Final Report

Local Sustainable Material Alternatives for Cricket Pads & Gloves

Dr Darshil U. Shah

Centre for Natural Innovation

Department of Architecture

University of Cambridge

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1. Introduction

Cricket is the second most popular sport in the world; over 200 million people play cricket regularly. Notably, cricket is also one of the most equipment-intensive sports. In fact, there are over 40 different types of specialist cricket gear [1,2], each of which comprise of multi-component materials that are derived, processed and assembled through complex and global supply-chains. While cricket's governing bodies, clubs, and players are becoming interested in and aware of issues around sustainability, current designs and material choices of cricket gear are not sustainable. For example, manufacturers do not consider embodied emissions of the component materials, design for manufacture and assembly (DfMA), design for disassembly (DfD), and strategies for end of product life management as part of cricket gear design and manufacture.

The Centre for Sustainable Design ® (CfSD) at the University for the Creative Arts (UCA) and the Centre for Natural Material Innovation (CNMI) at the University of Cambridge have collaborated on a number of projects in the past couple of years, pioneering circular cricket gear through concepts and visions, focussed stakeholder engagement across the product value-chains, and dedicated experimental and action research. Based on the 10R hierarchy[3] in the pursuit of circular cricket gear products, a priority has been design innovation for extending the life of the product. Secondary to this approach, the substitution of high environmental impact materials – in the primary production stage of cricket gear or as part of refurbishment, repair, and remanufacture processes – with more sustainable alternatives has been another focal point. For example, a report that is available via the Platform for Acceleration of Sustainability in Cricket (PASIC)[1,2] started by identifying the range of materials used in cricket gear at present and the scale (quantities) of end-of-life waste generated. Subsequent projects, such as the AHRC IAA-funded Vegan Leather Cricket Gear project (VLCG) [4] focussed on identifying and testing alternative leathers (ranging from plant-based to fish-waste based) for use in cricket balls, pads and gloves. The UKRI CE-Hub funded Circular Cricket Gear project [5] focused on identifying relevant product circularity strategies for the cricket gear sector, and within this material substitution strategies. The Circular Cricket Gear project [6] also identified a range of sustainable alternatives that may replace current component materials, based on the function requirements they satisfy in the cricket gear.

The vast amounts of cricket gear are now produced primarily in the Indian subcontinent. No cricket gear 'softs' (e.g. batting pads and gloves) are produced in the UK. There is an opportunity to rejuvenate primary production of cricket gear in the UK, or at the very least pioneer end-of-first-life cricket gear management schemes (such as repair, refurbishment, remanufacture). The use of materials from the UK will not only reduce emissions related to transportation of materials, but also bring agility in rapid prototyping, and offer a footing for a resilient locally based circular supply-chain. There are also likely to be positive social impacts, through emphasis on craft, skills and jobs. Indeed, these are all considerations as

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[1] Charter, M. and Clark, T. (2022), Sustainability, Cricket Gear, Clothing and Apparel: Report on Cricket Gear.

[2] Wetherfield, M., Charter, M., Shah, D., Whitaker, C. (2022) Sustainability, Cricket Gear, Clothing and Apparel: Report on Components, Materials, and Innovation Opportunities.

[3] Cramer, J. 2017. The Raw Materials Transition in the Amsterdam Metropolitan Area: Added Value for the Economy, Well-Being and the Environment, *Environment*

[4] Taylor, B., and Shah, D. (2023) Leather Alternatives for Cricket Gear.

[5] Taylor, B., and Shah, D. (2023) Application of Vegan Leathers for Cricket Balls and Gloves.

[6] Shah, D., (2023) Materials in cricket balls, gloves and pads and their sustainable alternatives.

part of 'what if' and 'how to' exercises: e.g. what-if cricket gear production came back to the UK, and how can we enable this transition as part of a strategic and longer-term initiative. Such exercises may not only lead to new concepts of designs, materials and material supply-chains, but also drive cricket-governing bodies and typically conservative and innovation-averse cricket gear manufacturers to prioritise sustainability and local production.

As part of the AHRC IAA-funded Advancements in Circular Cricket Gear (ACCG) project [7], this report aims to identify lower-impact local materials, and in particular bio-based materials, as alternatives for use in cricket batting pads and gloves. The report also presents potential routes to valorise food waste (production or post-consumer) for the manufacture of such biomaterials in the UK. The work is based on a mix of desk and primary research.

2. Current Materials in Cricket Pads & Gloves

Cricket batting pads and gloves are personal protective equipment (PPE) worn by cricketers to reduce injuries from impact by cricket balls. The relevant performance criteria for both are similar: light-weighting, impact absorption, durability (abrasion and wear), breathability, colour fastness and ability to incorporate advertising features. Colloquially, they are also referred to as 'softs'. Both PPEs are described by the BSI EN 6183 group (*Protective equipment for cricketers*). The standards principally specify dimensions and geometries for the specific PPE depending on the player's characteristics (e.g. sex, height), the effectiveness of the restraint system, as well as impact performance of the PPE product. However, neither BSI 6183-4:2001 ('*Gloves for batsmen*') nor BSI 6183-3:2000 ('*Leg protectors for batsmen…*') specify any materials.

