, whilst householders need to be directed to place in the food/garden waste where they do not have home composting for thin films such as bags.

To enable this the Government should specifically define "biowaste" with a wider definition allowed under EU law in the 2018 Waste Framework Directive[106] as per Articles 3 comma 4 and 22 and which should be transcribed into UK law under the Environment Act in 2020 and notably:

"bio-waste" means biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants;

Member States may allow waste with similar biodegradability and compostability properties which complies with relevant European standards or any equivalent national standards for packaging recoverable through composting and biodegradation, to be collected together with bio-waste.

By allowing the collection of materials that are compostable with food waste, the UK Government gives a clear mandate that these materials may be collected and destined to organic recycling.

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[104] https://ee.ricardo.com/news/our-new-report-highlights-potential-tenfold-increase-for-uk-compostable-plastic-packaging-market-by-2025
[105] http://www.wrap.org.uk/content/plasticflow-2025-plastic-packaging-flow-data-report
[106] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L0851

29. How would waste collection systems need to be adapted to accommodate the mass introduction of biodegradable plastics?

We do not foresee in the next decade a mass introduction of biodegradable/compostable plastics. However, the same criteria for collection and treatment of those as answered in chapter 28 would apply.

30. How do anaerobic digestion, composting, and energy-from-waste operators currently manage compostable plastics in areas where food waste is collected in bags/liners?

Assuming that biowaste is collected with compostable packaging in it, what happens next? Currently the UK has a mixed final treatment system with composting on the one hand and anaerobic digestion plants on the other. Rarely do the two plants operate in the same site or in a connected way as they do, for example, in Italy.[107]

The consequence of this is that packaging waste of any nature sent to AD plants is stripped out and discarded, either in landfills or incinerators. We do not know the volume of food waste discarded with that packaging. Anecdotal evidence from Italy suggests it can be as high as 10% of the food waste delivered but technologies are improving and we believe this figure can in reality be lower.

In any case, an AD plant in the UK will strip out all packaging and dispose of it, with a certain loss of food waste and associated costs that we have seen above under chapter 26, which could be in the range of tens of millions of pounds annually.

A composting plant will be able to accept compostable packaging and, therefore, has only the cost of stripping out non-compostable packaging, such as plastics, aluminium, glass and other undesirable materials.

Logic would, therefore, beg the question: ***why not compost the packaging that comes from the AD plant where this is compostable?*** This is precisely what happens in Italy and many other European countries where either AD plants are "dry" i.e. take not just food waste, but compostable packaging and garden waste; or where the stripped packaging is sent to aerobic treatment with a part of the digestate that is an output from the AD process to produce nutrient rich compost.

Robin Szmidt of Target Renewables Ltd has made an analysis of the comparative efficiency of wet versus dry AD systems. He has written that: *"Elsewhere, particularly in mainland Europe, Anaerobic Digestion technologies that can receive and manage packaging within the digestion process are more widely employed. In particular so-called Dry-AD systems typically are capable of receiving packaging material in the feedstock, together with a higher level of physical contaminants than tolerated by Wet-AD systems. Dry-AD systems that can do this are generally referred-to as plugflow or batch systems. They normally operate in the thermophilic (high temperature) range which is relatively high compared to the mesophilic (low temperature) range commonly seen in the UK."* Examples of such installations can be seen at:

