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The future of UK plastics recycling: One Bin to Rule Them All

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ABSTRACT

The use of plastics, and even the existence of this versatile material, has been increasingly demonised in the UK. Public campaigns exist to expand use of recyclable cups and to eliminate plastic straws. Retailers supplying 80% of the market are now members of the UK Plastics Pact, with goals to ensure that products are designed to be recycled, that recycling takes place, and that more recyclate is used in new products.

Public awareness has not translated into action, as domestic collection rates for discarded plastics remain pitifully low. We started with a systems-wide vision that these rates can only be increased if all household plastic recycling is made easy and consistent christened 'One Bin to Rule Them All' - and used this premise as a starting point to examine the implications of a fully mixed plastics waste stream entering the supply chain. An agenda for future research was developed through 25 interviews with senior industrial and commercial management and a cross-sector workshop.

We determined that if improved household collection rates are to translate into significantly improved recycling rates, rapid progress is required in four areas: standardisation (materials, kerbside collections, waste sorting), infrastructure investment, development of cross-supply chain business models and creation of higher value recyclate. Creating a harmonised national solution to plastic waste sorting is critically dependent on maintaining value in discarded plastics. This in turn reduces plastic leakage into the environment. Enabling this value-based scenario in the UK would form a best-practice model for other regions.

1. Introduction

1.1. Plastic use and post-use collection

Plastic is a remarkably versatile material that has transformed our healthcare, food security and built environment industries. Often easy and inexpensive to produce, the different polymers, formulations and laminations have almost infinitely malleable properties tuned to the application. In the UK, 2.4 million tons of plastic were sold in 2017 (WRAP, 2018). Much of this adds to the stock of plastic in buildings and homes, but the largest single element is for packaging, some 1.3 million tons (56%) (ibid), most of which is single use and instantly discarded. Normally the greenhouse gases produced in the production of a plastic container, such as a food tray or drinks bottle, are significantly less than the equivalent in glass, paper or aluminium and single use plastic packaging reduces food wastage (BPF, 2019; Green Alliance, 2020:p16): the use of plastics are environmentally beneficial versus available alternatives. However, post-use leakage of plastic packaging into the environment through landfill and littering is a major problem (BPF, 2019; Defra, 2019a); as highlighted by David Attenborough's 2017 Blue Planet II film showing the extent of seaborne plastic pollution (Green Alliance, 2020:p8). This programme is credited with changing the attitudes of the UK towards plastic waste.

However, this concern has not translated into higher collection rates from households (Table 1). Barely half (54%) of rigid plastics (e.g. drinks and detergent bottles, supermarket trays) and virtually none (4%) of consumer films (e.g. plastic bags, pet food sachets) are collected from households. While part of the uncollected tonnages is represented by 'on the go' disposal, the most significant opportunities for increasing tonnages recycled depend upon the effectiveness of home collections. As seen in Table 1, 60% of plastic collected is exported, primarily for commercial incineration. While incineration recovers around 5% of the polymer value in energy (EMF, 2015), we regard this economic waste as another form of unsustainable environmental leakage.

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Table 1
Tonnages of plastics placed on the market (POM) in 2017 (WRAP, 2018).

Stream	POM	Collected	Collection rate	Recycled	Exported for incineration
Consumer Total	1532k	525k	34%	226k	299k
Consumer PTTs/Bottles	*935k*	*509k*	*54%*		
Consumer Film	*395k*	*16k*	*4%*		
Consumer Other	*202k*	–	–		
Non-Consumer Total	830k	586k	–	199k	387k
Non-consumer Rigids	*453k*	*155k*	–	*55k*	*100k*
Non-consumer Film	*364k*	*431k*	–	*144k*	*287k*
Non-consumer Other	*13k*	–	–		
Grand Total	2361k	1111k	–	425k *40%*	686k *60%*

1.2. Circular Economy and recycling

Important in any vision to reduce environmental leakage is the Circular Economy (CE), itself a key EU strategy (EU, 2018). CE aims to keep material resources in their highest value condition (EMF, 2015), to enable discarded materials from one process to become raw materials for others. As a concept, CE has inspired much academic research, mostly concerned with overall rationales (Vilella, 2018), its wider issues (Kircherr et al., 2018), its morality (Gregson et al., 2015; Herrero and Vilella, 2017), or reviews of developments in specific sectors or geographies (Mulrow et al., 2017; Su et al., 2013). Relevant here are papers highlighting the need for newer business models (e.g. Heyes et al., 2018; Tukker, 2004) and increasing recognition of the role of the consumer and citizen in circular practices (Baxter et al., 2017; Gregson et al., 2013; Norris, 2019).

Recycling-orientated behavioural literature focuses on why people do or do not recycle. Changing people's attitudes to recycling is difficult (Quested et al., 2013) and previous research shows that even if attitudes change, little increase in recycling occurs (Oom de Valle et al., 2005). Visible structural changes that improve the ease of recycling do improve recycling rates (Guagnano et al., 1995). However, we are not aware of any specific research on why households, given the facilities to recycle relatively easily, struggle to do so: the 54% collection rate for household plastics suggests that a great deal is being placed in the residual waste bin. Behavioural literature suggests that recycling is highly normed[1] (Barr, 2007; Tucker, 1999) although Kleinschafer & Morrison remark that there is very limited work on the role of household norms in decision making(2014). There is minimal agreement on the influences over recycling behaviour (Thomas and Sharp, 2013) and little or no work on whether consumers are confused by product packaging. Some households do not recycle (Barr, 2007); reducing waste contamination implies addressing these households. This is complicated by the fact that practices in the home are often highly personalised, ingrained and routinised, making the study of social norms difficult (Southerton, 2012) and that discarded plastic is thought of as valueless waste and not as a valuable resource (Green Alliance, 2020).