Cricket pads and gloves are – and have always been – complex, multi-material products with intricate assemblies. Disassembly exercises by Dr Sanchez-Moreno and Professor Charter as part of the Circular Cricket Gear project exemplified this clearly[8]. Materials currently used in pads and gloves have been plotted on the materials property chart (Figure 1). Such a chart demonstrates the diverse property profiles of materials that are combined together to offer cricket gear products their requisite performance. A key observation is that current materials used in batting pads and gloves are *principally* synthetic plastics (100% fossil fuel derived) with a marked carbon footprint. Indeed, as found by Dr Sanchez-Moreno and Professor Charter, around 80% of the mass of a pair of cricket batting pads is fossil-fuel based synthetic plastic which accounts for virtually *all* (95%) of the materials and transport related emissions (ca 2.6kg CO2 equivalent). In particular, polyester in the product's lining and mesh, and high-density polyurethane foams for the protective padding are the main contributors to the carbon footprint. On the other hand, while cane and paperboard – the only bio-based materials already currently used in batting pads – account for 20% of the mass of a pair of cricket batting pads, they account for only 5% of the embodied carbon.

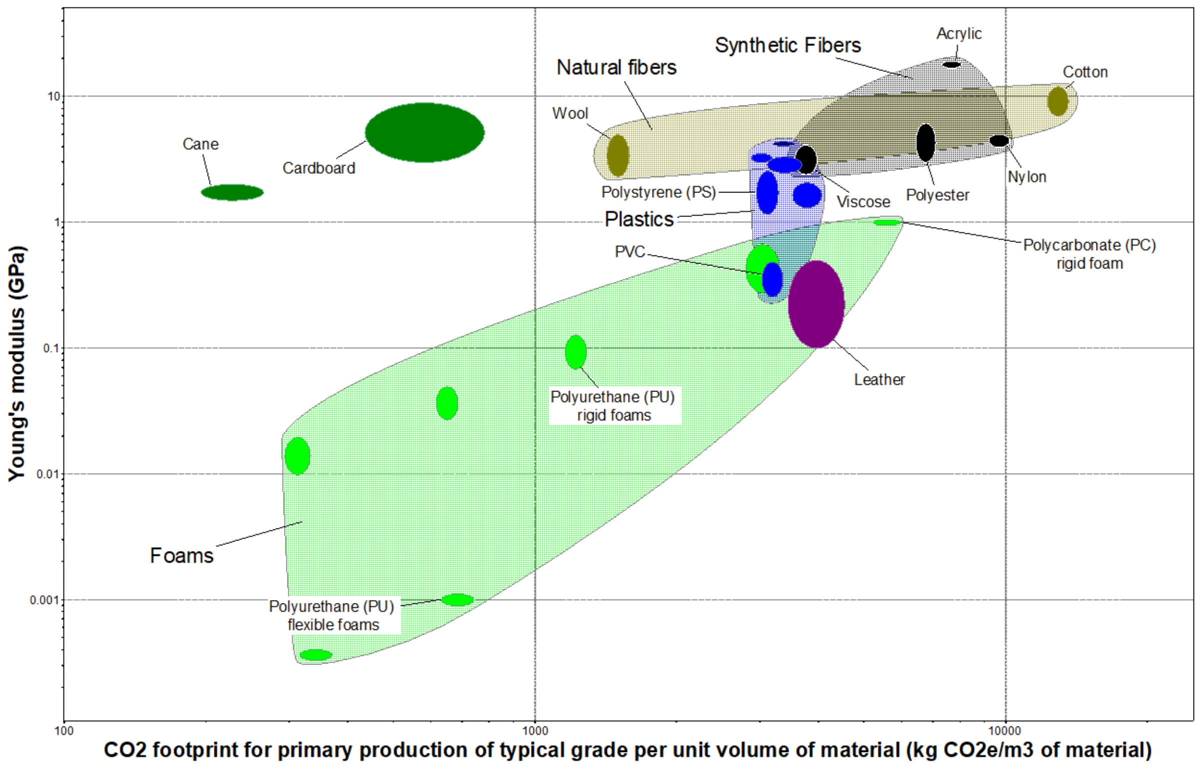
In addition to the materials, the property chart also groups these materials into i) Foams (e.g. flexible or low-density and rigid or high-density polyurethane foams), ii) Natural Materials (cane, card/paperboard, leather), iii) Plastics (e.g. polystyrene, polypropylene, PVC) and iv) Fibres (Synthetic & Natural). Notably, the density of all the materials used is typically below

[7] https://cfsd.org.uk/projects/accg/

[8] Sanchez-Moreno, L., Charter, M., (2023). Streamlined Life Cycle Assessment: Pair of Cricket Batting Pads.

ca 1,500 kg/m^3 (reference density of water is 1,000 kg/m^3), and therefore clearly lightweighting is a prioritised property even in PPE cricket gear. The materials are typically in the form of foams (padding), fibres and textiles or sheets (leather casing) for wrapping, or bulk materials (kneecap) when a specific defined shape is needed. For cricket batting pads and gloves, materials selection and their forms are driven by requisite function, and the following material groups can be identified:

- Rigid, impact-resistant, lightweight (moulded plastics, composites)
- Cushioning, impact-resistant, lightweight (foams, fibre fill and wadding)
- Breathable linings and skins (fibres, textiles and leathers)
- Coatings and Adhesives