https://www.thoeni.com/en/energy-engineering/

http://www.hz-inova.com/cms/en/home?page_id=543

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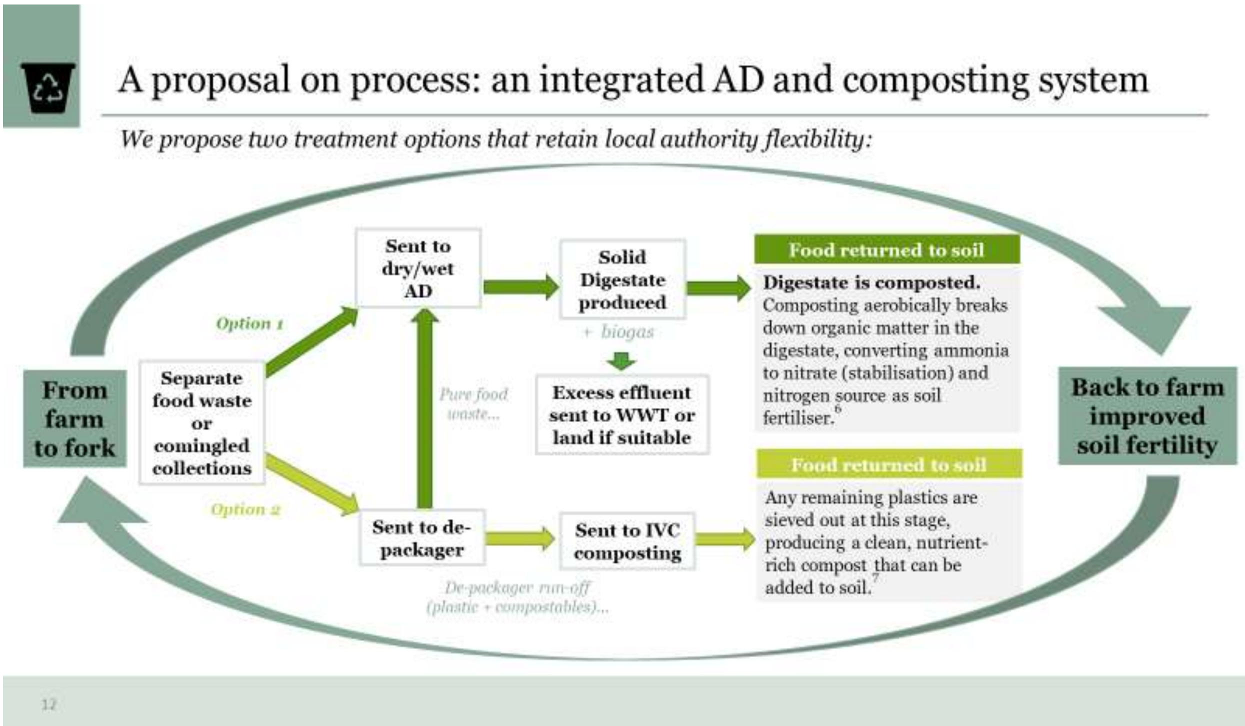
[107] https://www.compost.it/en/

Systems that can be designed to include a proportion of non-biodegradable materials, whether naturally occurring or waste, tend to result in a higher level of recovery of that material if biodried, post-AD. There is little reliable data in this regard but as an example, the Thoeni-built Dry-AD facility at Gavle, Sweden, was specifically designed on this basis. At that site, post-AD separation allows a higher degree of product quality (lower product contamination) that might be expected under UK conditions. A similar approach is being adopted at a number of, particularly, Scandinavian sites. Such sites are generally designed to a level of > 90% biological efficiency and to a level of contaminant removal that exceeds that required under PAS110 or PAS100."[108]

Dry AD or combined wet AD and composting systems may have extra costs compared to the current UK model where wet AD dominates, but they also offer notable savings in disposal costs from the current model. The benefits are manifold, including reducing plastic waste, sending less food waste to landfill/incineration, storage space for waste plastics on site, and the production of compost rather than wet digestate with consequent benefits to farming, soil quality, ammonia emissions and nitrate run-off.

This combined model could look something like this:



Of course, there are many variants possible. **What is important in terms of compostable packaging is that the packaging is sent to recovery with the food waste attached to it rather than to disposal. For this to happen, the packaging being received by both AD and composting plants would need to be largely free of contamination. This is another reason why mandating collection of food and garden waste with compostable materials is the right way of approaching a resource efficient circular economy model.**

Compostable plastic films compatible with the short cycle of an AD plant (less than 30 days) are recently available on the market place.[109][110][111][112] Where collection schemes can use

[108] Paper available upon request
[109] http://www.futamuragroup.com/sustainability/certifications/
[110] https://www.aquapakpolymers.com/biodegredation/

these materials and there is a low level of contamination, AD operators would not need to even extract them from the food waste, but can digest them together.