Reflecting on businesses, using recycled inputs is often more practical than changing the business model to incorporate reuse or remanufacture, and so recycling features prominently in existing CE studies (Ranta et al., 2018). However, government-facilitated industrial symbiosis projects in the Global North have poor rates of success due to lack of industrial cooperation, inconsistent material streams, reluctant capital providers and unintended regulatory barriers (Mulrow et al., 2017). Whilst the EU urges key players to work together and technical barriers are not regarded as the main issue, issues of culture and co-operation are significant (EU, 2018; Kircherr et al., 2018). There is also no developed structure of standardised traded plastic wastes across the UK, let alone across national borders. This is often considered a pre-requisite for investment into reprocessing capacity (Gregson et al., 2015), as has happened in areas of China (Su et al., 2013). Without active waste markets, any reprocessor is entirely dependant on individually negotiated sources of supply: a precarious position unlikely to be an attractive investment.

1.3. UK recycling infrastructure

UK recycling infrastructure for household waste generally consists of multi-bin kerbside collections taken to Materials Recovery Facilities (MRFs) to be further sorted. Plastic bottles (PET & HDPE[2]) are extracted and sent to recyclers. Other plastics, roughly sorted into single polymer bales, are sent for further processing to Plastics Recovery Facilities (PRFs) or exported for incineration. Polymers which can be sorted to a high degree of purity at Plastic Recovery Facilities are mechanically recycled using heat and pressure treatments to form flakes or pellets which can be extruded or blow moulded into new uses. The remainder is incinerated in Energy from Waste plants, often abroad. As far as we are aware, no chemical recycling plants, which break discarded polymers down selectively into monomers for reformulation into new polymers, are in commercial operation anywhere in the world, although non-selective chemical transformations such as pyrolysis and hydrocracking do exist and pilot plants are emerging.

The responsibility for UK household waste collections lies with Local Authorities, mandated to operate multi-bin collection systems (EPA, 1990). Conventionally, each household pre-sorts their waste into differently coloured bags or bins, with each colour collected either weekly or on alternate weeks. However, there is no national government co-ordination. Most Local Authorities collect all plastic bottles and many collect some or all rigid packaging plastics (such as Pots, Tubs and Trays). Few collect plastic films, as these are essentially unrecyclable through current systems.[3] Consumers are expected to sort plastic

[1] Norming refers to the concept that behaviour is influenced both by the individual's personal beliefs and their understandings gained from others about what constitutes 'good' behaviour. These are drawn from seeing what others do – 'descriptive' norms, to create copying behaviours – and from considering actions an individual believes others will approve or disapprove of – 'injunctive' norms.

[2] The polymers referred to in this paper are: PET - polyethylene terephthalate; HDPE – high density polyethylene; PP – polypropylene; PS – polystyrene and PVC – polyvinylchloride. In the consumer food packaging sphere PET is primarily used for soft drinks bottles and supermarket food trays, HDPE for milk bottles, PP for food containers, especially those which can be microwaved. PS and PVC are in small and declining use.

[3] Many films are laminates, composed of multiple thin layers of different polymers with different properties. Commercial separation of these layers is necessary to produce valuable recyclate and industrial-scale processes do not exist to do this. Nor do industrial processes exist to separate laminated films

recyclables and non-recyclables into different bins. The 391 Local Authorities each use one of 39 different collection regimes (Co-op, 2019). Consumer uncertainty results (BBC, 2018): both about the types of items which are recyclable (for example, is a shampoo container a bottle or not?) and because an individual's recycling rules may differ between locations such as home, workplace and leisure spaces. Clear consumer communication is challenging when rules are location specific. Levels of contamination (any non-target material) in any bin are non-trivial (4% - 18%) (WRAP, 2020). In addition, structural difficulties between collection rounds within the same authority make consistency problematic: for example, space and waste chute constraints in apartment blocks make accurate waste sorting less likely than in suburban houses. The variation in bin contents within and between authorities, plus contamination levels, make it difficult for MRFs to produce consistent high-quality recyclate.

1.4. Regulatory background

The four UK national governments are aware of many of these issues, and indeed conducted four waste consultations between them in 2019/20, concerning

- consistency of collections (England only)
- a Plastic Packaging Tax (UK)
- Extended Producer Responsibility (UK) and
- Deposit Return Scheme (DRS) for drinks bottles (England, Wales & NI).

Scotland has already announced plans to introduce a DRS in 2022. In addition, the Welsh Government ran a consultation on its CE strategy, which centred on recycling. This illustrates the diversity of governance approaches hindering creation or application of a single UK-wide solution to reflect the realities of consumer engagement, commercial operations (retail and waste), and the widespread distribution of identical plastics across the UK.