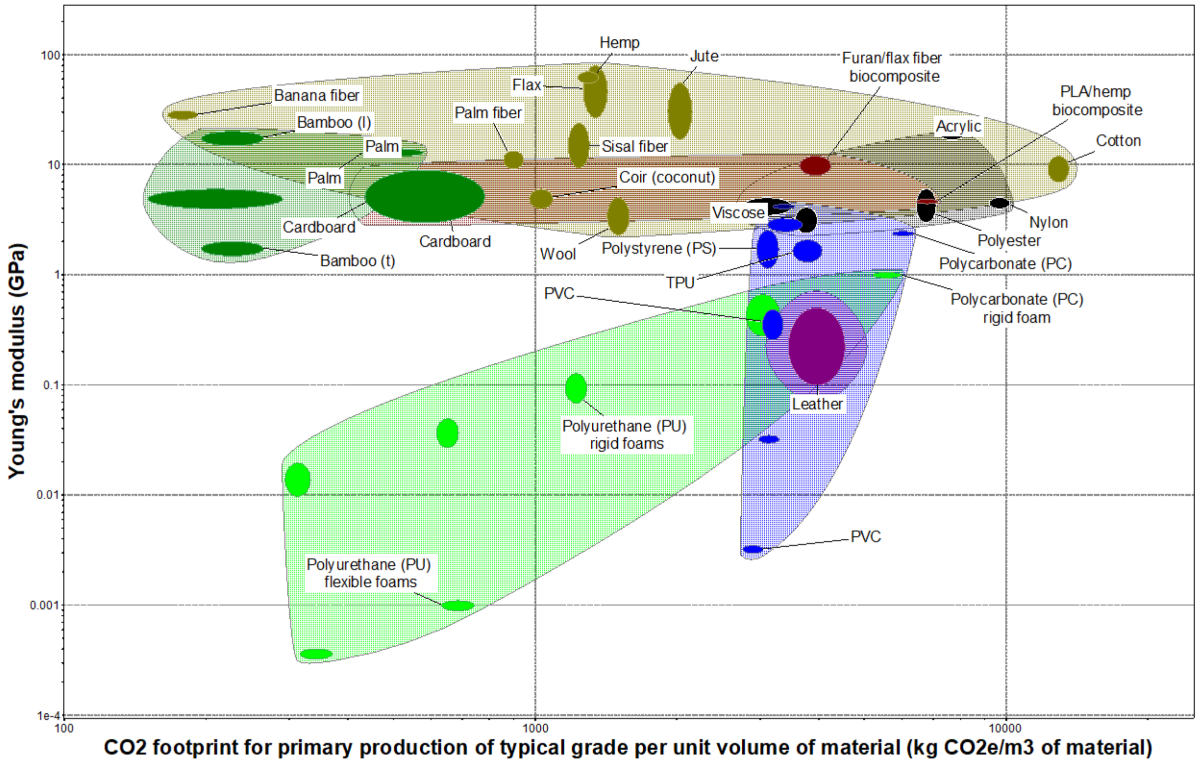


Figure 1. Materials property charts (Ashby charts) illustrating the range of conventional materials used in cricket pads and pads (TOP). In the BOTTOM graph, alternative materials are also included.

3. Alternative Sustainable Materials for Cricket Batting Pads and Gloves in UK

A range of sustainable material alternatives are available. Many of these have been listed as part of the Circular Cricket Gear project [9]. Here, we focus on low environmental impact materials – or rather 'lower' environmental impact materials than current materials – that are produced (or at least part-produced from imported raw materials) in the UK. These are also illustrated on the material property chart in Figure 1. As a cautionary note, we emphasise here that these are considered as 'lower' environmental impact notionally, as they may be bio-derived (less reliant on petrochemical or non-renewable resources) or have lower embodied energy or carbon footprint. Although it is recognised that a full life-cycle assessment is necessary, including consideration of wider environmental impact indicators, scale-effects and complexities in supply-chains.

A longer list of these materials and UK-based producers has been generated as part of AHRC Design Accelerator funded Circular Cricket project. Below is a synthesised list of alternative lower impact materials produced in the UK and grouped under generic categories:

- Bio-based polymers and plastics (e.g. PLA/PHA, seed-oil derived plastics, starch-based plastics)
- Bio-based composites (e.g. flax reinforced PLA)

[9] Shah, D., (2023) Materials in cricket balls, gloves and pads and their sustainable alternatives.

- Fibres and textiles: plant-based; animal-based (e.g. wool); insect-based (e.g. silk); semi-synthetic (e.g. viscose)
- Wood and wood pulp based materials
- Leathers and alternative leathers
- Micro-organism based (e.g. algal materials; mycelium/fungal materials)

Indeed, most of these lower-impact materials are 'biomaterials' or 'bio-based materials', that is, they are wholly or partly derived from biomass (e.g. wood and biocomposites, cotton and plant fibres). In some cases, they could be referred to as 'biosynthetic materials'. Biosynthetic materials are a subset of biomaterials and involve bio(chemical) processes using biotechnology and/or biofabrication carried out by living cells and/or microorganisms (e.g. protein, bacterial, microbial, enzymatically driven processes, and PLA/PHA, mycelium, algal materials). Biosynthetic materials are a new and growing category of materials. Notably, while the majority of lower-impact materials are bio-based – and typically plant derived – they do need processing (e.g. (bio)chemical, mechanical).