Fortunately for the UK the number and size of AD plants treating food waste is relatively small, around 75[113][114] and they are not yet individually of a scale comparable to similar EU countries. Therefore, we have the opportunity now of getting the system corrected before we start to collect and treat greater volumes of food waste. Individual plants in Denmark[115] and Italy[116] are now treating over 500,000 tons p.a. of food and garden waste together, extracting energy and producing compost. Two of these plants combined, treat more food waste than England - the opportunity for change in England is now, rather than maintaining a system that has evident loss of materials, energy and consequences in terms of air[117] and soil quality[118]. 55% of English land is classified as a Nitrate Vulnerable Zone[119] where the seasonal opportunity for spreading of wet digestate is short – **by combining anaerobic digestion and composting to produce a dry, solid material, organic carbon as well as nutrients can be returned to soil with lower risks of nitrate leaching and for a longer season. As the increase in food waste to AD will be significant over the next years, it is vital we get the use of outputs right now.**

As regards EfW operators, we have to assume the waste is all incinerated. We have no other evidence.

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[111] https://www.novamont.com/eng/leggi_press.php?id_press=42
[112] https://products.basf.com/de/ecovio.html
[113] https://anaerobic-digestion.com/anaerobic-digestion-plants/anaerobic-digestion-plants-uk/
[114] http://adbioresources.org/map
[115] https://www.renewableenergymagazine.com/biogas/eastern-denmark-s-largest-biogas-plant-ready-20180622
[116] http://www.montello-spa.it/anaerobic-digestion-with-biogas-production/?lang=en.
[117] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf
[118] https://publications.parliament.uk/pa/cm201719/cmselect/cmenvaud/656/65607.htm
[119] https://www.gov.uk/government/collections/nitrate-vulnerable-zones

Appendix 1

Factors Affecting the Life Cycle Assessment of Biopolymers

Factors Affecting the Life Cycle Assessment of Biopolymers

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October 2019

Life Cycle Assessment (LCA) is a widely used approach for calculating the eco-profile of a product or production system. Its use has escalated in the last fifteen years, seeing it replace a number of other methods that typically focused on a single environmental impact category, and it is LCA's broad spectrum of analysis that makes it so appealing. However, whilst LCA is the most comprehensive environmental footprinting tool available, interpreting its output is not without its challenges and those seeking information from LCA reports need to do so with a certain amount of care.

Two standards outline the principles and requirements for conducting LCA, namely ISO 14040 and ISO 14044. By design, these allow analysts the flexibility, within defined limits, to shape studies to suit their own research needs. There are good reasons for this - unlike established product carbon footprinting protocols (such as PAS 2050 and GHG Protocol) LCA emerged not as an organisational eco-reporting standard, but as a research tool. However this does mean that the results from one study are not necessarily readily comparable with results from another. Whether setting system boundaries, selecting approaches to co-product allocation, or using an attributional versus a consequential modelling paradigm, these decisions all radically affect headline results and this can confuse the casual / non-technical reader. Over time, as LCA has become more central to organisational product footprinting (in particular, with a view to informing green marketing opportunities) this flexibility has led to some frustration as to the way LCA studies can potentially be shaped. Whilst this criticism is usually (though not always) unjustified, there is still a need for greater harmonisation of the approach when it comes to using LCA for product reporting purposes and to this end, work is underway to update the ISO standards (originally issued in 2006). This work is currently at an early stage.

Schemes such as the International EPD (Environmental Production Declaration) System[1] were set up to address this issue. In principle, these schemes take LCA results, critically review them, and then re-present them in a unified format for wider consumption. Underpinning the EPD principle is a catalogue of sector-specific Product Category Rules (PCRs) that outline modelling requirements for particular sets of products within a single product category. In theory, this ensures that results for products within the same sector are directly comparable with each other. A PCR for primary plastics[2] has recently been updated (Sept 2019) although there don't appear to be any EPDs published currently for bio-polymer products.