The English government intends to list specific items that each English Local Authority must collect for recycling by 2023,[4] making an initial move towards consistency of collections. It is hoped that Scotland and Wales match this promise, as otherwise these open borders will still create confusion. Cost is a major issue preventing standardisation of bin colours. The UK government intends to impose a £200/ton Plastic Packaging Tax from April 2022 on any packaging containing less than 30% recycled content, irrespective of polymer or the technical difficulty of achieving it (HMRC, 2020). The four governments also plan to introduce an Extended Producer Responsibility scheme (EPR) in 2023 (Defra, 2019b). This scheme aims to make the producer responsible for the full cost of managing the packaging produced at the end of its first life, and the proposals were generally broadly supported (Defra, 2019c). Operational details are unclear, but retailers are likely to have to pay the tax to the government and there is an intention to remit all or part of the funds raised to Local Authorities to provide higher quality recycling (HMG, 2018). Lastly, The UK and Scottish Governments are also exploring DRS for plastic and glass drinks bottles, whereby each bottle sold carries a reclaimable deposit of £0.20 (Defra, 2019a; ScotGov, 2019). These would be implemented at different times, with Scotland first. There are concerns about cost (BRC, 2019), with retailers being obliged to establish collection networks for bottles, and fraud potential (especially cross-border trafficking when DRS exists in Scotland but not England). DRS would remove the one profitable plastic household waste stream which is currently well sorted and recycled through MRFs [PET bottles: 74% collection rate (BPF, 2017)], with a consequent negative impact for Local Authorities.

Internationally, the Norway amendment to the Basel Convention on Movements of Hazardous Waste subjects mixed unsorted plastics to full administration requirements for toxic wastes from 1 January 2021 (Basel, 2019). Theoretically this amendment prohibits UK exports of huge volumes of mixed waste plastics for incineration and could radically reshape the industry. However, current exports are already technically unviable, as Plastic Export Recovery Notes (see Section 3.2) are supposed to be granted for single polymer plastic shipments sent abroad for sorting, not for mixed waste incineration. This rule is not enforced at the docks: arguably the Environment Agency is under-resourced to do so (Green Alliance, 2020: p33). Anecdotally, the industry is assuming the Basel Convention amendment will not be either (Personal communication, partner interview). However, this assumption places faith in the receiving country also ignoring the revised Convention.

The current situation is complex, inefficient, decentralised, underfunded, diverse and subject to numerous, sometimes conflicting, ideas on the way forward. To date, the UK government has been trying to meet national targets through uncoordinated local bodies, although the proposed legislation suggests a recognition that tighter targets require national regulation. However, all policy proposals aim at different parts of the system with little overall vision of how the elements fit together or across a supply chain. For example, the recommendation on collections consistency lists a set of items that English Local Authorities must collect for recycling by 2023. It does not specify which items should be collected in which bins or what the bin colours would be. Thus non-standardisation and subsequent confusion is perpetuated.

1.5. The 'One Bin to Rule Them All' vision

Our future overarching vision, co-developed with cross-sector stakeholders, was inspired by several connected observations; that virtually all sorted polymers have value, that leakage into the environment occurs principally through landfill, commercial incineration and littering, and that collection rates from households are low. From the perspective of materials science, social science and economics, these observations suggested a new way forward: a properly investigated and tested set of rules, designed to recover polymers through an integration of reuse, mechanical recycling and chemical recycling. Without such an all-encompassing umbrella framework we believe that it is likely that the progression of well-meaning but disconnected initiatives will continue, ultimately leading to sub-optimal recycling levels and continued leakage of plastics into the environment.

We hypothesised that the only way to significantly increase household plastic collection rates is to make household compliance easy, building from the premise that many consumers are confused (Defra, 2019d). The moniker 'One Bin to Rule Them All' emerged as an energising way to convey the substance of the project, and an invaluable tool to build stakeholder relationships without which there could be no research and no potential supply chain cooperation.

To reach this idealised future of a single household bin for all plastics we then sought to understand the significant impacts of 'One Bin' on the collection and recycling supply chain. While plastic sorting in MRFs and the related need to create value in discarded plastic to finance necessary sorting equipment would be key, the interrelationships within any prospective business model seemed daunting. These considerations lead to a second hypothesis: maintaining discarded plastics in their highest value condition is fundamental to enabling the best reuse, mechanical recycling or chemical recycling decisions to be made. This claim is closely tied to CE principles and aligns with the European Strategy for Plastics in a Circular Economy (EU, 2018). The initial 'One Bin' vision is summarised in Fig. 1.

The aim of the interdisciplinary study was to use the One Bin vision as a vehicle to examine the wider contestations across the supply chain,

(*footnote continued*)
from mono-layer films.

[4] Glass bottles and containers, paper and card, plastics bottles, plastic pots, tubs and trays, steel and aluminium tins and cans

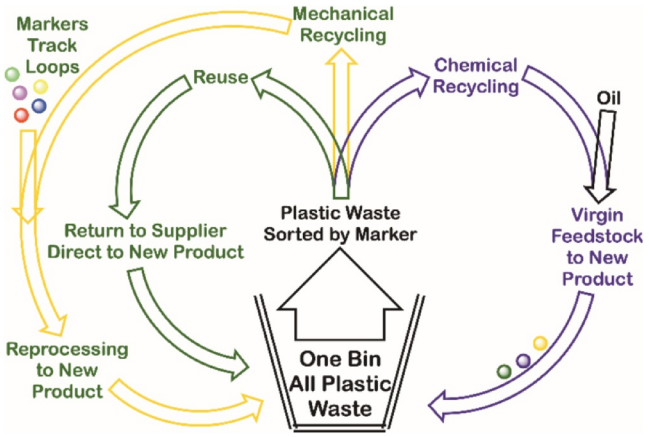

Fig. 1. Conceptualisation of plastic flows associated with the 'One Bin to Rule Them All' vision.

to identify areas requiring development with industrial, local authority and regulatory partners, with an ultimate aim of creating systemic improvements to first reduce and then eliminate plastic leakage into the environment. It was anticipated that key questions would arise in polymer chemistry, supply chain collaboration and household behaviour as framing for the focus of further research, and indeed as motivation for the formation of a working group of partner organisations to enable this vision. It was recognised that a focus on value creation would by necessity create profits for some partners to enable investments essential to obtain the benefits.

