



Dissertation

Encouraging the manufacturing use of low carbon footprint materials. The benefits, challenges and considerations exemplified by a single-use sharps container case study.

Submitted by:

Tom Ditton

2021123

Submitted to:

Alan Mumby

University of Wales Trinity Saint David

In partial fulfilment of the requirements for the degree of Masters in
International Innovation Management (MSc)

28th of February 2023

Acknowledgements

I would like to thank Alan Mumby for his guidance, support and laughs throughout the last two years of study. A special thanks to my parents for their support and words of encouragement. Lastly, words cannot express my gratitude to my incredible fiancée, Alex, for putting up with my stress, long working hours and personal doubt, who encouraged me constantly. Thank you.

Abstract

As concerns grow about the environmental impact of manufacturing processes, products and services, a greater focus is being placed on sustainable solutions. Addressing these impacts can be solved through a variety of ways, but this dissertation explores and details the requirements that manufacturers must follow if they are to successfully implement recycled plastic to reduce their carbon footprint into their manufacturing processes. This research follows a traditional literature review which details what the state-of-the-art research currently says on material sourcing, trialling, continuous improvement through Industry 4.0, commercialisation and developing products for global use. Besides the current literature, a case study is referenced throughout the “implementation guide,” of a company’s recent recycled material implementation, whereby a review and analysis is provided to form a constant comparative example of the level of detail such implementations require. The outcome concludes that there are several benefits to implementing a recycled plastic into a company’s manufacturing process. It can yield great carbon emission reductions, whilst providing an opportunity to deliver strong marketing campaigns for new products. Although not all companies have the ability to develop brand new sustainable products, transitioning to a recycled plastic can provide a feasible alternative. However, research shows that there are many considerations, actions, and challenges that companies must overcome and how the process is not simply changing from one raw material to another. Additionally, each company is different with nuances to their products and processes, and that they must be able to apply the knowledge of their business to the principles discussed, which may not directly correlate with the research. Furthermore, development upon this research would aim to provide a more comprehensive analysis on the sections less discussed and would aim to seek the collaboration of funding schemes, agencies, consultancies, and organisations to be direct contacts for when companies are ready to begin such a project.

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List of abbreviations

Abbreviation	Definition
CE	Carbon Emission(s)
CF	Carbon Footprint
PP	Polypropylene
PPT	Plastic Packaging Tax
RM	Recycled Material(s)
RP	Recycled Plastic(s)
RPP	Recycled Polypropylene
RSC	Reusable Sharps Container(s)
SUSC	Single Use Sharps Container(s)
VP	Virgin Plastic(s)
WRAP	Waste and Resources Action Programme

INTRODUCTION

1. Introduction

1.1 Introduction

Extreme weather events are happening more frequently and becoming more intense across the globe. In 2022 the UK topped 40°C (Andersson & Faulkner, 2022), India and Pakistan faced five successive heatwaves with temperatures up to 49°C (Rowlatt, 2022), and Spain and Australia had flooding, with Brisbane experiencing 80% of its annual rainfall in six days (Taylor, 2022).

Human activity is a driving force for the rising global temperature, as since the Industrial Revolution and the increasing burning of fossil fuels, the rate of global temperature rise is accelerating (Met Office, 2022). Generating power, manufacturing goods, cutting down forests, increased transportation, producing food, powering buildings, and consuming too much are all contributors (United Nations, 2022).

Countries, manufacturers, and consumers are changing their attitudes as to what they want their environmental impact to be and are looking for ways to tackle climate change. Various nations pledged to keep global warming to 1.5°C at the landmark 2015 Paris agreement, with many countries pledging to get to net zero by 2050 (BBC, 2022).

New products are being designed using less material or replacing virgin with recycled materials (RM). Modern technologies help redesign existing products by reducing material weight through computer simulations, testing high stress areas, highlighting areas of improvement. Not limited to products, services are now encouraging sustainability where returned products can be recycled, and materials broken down and reused. Technology has brought forth Industry 4.0 (I4.0) where old, high energy usage machines are replaced by less energy intensive and more sustainable, connected, and intelligent machines. However, with the optimised capabilities of I4.0 comes increased output, thereby increasing production, making it a difficult road to navigate. Whilst positive methods of reducing carbon emissions (CE), they can take considerable amount of resources to implement, often carrying significant risk.