Despite this, it is clear that from a global warming perspective, biogenic carbon is the single biggest selling point for bio-polymers over fossil-derived alternatives. So long as methane formation is avoided when the polymer degrades at end-of-life, then carbon embedded within the structure of the polymer returns to the biosphere with a neutral balance. This is of course in contrast to all petro-plastics, where fossil-derived structural carbon adds to the overall GHG burden on decomposition. However, since most product carbon footprints are reported on a cradle-to-gate basis (i.e. accounting for emissions up to the point at which the product leaves the factory gate) this benefit, which is realised later in the lifecycle, is not readily represented in the cradle-to-gate reporting. One frequently used workaround is to report biogenic carbon uptake as a 'negative emission' within the cradle-to-gate footprint, essentially representing it as a stored benefit to be released at a later date. This is the approach used by Natureworks in their peer-reviewed eco-profile for Ingeo® PLA[3] (figure 1). Another approach is to report biogenic emission flows separately to the main numbers and this is the approach specified by the PCR for primary plastics. Whichever approach is taken, it is important for the bio-polymer sector (as it has been for the wood products sector) to recognise the importance of biogenic carbon to the eco-profiles of these materials, and to push for clear, consistent reporting mechanisms that unambiguously reflect this benefit in the reporting standards.

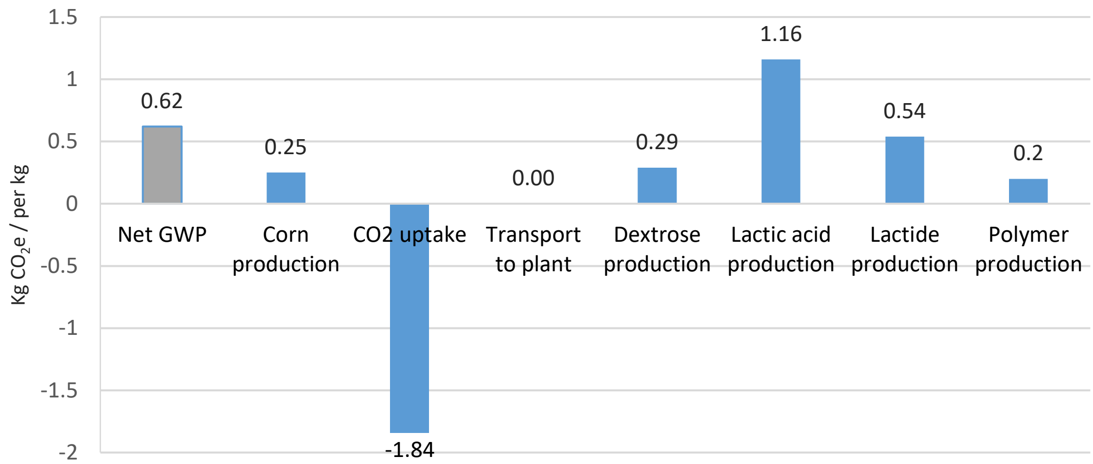

Figure 1: Global warming potential of 1 kg Ingeo PLA (cradle-to-gate); biogenic carbon content represented as a negative emission (reproduced from Vink *et al.* 2015)

While representation of biogenic carbon is a key opportunity for biopolymer carbon accounting, it is their scale of production that currently represents the biggest challenge. Aside from PLA and starch, LCA data of most other biopolymers is currently only available at lab or pilot-scale with all the inherent inefficiencies that this implies[4,5,6]. Furthermore, of the existing publications, proposed feedstocks and production technologies differ from study to study and as the research evolves. Perhaps unsurprisingly given the production scale, process energy is typically reported as a dominant hotspot for these earlier stage polymers. Optimisation is the key opportunity in terms of driving down reported footprints.

In terms of PLA and starch, life cycle inventory (LCI) data is available from the licensed LCI databases (that provide the detailed environmental impact datasets that underpin LCA). The dataset for starch is based on highly aggregated background data from a 2004 Materbi study by Novamont and available from the Ecoinvent database. This returns a cradle-to-gate GWP of 1.5 kg CO_2e per kg granulate, though this data would benefit from being updated. Data for PLA is available through the USLCI database and is based directly on the 2015 Natureworks publication[3]. This returns a GWP of 2.5 kg CO_2e per kg granulate (or 0.6 kg CO_2e when biogenic carbon is factored in). These results compare favourably to traditional fossil-plastics when compared on a mass basis (figure 2), though the data for PLA is specific to Natureworks' Ingeo.