2. Methods

Project partners were recruited from existing University of Manchester industry contacts, strategic university partners and through lectures at trade events and conferences. We deliberately recruited partners from across the supply chain (from thermoformers, product tagging specialists, retailers, fast moving branded consumer goods manufacturers, major waste processing organisations, local government, plastics recyclers and waste compliance organisations) and organisation size (from large multinationals to microenterprises). Each were recruited as they represented a different view of the key issues which needed resolving, although there was a commonality to the opinion that improvements were needed in recycling and waste management. Together the partners presented a comprehensive overview of the packaging supply chain.

As the first stage of the research, a series of 25 semi-structured interviews studied partners' different perspectives, in particular examining (i) the potential challenges they felt One Bin was likely to face, and (ii) what changes were required to the existing recycling processes to enable their business to create more value. Sections of the interviews that had significance for either the individual partner and/or the wider industry were summarised or transcribed, with key points and themes extracted from the longer text. This output provided a series of points of agreement across partners, together with four areas of contestation that required further exploration.

The second stage consisted of a full-day workshop. At this point, 20 interviews had taken place; 15 partners were invited to the workshop and 13 attended, covering the entire supply chain. This event confirmed areas of agreement and explored contestations to co-create an ideal circular plastics future. The interviews made it clear that there were four areas where either their views differed or where a more detailed understanding of the barriers to consensus was needed. The questions were formulated after several rounds of debate by the authors to frame the discussion without limiting either the subject matter or the approaches of the participants more than necessary. These four open questions were thus formulated:

(1) On the standardisation of materials: If we agree that standardisation is a good thing, what standards do we need?
(2) On sorting and technology: What do we need to do to ensure that Pots, Tubs and Trays are recycled?
(3) On value creation: If it were possible to create a marking system to enable separation of packaging by polymer, is this enough on its own to generate investment in the sorting infrastructure by MRFs and in marking of products by brands and retailers?
(4) On pilot trials: If we have an embryonic method of creating value (a marking process being one example), what would a trial be designed to prove?

The "World Café" discussion format (Brown and Isaacs, 2005) split partners across four tables with paper tablecloths, each with one of the four questions. Teams wrote their contributions to the question on their tablecloth, triggered by prompts and facilitated by an academic at each table. After ten minutes teams rotated to the next table. Newly arrived groups could see the previous contributions and add or comment as they wished. After four rotations the collected thoughts were fed back to the whole meeting by the table facilitator.

The partners were then split into four different groups for a backcasting exercise where participants devised their ideal One Bin future, detailing intermediate steps necessary to reach the endpoint. Starting with the ideal future helps to avoid extrapolating current trends or assumptions (Sharmina, 2017). Starting with their envisaged CE plastics goal in 2030 or 2040, the groups had to isolate specific actions to be implemented by specific times to realise their endpoint and record these on an A1 size pre-printed sheet of timescales and Action Categories (Fig. 2). Extracted text from the four backcasting sheets can be found in Appendix 1.

3. Results

While there are numerous findings relevant to specific sectors of the supply chain, four broad areas of agreement arose from the interviews and were confirmed in the workshop: standardisation, infrastructure investment, collaborative business models and value creation. All are comprehensively interlinked, with the first three all contributing to the last, value creation. From interview and workshop inputs we can map these four themes, and the flows which enable their interconnections, as shown in Fig. 3. Standardisation has impacts across the entire supply chain, and many of its elements contribute directly to value creation. Material flows are unchanged in direction, but better sorting improves inherent value and increases the proportions being recycled rather than landfilled or incinerated. Infrastructure investment is underpinned by higher value sortation and the value of the data generated by it. The workshop revealed agreement on a fifth area, that of timing of initial system changes (Section 3.5).

3.1. Standardisation

Our findings explicitly confirm that to realise a circular economy of plastic, standardisation is crucial across the whole recycling sphere. While almost any homogeneous bulk polymer has value, the emphasis is on 'homogeneous' and 'bulk', necessitating year-round continuous streams to feed a reprocessing plant. Mixed unsorted polymers cost money to send for incineration, with varying market prices quoted by different interviewees between £40/t and £65/t plus transport. Standardisation throughout the supply chain, from bin collections to polymer grades, data, sorting techniques and machinery all facilitate value retention and creation. Standards need to be open, UK wide, accessible, impartial and owned by an unbiased stakeholder group. Manufacturing criteria should determine standards and be polymer and sector specific, covering performance criteria, contamination limits and