Due to the global nature of supply-chains today, there are very limited cases where the entire production and value chain is completely UK-based. In the majority of cases, materials are part-produced in the UK with raw materials being imported. Notably, plastics, textiles and paperboard (or wood-derivative products) are amongst the top commodities imported by UK [10], and these are the main materials used in cricket gear 'softs'. Nevertheless, there are some UK materials industries that present interesting opportunities related to the provision of lower-impact alternatives:

- Some industries are currently under-utilised (e.g. wood and wool) and need diversification and resource efficiency for first uses in higher value applications and strategies for cascading uses (e.g. into lower value products).
  - UK-based wood resources are under-utilised and there is an over reliance on imported timber. Based on findings by Forestry Research[11], around 80% of wood used in UK is imported. The majority of UK hardwood deliveries (83-84% on 0.8Mtonnes in 2022 and 2023) were used for wood fuel, i.e. harvested to burn directly for energy. No hardwood is used for making pulp/paper or wood panels in the UK. Although only ca. 10% of softwood was used for wood fuel, ca 70% of sawn softwood finds uses in fencing and packaging/pallets. As an aside, it is noteworthy that UK is the world's largest exporter of cricket bat willow, exporting of the order of 500-800tonnes.
  - Wool is an under-valued and under-utilised natural product in the UK [12]. While the value of wool was around £14/kg in the 1950's in the UK, this has dropped to <£1/kg since 2019. UK accounts for <3% of global wool production, and wool accounts for <1% of global fibre production. DEFRA, the British Wool Marketing Board and its member farmers and industry

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[10] UK Department for Business & Trade. (2024) Official Statistics. UK trade in numbers (web version – 19 June 2024) https://www.gov.uk/government/statistics/uk-trade-in-numbers/uk-trade-in-numbers-web-version
[11] Forestry Research. (2023) Forestry Statistics 2023 Chapter 2: UK-Grown Timber. 28 Sept 2023. https://cdn.forestresearch.gov.uk/2023/09/Ch2_Timber.pdf
[12] Department for Environment Food & Rural Affairs. (2023) Research and analysis. British Wool Review 2022. 27 March 2023. https://www.gov.uk/government/publications/british-wool-review-2022/british-wool-review-2022

representatives have been making an effort in the past decade to diversify the applications of wool. These include the use of wool as an insulative fibre for food, pharmaceuticals and in construction. Wool is also being considered for engineering, automobile, horticulture, and consumer products (e.g. luggage trolley bags). Wool could be used to create the cushioning, impact-resistant, light-weight components in cricket batting pads and gloves (e.g. fibre fill and wadding) or perhaps textiles and meshes.

- Some industries (e.g. fibres and textiles) have been in decline and endangered (e.g. a few mills) and need support for revival. The fibres and textiles sectors have a diverse and broad value-chain, supporting many other industries.
- Some industries (e.g. biosynthetic materials) are in infancy, but well-supported through research and innovation, and need further support to grow and up-scale.
- There is scope for using recycled materials, or agro/food-waste materials, however such companies need well-connected supply-chains and large-volume productions for resilient business models.

There are a number of challenges that such lower-impact biomaterials face in terms of their applicability for the specific cricket gear. Firstly, many of these materials may be 'new', or at least 'new' to current manufacturers. The cricket gear manufacturing sector is innovation-averse, and perhaps restricted by the stringent standards and laws of the games. Consequently, manufacturers may be hesitant to adopt 'new' materials. Being a conservative and risk and innovative averse industry, the cricket gear production sector may also be hesitant to change supply-chain dynamics and explore new sources of materials. Secondly, the 'sustainability' of these potential alternative materials needs to be demonstrated through LCAs and more holistic analysis, including consideration of which impact indicators ought to be prioritised. Finally, scale and scalability and supply-chain considerations are critical to their successful deployment in the sector. It is likely that current manufacturers have a long and established relationship with their raw materials suppliers to produce their products.

3.1 Materials availability in the UK and the role of bioplastics

A growing list of various producers in UK has been generated, as part of the AHRC Design Accelerator funded Circular Cricket project. Notably, none, if any, biomaterials have previously specifically targeted sporting gear (beyond shoes/clothing or perhaps automotive and transport components).

It is also worth re-emphasising that materials supply and value-chains are increasingly dispersed: a very small fraction of companies are fully UK-based. In most cases, feedstocks (raw materials) are imported. If we take Vegware – a renowned British bioplastic packaging company and brand – as an example: the vast majority of their product material constituents are imported to the UK [13] (paper and card, polylactic acid, moulded fibre, palm leaf, inks, NatureFlex, BioPBS, Mater-Bi).

[13] Vegware. https://www.vegware.com/uk-en/page/our-materials/#:~:text=As%20such%2C%20our%20supply%20chain,are%20in%20their%20finished%20form.

Given the large use of petrochemically-derived polymer based materials in cricket pads and gloves, exploring sustainable alternatives to these – e.g. in the form of bioplastics – is important. The production of plastics in UK has stagnated for the past 10 years, and the UK consumes (3.3Mtonnes) twice as much plastics as it produces (1.67Mtonnes) and hence is a big importer of raw material. The compostable bioplastics packaging market in the UK is ca 50Ktonnes.