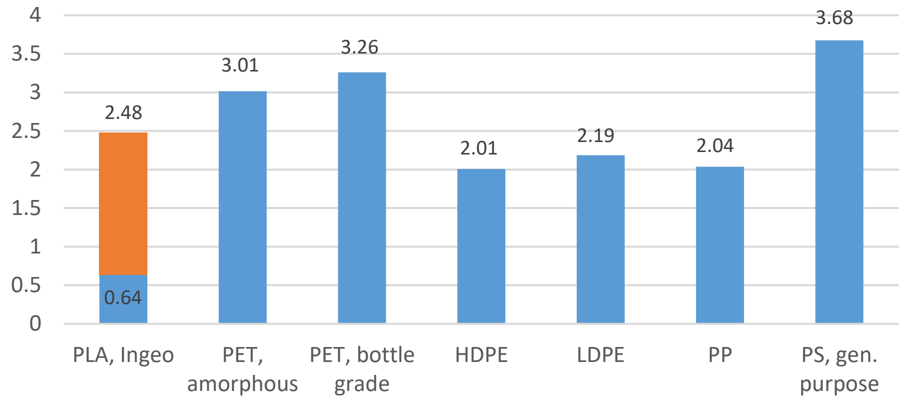

Figure 2: GWP of various polymers, 1 kg granulate. Results for PLA presented with / without biogenic carbon accounted for (orange block represents CO_2 uptake). [Source: PLA, USLCI database; Rest, Ecoinvent database]

Several studies have been published for bio-PBS production (or more accurately hydrid-PBS, using bio-based succinic acid and fossil 1,4 butanediol)[7,8,9]. Again, these studies are based on sub-commercial processes, though Tecchio *et al.* used a theoretical scale-up model to attempt to account for this. Their study reports a GWP of 4.17 kg CO_2e per kg for future industrial production under their best scenario (sugarcane feedstock and electrodialysis extraction). This would reduce to 2.12 kg CO_2e if biogenic carbon content were credited in the same way that Natureworks adopted for their Ingeo eco-profile. Other modelled feedstocks were maize starch and lignocellulosics and the other processing technology was crystallization extraction, though these returned higher results. Bio-PBS is now produced commercially by Mcpp / Mitsubishi in Thailand but they have not as yet released LCI data for their product. A peer-reviewed eco-profile for Mitsubishi's bio-PBS would be a welcome addition to the data.

As indicated by the results above, variability of feedstock and processing choices in bio-polymer production is an issue for the consistency of their eco-profile results. Unlike fossil-derived plastics, where the feedstock is uniform and the production technology already highly evolved, bio-polymer production is likely to vary from location to location. PLA, for example, is currently produced from maize, sugar cane, sugar beet and cassava feedstocks. Each of these has a different agricultural footprint and this may vary significantly from farm to farm, and region to region, depending on the farm management system, fertilizer use, climate, soil type, degree of intensification etc. (figure 3).

Similarly, GHG emissions associated with process electricity are highly dependent on the country of production, depending on the carbon-intensity of the local grid (figure 4). Given bio-polymers early stage of development, they are currently manufactured by a relatively small number of large manufacturers, typically with a single site of production. Where these sites are located in countries with relatively high-carbon intensity grids, GWP's for these bio-polymers will suffer relative to fossil-plastics produced in relatively low-carbon economies (such as the EU). Whilst this may affect some bio-polymers now, this effect will dissipate as more bio-polymer plants come online and as nations across the global move to further decarbonise their grids. In the meantime, whilst generic industry data is acceptable for use in determining petro-plastic profiles, biopolymer profiles may need to be determined on a company-by-company, site-by-site basis, in order to capture the effect of this variation.