Another method of reducing CEs, avoiding risk and time to develop new products is changing the core material. One of the most used materials in manufacturing, 8.3 billion tonnes of virgin plastic (VP) is estimated to have been used to manufacture products for industrial and consumer use (Geyer, Jambeck & Law, 2015). Transitioning to recycled plastics (RP) can drastically reduce a manufacturer's carbon footprint (CF), without investing the time and resource in developing new products, avoiding the associated risks.

Switching to RP can help meet increasing consumer demands as attitudes change to what environmental impact they want products to have (Lee, 2012). Additionally, it can positively satisfy supply chain demands such as the NHS's net zero targets which they aim to achieve through the purchasing power of their suppliers (NHS, 2020). Changing legislation also means manufacturers must adapt, as with the recent UK Plastic Packaging Tax (PPT) on products with <30% recycled content (HM Revenue & Customs, 2021). It can also future-proof against changing legislation as that <30% may increase (Hesselink & Duuren, 2021, p.5). Whilst environmental efforts are at the core of this endeavour, by providing new RP-products, companies can build strong marketing campaigns to promote the new product, setting themselves apart from competitors.

However, the road to implementation is complex, whereby many considerations must be factored into the decision prior to progressing too far. Not all RPs have equal CE benefits, so understanding what an environmentally friendly RP is is essential. Furthermore, the sourcing and material trialling efforts needed to succeed are arduous. Variances in mechanical properties, colouring options, availability, costs, product performance, and quality are all aspects for consideration, and all carry their own impact on the final product.

1.2 Aims

The aim of this dissertation is twofold:

- To provide a guide for manufactures to reference when implementing RPs.
- To use a case study example throughout, analysing the implementation against existing literature.

The aim of the guide is to:

- Encourage manufacturers to transition to RP, where possible.
- Help manufacturers and customers achieve green targets.
- Detail the benefits, challenges, risks, and considerations when implementing RPs.

1.3 Objectives

The aims of this dissertation will be achieved through a literature review on the specific areas, whilst providing a consistent case study throughout and analysing against the literature.

Specific objectives are:

- Analyse types of RP, the processes used, and the impact on its overall CF.
- Analyse material sourcing actions, ensuring mechanical properties, quality, costs, availability, and supplier requirements are achieved.
- Analyse material trialling actions, ensuring manufacturability, product performance, blending options, and sample quantity are defined.
- Analyse areas where process improvements can be made to aid with RP implementations.
- Analyse the types of innovations that can be achieved, detailing the risks and benefits of leading the market and considerations for developing products for global use.

1.4 Justification

In a period of sustainability uncertainty, regulatory and consumer attitudes are changing as to the impact products should have. Where the ecological impacts of manufacturing are becoming evident, manufacturers must look to improve their CF, either through the way they manufacture, or the products they make. Risks are always associated with any change to the norm, but change must happen so the world is not impacted beyond saving. Large companies may have the resource to investigate the requirements for a material change, however, smaller companies may not have this luxury. While previous research has captured several aspects of a RM implementation, this dissertation goes further in providing information on the technological improvements and

commercialisation of such a project. Additionally incorporated throughout is a constant example of a project recently completed, providing valuable insights for other companies to relate to.

1.5 Methodology

There are two popular styles of literature review with varying characteristics, the traditional and systematic review. This literature review follows the more informal traditional approach for a state-of-the-art review of current research (Jesson, Matheson & Lacey, 2011, p.15), using a less formal study protocol and search strategy (Demeyin, 2016). As the dissertation is not answering any specific question, usually at the forefront of a systematic literature review and is using a less structured approach to the strategy and protocol (Rother, 2007), a systematic literature review process has not been followed. However, a wider range of sources of literature shall be used, more commonly associated with a systematic literature review, such as scientific articles, case studies, journals, and books.

Throughout the report, several case studies will be explored from various information sources, however, a case study of a single-use plastic injection moulded sharps container manufacturer who recently implemented a RP, will be used as a constant comparison throughout the “guide” sections. Each section will detail the research and then carry an analysis of what the manufacturer did and the lessons obtained.

1.6 Research ethics

There are ethical considerations that must be addressed. Regarding the sharps container manufacturer, the sources of the newly implemented RPs are confidential, so will only be referenced as RPs.