Biopolymers exist in nature (e.g. cellulose, starch, lignin), or can be processed from bio-based feedstocks (e.g. PLA, Bio-PE, Bio-PBS). It is noteworthy that even if a material is bio-based, it does not necessarily follow that it is biodegradable (i.e. will break down naturally in the environment). Professor Callum Hill's report on biopolymers to the Climate Change Committee [14]provides in depth report on the state of bioplastics in the UK. Bioplastics account for a very small share (0.5-1%) of the 300-400Mtonnes global plastics market. Rigid and flexible packaging are the largest target market segments for bioplastics.

The low price of oil – and in contrast, relatively high, and equally volatile price of bio-based feedstocks – has meant that companies producing bio-based feedstocks for bioplastics are focussing on low volume markets (such as in cosmetics, nutrition and flavours, pharmaceuticals and fine chemicals, and niche markets). As an example, the price of oil (for petrochemical feedstock based synthetic plastics) is ca £450/tonne, and the landfill cost for waste is £100/tonne. However, biobased feedstocks can cost anywhere between £250-£1000/tonnes depending on quality. The UK is a slow adopter of bioplastic production, in part due to the fewer (quantity and quality) and expensive bio-based feedstocks locally available. Starch as a future plastic feedstock: UK grows wheat and potatoes, both of which are low-value starch feedstocks [15] (e.g. 250-350£/tonne import value), versus higher value maize and cassava (350-1000£/tonne import value). Quality yields and value will be even poorer/lower if waste (rather than virgin) wheat/potato is used. Consequently, bioplastics is not the first target market for starch feedstock producers. For example, the UK starch industry extracts 0.8Mtonnes from cereal grains (0.7Mtonnes of UK wheat and 0.75Mtonnes of maize from France) and processes it. The bulk of starch products (70%) are used for sweeteners.

For bioplastics production to gain further traction in the UK

- Fossil fuel prices need to be much higher
- Prices of bio-based feedstocks, such as sugars and starches, will need to be much lower (but at the same time have higher quality and availability than non-bio-based feedstocks)
- Continued technological progress, including in up-scaling, utilisation of biomass, biosynthesis and processing technologies

While bioplastics will be important candidates as material alternatives for many of the material ingredients in cricket gear 'softs', it is worth highlighting that:

- Based on LCAs (cradle-to-gate), effectiveness of biopolymer alternatives to reduce carbon emissions is unclear. In many cases biopolymers such as PLA, PHS, Bio-PET can have similar carbon footprints to PE, PET, PP, PS, PVC. Indeed, as a significant

[14] Hill, C. (2018). https://www.theccc.org.uk/publication/biopolymers-bio-based-plastics-an-overview/
[15] British Plastics Federation.
https://www.bpf.co.uk/plastipedia/polymers/Biobased_plastics_Feedstocks_Production_and_the_UK_Market.aspx

proportion of bio-based feedstocks are imported (i.e. there are transport related emissions), and the production of such feedstocks requires extensive use of land and water, bioplastics may perform worse than synthetic plastics in some environmental impact indicators. There are also long-standing debates in academia and industry – due to the lack of clear LCA standards or guidelines – as to how the environmental burden of secondary or waste stream resources should be accounted.

- While transportation contributes to carbon emissions, mode of transportation has an important effect on the magnitude of this contribution. E.g. road (80gCO2/tonne/km) vs shipping (3-8 gCO2/tonne/km). So for example, there can be fewer emissions to transport by ship from Canada than by road from Scotland. Hence, provenance of raw materials (local vs global) may not need to be a huge concern.
- There is notable uncertainty around end-of-life disposal of bioplastics and extent to which resources could be recovered. This is further exacerbated by the lack of infrastructure in the UK in waste disposal, recycling and recovery (in part to the highly devolved nature of waste management by local authorities), and due to the multiple standards and guidance around biodegradation and composting (e.g. industrial, garden, or home).
- Cascading uses of bioresources and implications on existing current downstream products and supply-chains needs to be better understood.
- There is also a risk that limited resources may be diverted away from uses which give greater benefits

3.2 Organisations supporting innovations in biomaterials in the UK

There are a number of clusters, groups, agencies that promote and champion the bio-based materials industries in the UK:

- UK Bio-based and Biodegradable Industries Association (BBIA)
- The UK Bioindustry Association (BIA)
- The Industrial Biotechnology Innovation Centre (IBioIC) in Scotland
- The National Non-Food Crops Centre (NNFCC) Bioeconomy Consultants
- National Institute of Agricultural Botany (NIAB) and Scotland's Rural College (SRUC)
- Biorenewables Development Centre (BDC) in York
- Natural Materials Association (NMA) at the IOM3
- Sustainable bio-based Materials and Manufacture (SusBioMM) Cafes by Innovate UK to support biomanufacturing activities in the UK [16]
    - SusBioMM CR&D funding programme ongoing
- Bioladies Network
- Algae Innovation Platform
- Fibral Material Alliance (global focus)

3.3 Biomaterials and Biosynthetic materials from food waste in the UK

The imported nature of virgin bio-based feedstocks, their relatively higher costs (in comparison to non-bio-based feedstocks, for example), and the relatively lower volumes that

[16] https://iuk.ktn-uk.org/events/sustainable-bio-based-materials-and-manufacture-cafes/

are readily available in (due to various competing uses) are a barrier to rapid commercial production and uptake of biomaterials in the UK. Hence, locally sourced bio-based feedstocks from waste, such as food waste, can be an interesting avenue to explore.