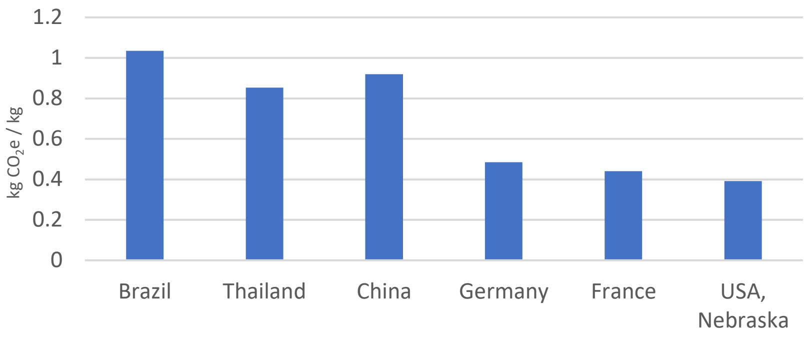

Figure 3: GHG emissions associated with production of 1 kg maize, at farm gate, by country [Source: Agri-footprint LCI database]

An important advantage to some bio-polymers relative to fossil alternatives, is their enhanced degradability. Whilst this is a clear benefit in terms of dealing with plastic waste accumulation in the environment, modelling GHG emissions from composts in LCA is complex and subject to significant variability. Assumptions around the generation of decomposition gases, in particular CH_4 and N_2O (powerful greenhouse gases) vary by several orders of magnitude, even within assessments of the same composting technology[10]. Studies suggest that anaerobic digestion returns better LCA results, primarily due to the modelling of post-degradation products (compost, digestate, bio-gas etc.)[11,12,13]. Not all bio-polymers will degrade anaerobically (e.g. PBAT).

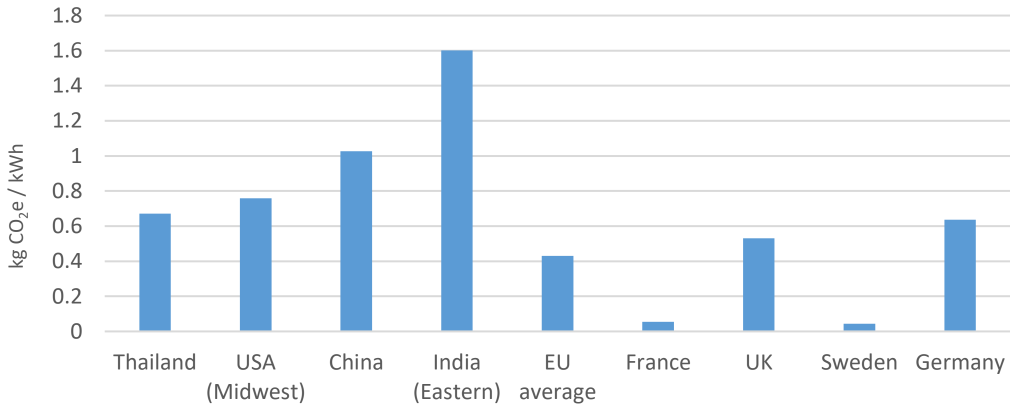

Figure 4: GHG emissions associated with 1 kWh medium voltage electricity from various national grids, incls. transmission losses [Source: Ecoinvent LCI database]

Where possible, recyclability is the preferred route from a LCA and circular economy perspective. As such, the lack of established collection systems for bio-polymers, such as PLA, is often cited as a disadvantage to their use. This needs to be addressed if they are to become more widespread in the marketplace, and policy may need to drive this until volumes become such that recycling is economically self-sustaining. Finally, it is worth noting that LCA has no mechanism by which to assess littering *per se* (other than as a source of resource depletion), and is not currently well equipped to report on impacts associated with the long-term presence of microplastics in the environment. There is some academic work underway to develop metrics for LCA that will address this.

In summary, bio-polymers have an inherent advantage over fossil alternatives in terms of the biogenic carbon content of their structure. LCA analysts have used different approaches to representing this benefit in their modelling and when reporting their results, and more uniformity is needed around this point so that this benefit is clearly communicated. Counter to this, the current early stage of development of many bio-polymers has a disadvantageous effect on their eco-profiles when compared to the highly optimized, large-scale production processes of fossil-plastics. Scale-up is needed and this will bring economies of scale that will be to the benefit of the emergent bio-polymer profiles. Despite this, some care will still be needed when considering bio-polymer profiles given the variability of feedstocks and processes that are likely to remain a feature of global bio-polymer production. Within the UK (and more broadly) biopolymer collection systems are desperately needed to further drive market uptake whilst simultaneously driving down the cradle-to-grave environmental impacts of their use.

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