As the dissertation is predominantly literature review based, whereby multiple sources of information will be discussed, the researcher will avoid plagiarism by referencing appropriately so as not to misrepresent someone else’s work as their own (Polonski & Waller, 2004).

2. Methods of achieving sustainability

2.1 Sustainable design

With increasing social awareness of the world's environmental issues, designers, engineers, and manufacturers cannot ignore the impact their products, processes and services have on the environment. In recent decades, more focus has been placed on sustainable design and ways in which things can be changed to reduce their impact on the environment.

Principles of sustainable design have existed since the 1960s when the term "Spaceship Earth" was coined (Fuller, 1969), highlighting the concern of earth's limited natural resources and the need for cooperation between professionals, planners, architects, and engineers. This concept was further promoted in the 1980's through a developed explanation stating, "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p.37), and again into the new millennium, "Sustainable design approaches consider the environmental impacts of products during their whole lifecycle. The application of sustainable design leads to the development of more environmentally benign products and processes" (Chen *et al.* 2011, p.1937). A pivotal point for these approaches emerged after the United Nations Conference on Environment and Development (1992), where the three fundamental "pillars" of sustainability; economic viability, environmental protection, and social equity were identified as areas of improvements (Klöppfer, 2003).

Today, we commonly follow the concepts of cradle-to-gate, cradle-to-grave, and cradle-to-cradle (Haemmerle, Shekar & Walker, 2012). While cradle-to-cradle products aim to use infinitely sustainable materials, not all companies have the means to develop products like this, and not all products can meet this criterion. However, many companies will need to implement at least some of the above concepts in their development.

These concepts highlight the environmental impact our actions have and aim to set out tools to overcome these issues, or at the very least, reduce the impact such actions have. However, it may be difficult for companies to achieve this, whether because of resource, finance, knowledge, or even misunderstanding a market. When done well, the benefits can be great for the environment and the company, but when done poorly, can be very costly for a company (Booker, 2020; Robinson, 2022).

2.2 New products

Sustainable development and the decisions companies make are essential to reduce environmental impact. This can be achieved through product design and the introduction of new types of products that previously would have had a high CF.

Such an example is Orangebox (n.d.) who recognises that continued growth and success is dependent on the long-term sustainability of materials. A high-quality office furniture manufacturer, through NPD they maximise use of recycled and recyclable materials, use stress analysis software to optimise material usage, and design for disassembly improving ease of recycling of components. Similarly, Persil reduced their own CF and their customers, by changing their liquid detergent to a double concentrated product, requiring half the water to make, half the packaging, and half the number of trucks to deliver to customers (Donato, 2022).

However, companies must be careful not to jump on the “green” bandwagon without careful consideration, as new product introductions are always at risk of failing. For example, Nike’s sustainable shoe was discontinued within a year because they failed to consider their customer base, resulting in poor sales. It’s important for companies to ensure new products align with their brand perception and do the research to ensure its something customers actually want (Booker, 2020).

It can also be difficult for companies to introduce new products, with innovation opportunities being restricted as they often require additional resources, procedures, and manufacturing changeovers (Kahn, 2018, p.456). This highlights the need for due diligence, as the investment and resource required for new product introductions may be rare, making the success of the introduction paramount.

2.3 New manufacturing processes

Sustainable design does not only focus on new products for consumers. New manufacturing processes and systems have advanced using more efficient equipment, with increasingly more companies adopting such practices. “Sustainable manufacturing is the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community, and product safety” (EPA, n.d.).

Orangebox products for example, are all 100% made-to-order so there’s no obsolete stock, have very low levels of rejects and rework ensuring effective use of resources, and efficiently design their own aerodynamic delivery vehicles.

Additionally, Airbus is increasingly using additive manufacturing to manufacture lighter planes with 3D printing. This accelerates the manufacturing process, uses cheaper raw materials, and reduces production time, all having a positive environmental impact. The product-specific impact also results in 45% lighter parts that burn less fuel, saving around 465,000 metric-tons of CEs (Gençer, 2022).

2.4 New services

Sustainable development continues with new services and schemes that are increasing. Services encouraging sustainable practises are expanding through recycling schemes, collection services, and reuse initiatives which are effective in reducing environmental impact.