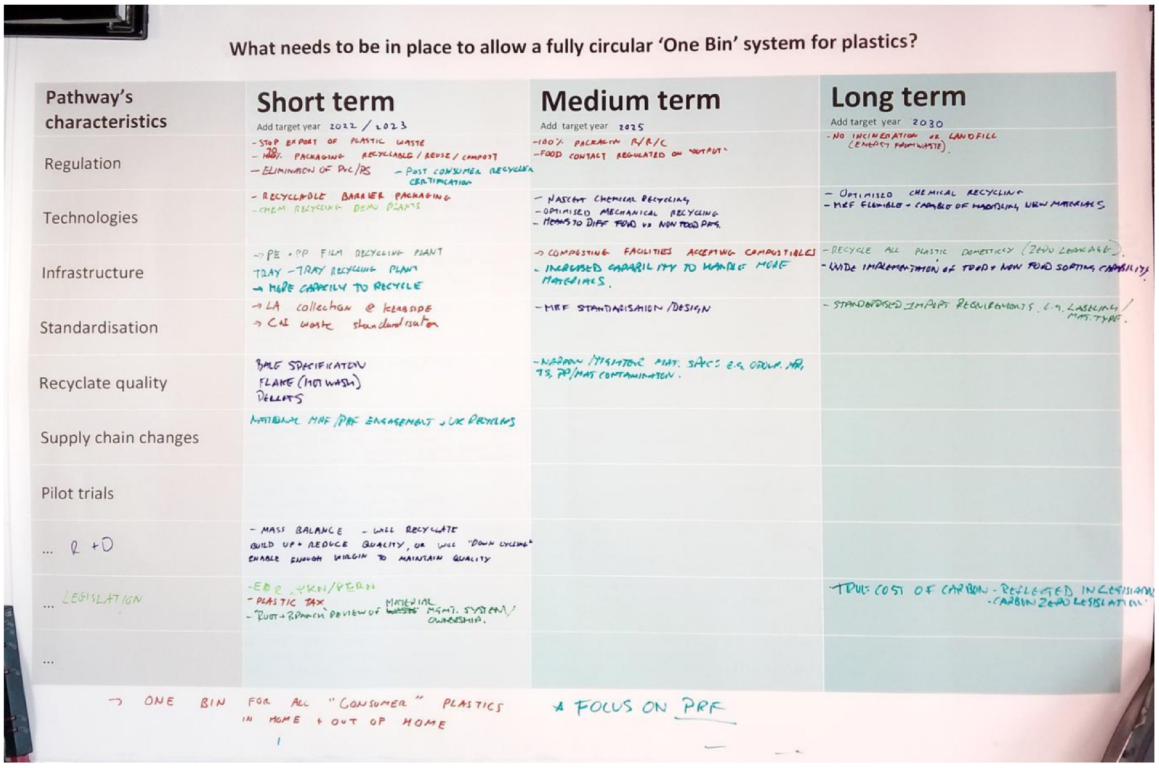

Fig. 2. An illustration of a completed backcasting exercise worksheet.

recycled material content. There was agreement from partners that packaging could be almost entirely standardised on PET, HDPE and PP and most agreed that a limited number of grades of each is feasible without limiting product performance; currently each manufacturer can use any grade to achieve functionality. Closed loop processing in CE benefits from standard grades to facilitate discarded wastes being used again as inputs.

As a corollary of polymer standardisation, designed-in

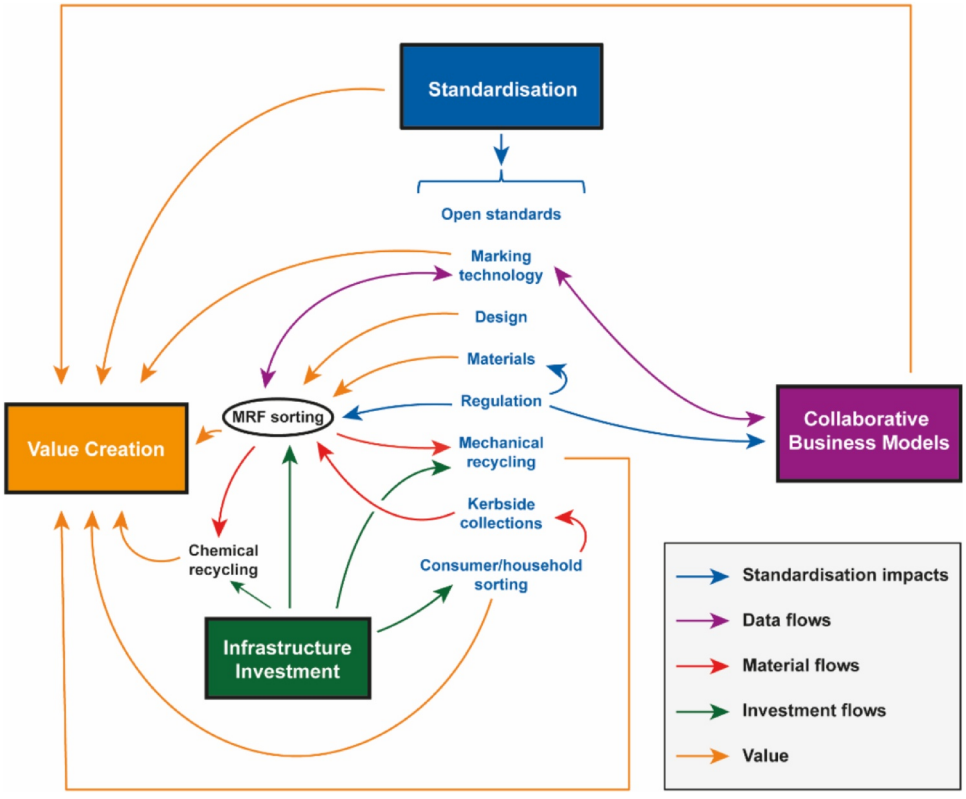

Fig. 3. One Bin flows.

contamination needs to be eliminated where possible. Included are items such as colour pigments, lacquers, labels which cannot be reprocessed the same way as the host product, and adhesives. All contribute to problematic reprocessing and lower quality, lower value recyclate. This includes laminates, such as PE lined PET food trays, which if recycled without separation of the two incompatible materials leads to plastic failure. Design for recycling is essential.