The UK wastes typically 6.7-9.5Mtonnes of food annually (ca 100-140kg per person) [17,18,19]. This includes waste along the production, processing, distribution, retail and household stages of the food supply chain (excluding the farm stages). There is a case for prioritising feedstock conversion from post-production food waste rather than post-consumer waste, due to relatively more straightforward collection and supply-chain logistics of post-production food waste (than post-consumer food waste). Bread, potatoes, fruit (grapes, bananas), tomatoes and milk are among the most wasted food items. Such food waste is rich in a range of material building blocks (e.g. sugar, starch, protein, fibre, oils), that are precursors to bio-based materials, including bioplastics. Notably, there is currently a great demand for food waste from other industries, including for animal feed, biofuels, composting, landspreading and energy recovery [20].

Converting food waste resources into suitable and consistent feedstock and then into functional biomaterials does require overcoming a number of challenges:

- Supply-chain and logistics
  - Quantity – viable volumes, collection points, transportation.
  - Quality – treatments, impurities, refining, quality control to ensure consistency
- Technological progress, including in up-scaling, utilisation of biowaste, biosynthesis and processing technologies
- Perception and Market penetration – generating confidence amongst consumers (incl. businesses and end-users) on the quality, particularly durability and requisite functional performance, of food waste-derived products, and leveraging mechanisms to drive behaviour change in consumption patterns (i.e. moving away from current materials to waste-derived materials).
- Entrepreneurial and legal – creating an environment to support businesses (including start-ups and ventures) to explore these at various scale and disrupt markets. Many biosynthetic materials producers in the UK are start-ups. There might have to be legal or policy levers to support wider use of waste-derived materials (e.g. no VAT on such materials).

[17] House of Lords Library. (2021) Dray, S. Food waste in the UK. https://lordslibrary.parliament.uk/food-waste-in-the-uk/

[18] Waste Managed. Food Waste – 2024 Facts & Statistics. https://www.wastemanaged.co.uk/our-news/food-waste/food-waste-facts-statistics/

[19] WWF. Hidden Waste: The scale and impact of food waste in UK primary production. https://www.wwf.org.uk/our-reports/hidden-waste

[20] Department for Environment Food & Rural Affairs (2024). Statutory guidance Food and drink waste hierarchy: deal with surplus and waste. 1 Jan 2024. https://www.gov.uk/government/publications/food-and-drink-waste-hierarchy-deal-with-surplus-and-waste/food-and-drink-waste-hierarchy-deal-with-surplus-and-waste

A number of UK companies are exploring food-waste as a feedstock or resource for the production of biomaterials. All rely on virgin food-based feedstocks or in a few cases post-production food waste (rather than post-consumer food waste). To name a few:

- *Floreon, Aqualyte, Chip[s] Board: PLA/PHA bioplastics* from food and food waste (e.g. corn, sugarcane, beetroot starch, sugars and plant oils)
- *Arda Biomaterials: plastic-free leather alternative* made from *spent barley grain* from London breweries. 100L of beer = 20kg of waste, which is rich in protein and fibre.
- *Modern Synthesis*: *textiles and leather alternatives* made from cellulose produced by bacteria growing on *food and agro-waste* rich in sugars

The process flow-charts of such food-waste derived materials are complex, requiring large-volume production for economic feasibility, and various steps for purification and quality control. Below are typical process steps for the relatively well-established PLA/PHA bioplastics industries. While, for example, the raw material precursors may be different for PLA and PHA production, some of the generic steps are comparable (such as microbial fermentation, purification and polymerization, palletisation and product manufacturing).

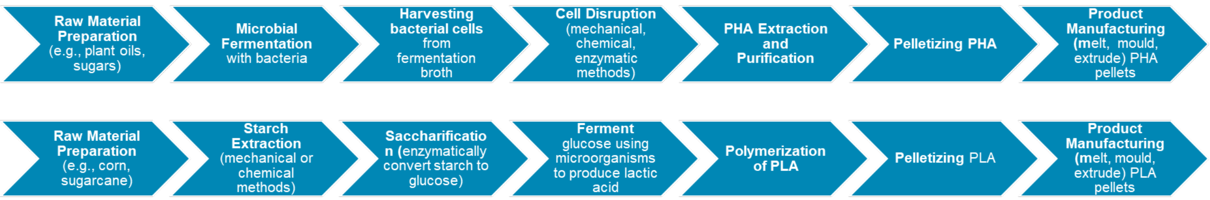
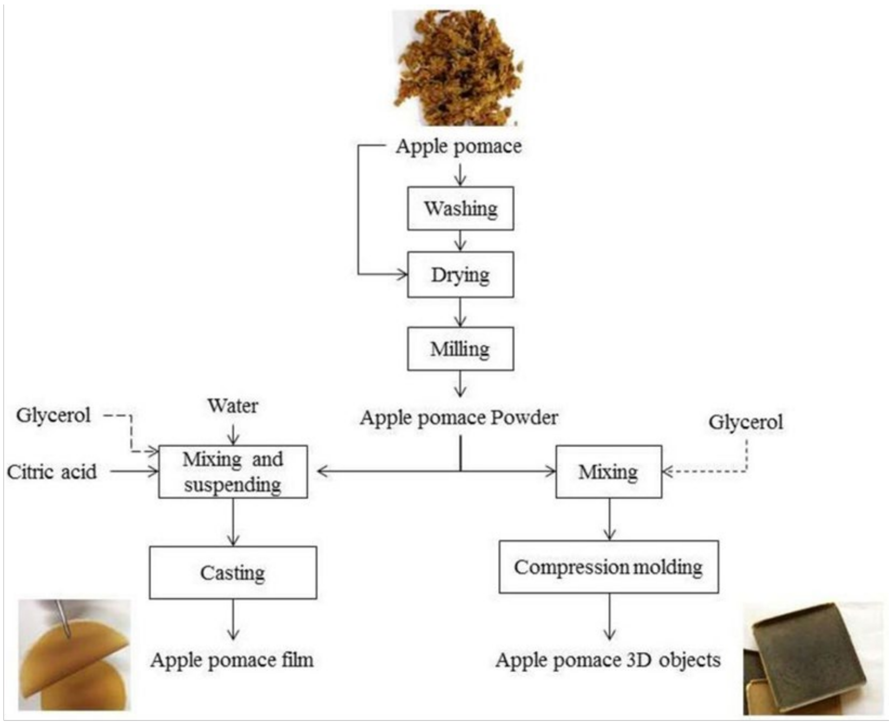