A major product development scheme of Orangebox is Orangebox Remade. This offers customers a product take-back service with options for purchasing remanufactured products, whereby remade products have been restored and sold with a warranty equivalent to a new product’s. This really promotes an attitude of reuse and recycle, greatly decreasing the number of products that end up in landfill and reduces the number of new materials required to fulfil new product needs.

Similarly, Patagonia’s Recycling Program made 34 tons of recycled clothes into new clothes, besides aiming to make all their clothes recyclable in three years (Umapathy, 2020). Their Common Threads Initiative encourages users to repair and reuse their clothing, offering a free repair service to keep products in circulation for longer, which is a great example of the profit-benefits a sustainable initiative can provide a company. The marketing community expected this to reduce Patagonia’s profits, however, the following year sales increased by 30%, showing consumer attitudes have shifted, and they want to invest in sustainable products and services.

2.5 Greenwashing

Whilst more companies are implementing sustainable practices, not all are equally beneficial, with many practices appearing good but the actual benefit can differ greatly. As sustainability consciousness grows, so do unsubstantiated claims companies make. Greenwashing is “the intersection of two firm behaviours: poor environmental performance and positive communication about environmental performance” (Delmas & Buerbano, 2011, p.65). Companies engaging in environmentally damaging practices may also emphasise sustainable practices to overshadow this (Hayes, 2022).

Unfortunately, large reputable companies are often the offenders. For example, Volkswagen admitted to cheating emissions tests, by fitting devices to their cars with software that knew when it was being emissions tested, and to perform with lower engine power, hiding the true emissions output. This was ongoing whilst the company was promoting the low-emissions and eco-friendly features of its vehicles (Robinson, 2022).

This practice of poor environmental performance and positive communication can be seen with different types of RMs. While not necessarily greenwashing, the choice of wording used to promote a RM doesn’t always indicate the true benefit. For example, a company can claim 100% RM in a product, but the processing involved in collecting, sorting, washing, and regrinding that material can have high CEs. See section 3.3 for further information.

With sustainability products and services estimated to be worth \$230 billion in 2009 and predicted to have grown to \$845 billion by 2015 (Tolliver-Nigro, 2009, cited in Lane, 2012) it’s clear why companies are focusing on sustainability, however, that doesn’t necessarily mean they will actually provide a good solution. To truly provide a good solution, it is essential that companies don’t fall into the trap of light-hearted efforts with the main goal to boost revenue. It must come from a genuine effort to reduce impact, and if done well and within their means, can provide a good solution that customers buy into whilst being profitable for the company.

2.6 Link to next section

This section highlighted ways companies can achieve sustainability. New products can achieve great success bringing something new to a company, providing good solutions for consumers and the market. New processes help manufacturers make products with less of an impact, and new services engage customers directly, making them part of the solution. However, these introductions carry risk. Even with the best research new products can fail in the market, new equipment can require significant investment not all companies can afford, and not all products align themselves with sustainable servicing. However, changing a product’s raw material can achieve great CF reductions, and if implemented on a product already in the market, reduces risk. However, carrying its own set of benefits, challenges, and risks, the next section discusses these elements of RM.

3. Recycled material & production

3.1 Benefits of recycled materials

The reusing of materials that have already had a life through a product dates back to 1031, Japan, with the first recorded instance of recycling paper (Hintons, 2018), and has since developed into a large industry. For many years, paper recycling was the most prevalent version, whereas in recent decades many materials have become widely recycled, on a community and industrial level. Reusing “used” materials reduces the amount of natural resources being used and prevents more product waste going into landfill or incineration, both with negative environmental impacts (Nabavi-Pelesaraei *et al.* 2017).

Ponte *et al.*'s (2017) life cycle assessment on the replacement of virgin materials for RMs for highway construction found significant environmental savings “equal to the energy consumption of 110,000 U.S. households per year, 9,300 bathtubs of water, and the carbon dioxide emissions produced by 58,000 cars per year”, and economic savings of \$62 million. While a larger-scale study than most companies, it highlights the cost-benefits that can be obtained, besides the collective environmental benefits if many companies make such changes.