Currently, plastics described as 'compostable' are rarely biodegradable at ambient temperatures. The most common polymer, poly (lactic acid) or PLA, is only compostable in an industrial process at 70°C, but this process is not available commercially in the UK. Multiple interviewees argued that without a means of separating 'compostables' from mainstream polymers they are another form of contamination, especially as the ester functionality in PLA polymers mimics that in PET. Several partners expressed a strong view that companies selling 'compostable' or 'biodegradable' packaging were more interested in the marketing message than the environment, as the end-of-life fate of the material was either landfill, incineration or at worst contributing to a decrease in recyclate quality.

The initial premise of 'One Bin', that customer confusion causes reduced collection levels and contamination, is supported by partners. Mirroring standardised household outputs, national output standards for MRFs and PRFs are also perceived to be important, covering standard bale qualities. This requires improved sorting and further investment. Nationally standardised output bales (sorted but unrecycled plastics) would enable a free market in recyclate to develop, facilitating increases in both general recycling and participation by more niche reprocessors.

Agreement around standards often focussed on the polymeric materials themselves, but design standards can also enable change. An emerging idea is that three standard shapes and sizes of PET trays for food use (principally vegetables and meat) could be used throughout the UK (Small, Medium and Large). If discarded by households as normal, collapsed and sorted into bales by MRFs and then washed and reused by all food packagers, considerable resources could be saved compared to recycling, although water and energy required for washing and logistics would need to be considered through a lifecycle analysis.

3.2. Infrastructure investment

Partners confirm that the UK does not generate enough recyclate to fulfil market needs for any of the main polymers (PET, HDPE, PP) and that the infrastructure does not exist to do so. Two reasons were commonly cited for this deficit. Firstly, the use of recyclate depends on it replacing virgin polymer. This depends both on the quality of the recyclate, itself dependant on the attitudes and skills of polymer processers, the aforementioned challenges around contamination, and the degradation of polymer chains through chain scission or crosslinking during reprocessing. It also is inextricably linked to the price of virgin polymer. Until recently, the limited demand from branded goods manufacturers for recycled content led to a preference for virgin, unless there was a worthwhile price advantage for recycled feedstocks. The fluctuating price of oil impacted prices for virgin and recyclate, causing periodic bankruptcies for most recycling companies and a disinclination of others to invest in capacity. Significantly, the two surviving HDPE reprocessors (for milk bottles) are now both owned by major MRFs (Biffa and Veolia), giving these reprocessors consistency in recyclate supply and a degree of price insulation from the market.

Secondly, the system of Plastic Recovery Notes and Plastic Export Recovery Notes (PRNs/PERNs), established to facilitate recycling of plastic, has unintendedly incentivised exports of unsorted plastics over investment in recycling infrastructure. Both PRNs and PERNs have the same value per ton. PRNs are granted when the polymer has been recycled, though after removing contaminants and reprocessing, there may be only around 70% of the original tonnage remaining upon which the PRN is paid. PRNs are paid on the 70% processed weight, PERNs on the 100% unsorted weight. The recycled polymer has value, but the incentivisation is slanted away from recycling and towards export of unsorted plastics. Additionally, the value of PRNs and PERNs is dependant on supply and demand, with the resultant fluctuations destabilising any planned investment into a market which has had historically limited profitability.

More investments into reprocessing capacity are now being made, but these are premised on long term demand for recycled content from branded goods manufacturers underpinned by proposed legislation, not by the PRN system. Guaranteed supply gives the large MRF owners a major advantage in risk mitigation when planning new infrastructure, compared to more disruptive organisations entering the market. Demand expectations generate a favourable environment for researching process improvement, as the purity of recyclate from UK MRFs is poor compared to recyclate purchased from continental Europe.

The need to create value to facilitate new investment and develop a circular economy of plastic waste causes partners – with their packaging focus - to recognise the need for a machine-readable marking system enabling high-speed, high-quality sorting of discarded plastic. Consider polypropylene, PP, a valuable polymer used for a multiplicity of packaging products. By law, recycled plastics incorporated into new food containers must have originated from containers used for food use. Currently, identifying food grade PP from non-food grade PP in a MRF is impossible, causing most food-grade PP to be landfilled, incinerated or downcycled into automotive products, losing the food grade value element. Product marking to enable automatic sorting would identify and segregate this food grade polymer, retaining it in a higher value state. Applications are much wider than this specific example, or indeed the conceptual limitation to packaging materials. Most recycling processes under development require specific inputs: a marking system will help enable this specificity. Increasing the purity of any polymer recyclate increases its value. Partners agreed that this is not a technology issue, as there are available systems ready for implementation, but a problem of supply chain cooperation. It highlights that One Bin - or any solution - needs to demonstrate value creation to all members of the supply chain to engage them. Most partners felt investment would be facilitated by regulating MRF output, either to force separation of individual polymers or by banning mixed plastics as an output of MRFs, and certainly banning their export. We note that neither of our two MRF partners were present for this specific debate.