Figure 2. Process flowcharts for PLA and PHA, based on food and food waste.

UK companies like Arda Biomaterials and Modern Synthesis are start-up biosynthetic material producers who are exploring the use of food waste (e.g. from the beer industry, collecting spent barley grain from local London breweries; or from food and agro-waste rich in sugars) to produce materials, primarily leather alternatives and bioplastics.

The process flowcharts of non-standard food-waste materials can be more complex. A number of recent innovations have been in using waste from the fruit sector (incl. fruit pulp and pomace *(solid remains after pressing for juice/oil)*) to produce leathers or bioplastics. In some cases, again, there are generic processing steps that are similar for a range of fruits (incl. apple – e.g. Apple skin; grape, banana, tomato etc) and even mixes of fruit waste. In such cases, pomace (fibrous solid waste after juice extraction) or juices/syrups are used for production of materials. Due to the nature of the food waste, a number of initial steps are around washing, drying and purifying and homogenising (e.g. milling to form a consistent powder). Thereafter, through casting methods, or mixing with other (bio-based)polymers (such as glycerol and citric acid), bioplastics and alternative leathers can be produced. Simplified process flow charts are included in Figure 3.



Gustafsson et al., Polymers, 2019

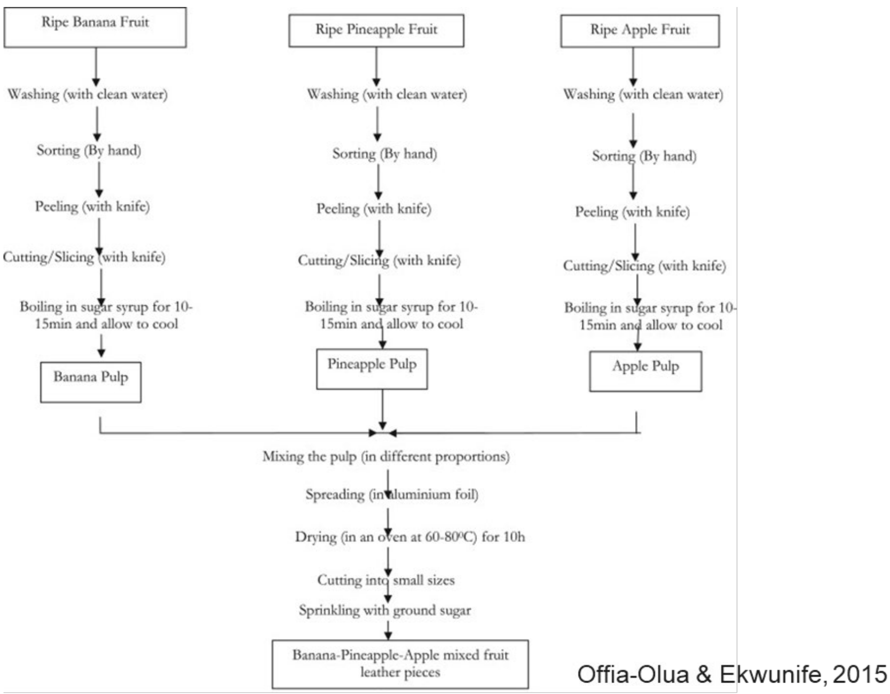
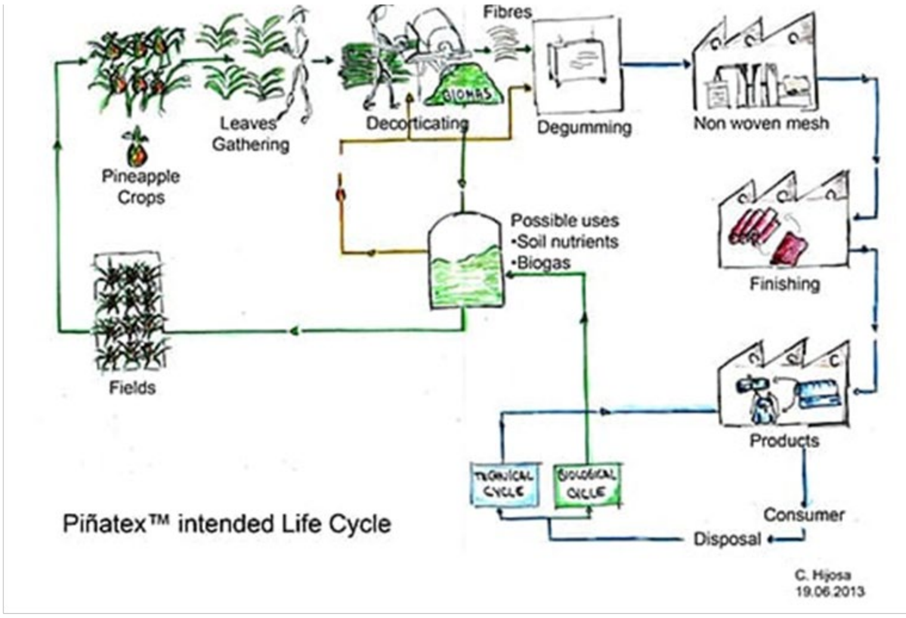


Figure 3. Process flowcharts for fruit-waste based material production.

Similarly, a number of innovative biomaterials have emerged from byproduct waste resources of the food industry, such as using leaves from fruit production for textiles and leathers. Processing steps are the same for a range of fruit (incl. pineapple, banana, and so on) and even mixes. Simplified process flow charts are included in Figure 4. It is arguable that these wastes might take place in the farming stage and are considered as agro-waste. The fibrous nature of these wastes enables the materials to be used as fibres, yarns, textiles, liners and meshes.



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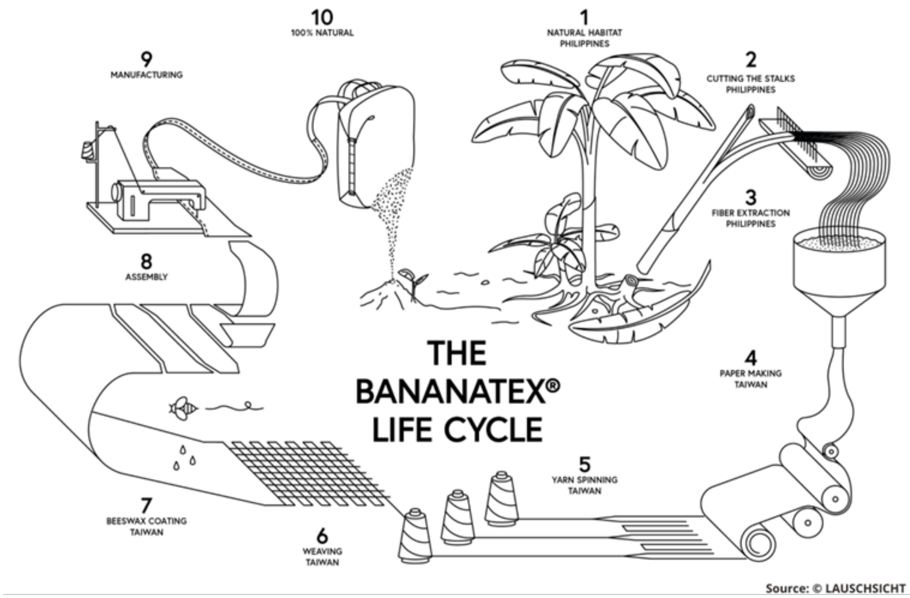

Bananatex

Figure 4. Process flowcharts for fibrous fruit production waste based materials.

4. Conclusions

There is growing interest in the area of biomaterials and biosynthetic materials in the UK, and there are opportunities to explore their uses as replacements for materials in cricket gear softs (pads and gloves). However, at present, none – as per the author's knowledge – have been designed or tested for sporting gear, let alone cricket gear.

Many of these alternative materials are still missing basic information and technical performance data. The lack of data and information presents significant challenges to facilitate design. As many biosynthetic material producers are start-ups, there is also scale challenges even to provide sufficient samples (e.g. $1m^2$) for initial testing and prototyping. In some cases, the lack of samples is due to the various other lucrative sectors where their materials are being applied to (e.g. fashion and brand), as well as limited technological progress (e.g. small pilot lines), or constant changes in formulations due to continuing R&D, performance development, and efficiency (including for reduced cost, or using new feedstocks). For any available materials, performance testing and sustainability analysis would need to be completed to assess the feasibility of using them in cricket gear, based on many of the key performance criteria. This testing should attempt to mimic the use of the cricket gear in practice.

Nevertheless, there are a rich combination of established companies in the UK working on relatively established technologies e.g. PLA/PHA bioplastics production, and start-ups working on innovative technologies e.g. biofabrication and biotechnologies. Food-waste could be an important bioresource for materials and material feedstocks. However, some key challenges include that the industry is not currently targeting the "performance sector" (e.g. most focussing on short-life packaging, or high mark-up fashion). Therefore, while there are some "established" bio-based alternatives, materials presently in innovation do not meet all design criteria for cricket gear. Scale and scalability are a big challenge, as are supply-chain challenges due to the disparate/discrete sourcing nature of waste and bioresources and ensuring quality feedstock and final product.

Finally, an important take-away is that while material innovation and substitution with lower-environmental impact materials in these cricket gear softs remains a vital way to improve sustainability of cricket gear, more direct, higher-impact routes and lower-hanging fruits are related to redesign, re-use, refurbishment and repair of cricket gear softs for circularity. These are less straddled by the multiple hindrances around technological and economic barriers that biomaterial innovation faces, let alone perception challenges around 'new', 'untested' materials.