3.3. Collaborative business models across the supply chain

We have found that different businesses along the supply chain are quite removed from each other. Partner interviews revealed minimal evidence of collaborative working other than through process-specific trade bodies. Multi-partner meetings highlighted the disconnect in understanding of drivers at different stages of the supply chain. This suggests that new business models will need to be co-developed to ensure adoption and propagation.

Using a machine-readable marking system that sorts based on retained value, instead of on the chemical nature of the polymer, involves supply chain cooperation around a single agreed system. Marking would be undertaken by manufacturers and/or retailers: benefits from higher value product accrue to MRFs who sort and sell it. Without a collaborative business model value would not return to the manufacturer/retailer to pay for marking the product. Marks would ideally contain not only the retailers identifying code – the SKU or Stock Keeping Unit – but also the specific details of the polymer and grade used for the package. More advanced marks could add coding for label material, adhesive type, and so on. Another variant would incorporate a serial number for the specific unit of the product, potentially useful in Deposit Return Schemes.

Marking the outside of packaging does little to improve the recycling potential of laminated films: a simple sealing film on a

supermarket meat tray may be five or more polymer layers, each of which needs to be separated to recycle it as each may need a distinct process. This suggests a different marking system, embedded within the material of the layers, is needed (e.g. fluorescent dyes, molecular marking). Our stakeholder research recognises that this strong framework needs to be complemented by significant specificity. It is unlikely that a single intervention will address all contestations. To the extent that partners did not address the technical aspects of reprocessing, the second discussion question (On sorting and technology: What do we need to do to ensure that Pots, Tubs and Trays are recycled?) is answered from the perspective of sorting and systems rather than enabling future innovations.

We envisage value being transferred from MRFs to manufacturers/retailers by reporting the volumes of individual products sorted for recycling. By proving volumes recycled, this data would reduce manufacturer/retailer disposal liabilities under proposed Extended Producer Responsibility legislation. There is additional marketing value if the recycled item can be linked (through a serial number) to customer data captured at the retailers till. For some manufacturers, returning their empty products for recycling into new products to demonstrate circularity in their marketing and branding may also be valuable. Underpinning this is the increase in bale purity, and therefore value to MRFs, of all materials sorted using the data contained in the mark, increasing the chances of the product being recycled.

Collaborative business models are inherent to the One Bin vision by creating value through better sorting, consequently limiting leakage of plastic into the environment.

3.4. Value creation

As highlighted in Sections 3.1-3.3, value creation derives from increasing the retained value of the discarded plastics (advanced sorting to achieve higher purity recyclate and generate data on products sorted) and the volumes processed (standardisation of household collections). Currently, MRFs are a service operation established to process large volumes of mixed wastes, primarily funded by a per household fee paid by Local Authorities. Without increasing the value of discarded plastics MRFs have little incentive to invest in the additional automated equipment (conveyors, air knives, cameras, computer controls) necessary to sort plastics to a higher purity. The vision outlined here increases the value of all volumes sorted by increasing the purity of bales sent for recycling. This increases income, enabling recycling of some or all the bales currently incinerated, thus turning a cost into an income. For MRFs this increase in the value would be the main benefit. The need for higher value recyclate is crucial in creating a circular economy of plastic, underpinning elimination of plastic leakage into the environment. Thus, value creation is inherently linked to the ability to maintain plastic in its highest value form.

3.5. Timing

The backcasting exercise revealed which actions partners felt to be essential in the short term (within 5 years) if the One Bin vision to reduce and then eliminate plastic waste leakage into the environment is realised by 2030 to 2040. Standardised kerbside collections, specification of bale outputs from MRFs and an end to exports of unsorted plastics by 2023 all feature strongly. Our diverse stakeholders anticipate impact from the EPR regulation planned from 2023. Additionally, the next five years need to prove the conceptual potential of both a digital marking system and chemical recycling (both selective chemical recycling to monomer and less selective pyrolytic routes). By this we infer trials of sub-economic pilot scale versions of these innovations, both being required to become mainstream in a 5–10 year timeframe.

4. Discussion

The requirements for systemic change to realise a circular economy of plastic in the UK are split into four over-arching, interlinked themes: standardisation, infrastructure investment, collaborative business models and value creation. dependant on these main themes there are specific technical, social and economic requirements, such as improving mechanical recycling processes, designing for recycling or reuse, developing economically viable chemical recycling and implementing regulatory changes. Each of these is highly impactful on its own, but none can reach their full potential without realisation of the main systemic changes. This paper does not attempt to address new technical processes for recycling plastics, instead concentrating on overarching themes and the necessity of addressing systemic issues in order to increase recyclate volumes to both existing and new processes of mechanical and chemical recycling. It however does recognise the need for flexibility, ensuring that new systems can seamlessly incorporate technological advances.

Consumer behaviour in the home is crucial in reducing contamination of MRF inputs (Defra, 2019d), and one aspect, consistency of collections, has been the subject of a government consultation in England. Our other findings do not appear to be priorities for any of the four national governments. The results of the consistency consultation do not move the situation substantively forward: while the English government has specified a list of mandatory items for every Local Authority to collect, it leaves much unspecified. It does not automatically apply to Scotland and Wales. It does not specify uniform bin colours, potentially to limit costs. While determining which items must be collected, it does not specify the bin system detailing which items are co-collected, resulting in a propagation of different collection systems, machinery for collection and mechanisms for sorting, leading to different sorted outputs. Finally, without specifying a uniform bin system it does not improve communication to consumers, which remains location-specific. Taken together with the results of our research, partial consistency may be insufficient and risks locking us into the current disjointed system for many years to come.

The overriding need for standardisation to create greater volumes of better sorted, higher value recyclate is clear. The spread of similar plastic ranges (i.e. in supermarket packaging) makes it essential that a workable solution encompasses the entire UK supply chain. We have highlighted interdependencies between supply chain members, and how progression to higher UK recycling levels must involve greater cross-industry cooperation. Its absence confirms findings by Kircherr et al. (2018) that cultural barriers stymie CE collaboration even where technological solutions exist. While such cooperation is not facilitated by competition law, the oligopolies in supermarket retailing and MRFs, together with the potential profit benefits to both sectors, enable a creative market-driven solution.

Partners' antipathy towards PRNs/PERNs is reflected in the welcome given to the government's intentions of reforming the system from 2023. The operational mechanisms of its successor, EPR, are unknown and potentially there is wishful thinking amongst partners in perceiving EPR as a panacea. For example, as standardisation involves short term costs and inconvenience missing from the consistency proposals (see above), will colour pigments, laminates or non-conforming plastics or grades be appropriately penalised under EPR? There is general agreement that EPR and DRS will significantly impact the economics of recycling, as will the Packaging Tax. Partners note that bringing in DRS, EPR and a Packaging tax simultaneously make unintended consequences likely.

Governments have a significant role to play in regulation and standardisation: often this role extends to encouraging infrastructure investment and business cooperation. In the plastics sphere this attempt at encouraging businesses to look at their waste streams is evident in the Plastic Packaging Tax and Extended Producer Responsibility. The record of governments creating good headlines but poor detail is of

concern: as highlighted above, the results of England's 'consistency of collection' consultation are, in our opinion, limited; and in the opinion of many in the industry, the planned DRS prioritises visibility of public action over effectiveness. Arguably, the David Attenborough 'Blue Planet II' TV programme, by dramatically raising public awareness, has had a more immediate impact on industry by increasing pressure to include recycled material in their products for marketing reasons. However, in combination, these factors have started to increase infrastructure investment: research into new processes has also increased, particularly into chemical recycling. The standardisation agenda has been driven through WRAP – financially supported by the government – but voluntarily with industry. Perhaps this is tacit acknowledgement that detail is often built better from the bottom rather than prescribed from the top. Regardless, there is a desire for government policies that provide a level playing field from which to build future solutions.

The interdisciplinary design of the research, involving material scientists, social scientists and economists, has been crucial to promote research progress, as the project has evolved from one conceived around polymer chemistry to one exploring the relationship between these polymers, household practice and collaborative business models. While polymer chemistry and engineering may ultimately determine the recycling approach and the form which best retains value, it is the sustainable system that will create this value.

5. Conclusion

Delivering a 'One Bin To Rule Them All' vision will conserve resources through the reduction and eventual elimination of plastic leakage into the environment. It is achieved through promotion of reuse, mechanical and chemical recycling pathways in a tightly linked circular economy of plastic. Sorting by value instead of polymer to increase UK plastic recycling volumes can be delivered. This requires immediate action across four key areas: standardisation, infrastructure investment, collaborative business models and creation of higher value recyclate, each of which is underpinned by cooperation across the supply chain. We do not try to suggest that ongoing initiatives by many organisations are misguided: One Bin seeks to provide a more ambitious, systems-wide vision of future framework through which progress can be framed.

Cross-supply chain standardisation (coherent bin collection, fewer polymers, fewer contaminants, consistent marking, standardised recyclate bales) and new recycling data must be produced using open standards accessible by all, avoiding control by one actor in the supply chain. Decisions made on reuse, mechanical recycling or chemical recycling rely on transparent and data-driven material hierarchies. Given the plethora of emerging regulations in the UK (Packaging taxes, Extended Producer Responsibility, Deposit Return Schemes, Norway amendment to the Basel Convention), resulting and complex interdependencies, with many unintended consequences, will introduce significant potential for missteps.

Thus, the true value of the One Bin proposal may be is its joint consistency and flexibility. As the infrastructure is not currently in place for economic recycling of all plastics, it remains essential to urgently maintain or even improve value through better sorting. If a plastic does not currently have recycling value, it could progress through to chemical or an existing waste management pathway. Segregation for mechanical recycling would only occur when economically viable – but importantly this can change as new technologies become available.

The research outlined in this paper shows that the basic premise of One Bin is, perhaps surprisingly, supported by both research and a broad range of stakeholders from across the supply chain. The ultimate goal of eliminating plastic leakage into the environment requires a harmonised national solution to plastic waste sorting. While the original hypothesis, that consumer confusion over recycling is a major barrier, is widely believed, it merits further research. The dependant hypothesis that maintenance of value in discarded plastics is paramount in enabling recycling is clearly evidenced by this work.

Author statement

Martin Burgess: methodology, formal analysis, investigation, writing – original draft. **Helen Holmes:** conceptualisation, methodology, investigation, writing- review and editing, supervision. **Maria Sharmina:** conceptualisation, methodology, investigation, writing- review and editing. **Michael Shaver:** conceptualisation, methodology, investigation, writing- review and editing, supervision, project administration, funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2020.105191.

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