3.2 Types of recycled materials

Today, manufacturing industries are utilising RMs to create products. Paper can be recycled avoiding landfill, with new paper made from recycled paper requiring 70% less energy than virgin pulp. With an annual global generation of 381 million tonnes of plastic waste, recycling plastic is vital (ISM, n.d.). As metals don't lose quality when recycled, there's no limit to how many times they can be recycled, however, the current recycling rate is only 34% (LeBlanc, 2021). Similarly, glass doesn't lose quality when recycled, hence the UK's glass sector target of 90% collection rate by 2030 (Recycled Now, n.d.). With 2 million tonnes of Waste Electrical and Electronic Equipment recycling (WEEE) items being discarded in the UK, the WEEE Regulations 2013 were introduced to prevent such waste going to landfill (HSE, n.d.). Considering that only half the annual 5 million tonnes of wood waste is recycled, the wood-recycling industry needs to be improved as even low-grade wood waste can be utilised for sustainable practices (WRA, 2018).

While it's important to avoid waste materials going to landfill, there are numerous reasons why manufacturers may choose to adopt a RM, whether for an improvement in cost, a reduction in CE, or simply for marketing purposes. While reducing environmental impact is the core of this dissertation's argument, not all RMs are environmentally equal, and each source requires investigation to get a true understanding of the CE benefits.

3.3 Defining an environmentally friendly recycled plastic

An increasing variety of RMs are available, however not all provide equal environmental benefits. Regarding RPs, a variety of methods are available for turning plastic waste into a recyclate and each have different environmental impacts.

Mechanical vs chemical recycling

The most common recycling technique for post-consumer waste is mechanical recycling where plastics are sorted, cleaned, shredded, and melted to be made into new products (European Bioplastics, 2020). Alternatively, chemical recycling uses high heats and chemicals to deconstruct plastic waste to its

molecular state. The resulting material performs like VP and can be used in products requiring higher quality materials (Gribkoff, 2022).

While both processes result in less landfill waste and require less resources than those used to produce VP, they both have their own environmental impacts. The energy required for chemical recycling is substantial (Bauer *et al.* 2022), with cynics arguing that due to the processes limited maturity, it is an unproven technology that's more of a PR stunt (Gribkoff, 2022). Similarly, Tabrizi *et al.* (2020) claims there is limited data corroborating chemical recyclers claims of environmental benefits due to its limited maturity at a commercial scale.

The collection, transportation and process associated with mechanical recycling do carry some environmental burdens, however, they are considerably less than those associated with production of VP, often making mechanical recycling the most environmentally beneficial option (TWI, 2022).

The source

The source of material is another consideration when defining an environmentally friendly RP, as this determines the reprocessing methods required. Post-consumer waste combines a variety of mixed plastics that requires several processing steps, including grinding, washing, sorting, drying, re-granulating, and compounding (European Bioplastics, 2020). The sorting process is especially important as the mechanical properties of blended plastics can be negatively affected, after already being affected by the recycling process (see sections 3.5 & 5.2). For example, brittleness is increased when PP is blended with HDPE (Singh *et al.* 2017). However, the mixed-plastic issues of post-consumer waste and the additional sorting requirements can be avoided by obtaining waste from its source (Meran, Ozturk & Yuksel, 2008). Post-industrial (pre-consumer) waste eliminates many post-consumer processing steps whilst having fewer contaminants and higher volume availability. Sourcing post-industrial waste also reduces transportation and energy costs (Hopewell, Dvorak & Kosior, 2009). This highlights the need for a case-by-case review when sourcing RPs as the availability, cost and compatibility can differ greatly between materials, however, not all products require such strict mechanical performance.

Carbon footprints of different materials

While different types of plastics have different CEs, it's important to highlight the differences between RPs when blended with their virgin equivalents, as the environmental impacts aren't straightforward. A comparison of recycled polypropylene (RPP) showed 25% lower CEs than recycled PET (Kosior, 2022). When blending plastics, the complexities of true environmental benefits of RP become more evident, as the CF of a 30% recycled-content PP-product is equivalent to a 73% recycled-content PET-product. While the PET product has higher recycled content, the environmental benefit is the same. This provides challenges to consumers and to companies. If a company is promoting its recycled content, this study highlights the importance of getting a true understanding of a products environmental benefit, as they may be promoting a high-recycled-content product, but that specific material may have a higher CF than another material blend with less recycled content.

It is important for consumers to understand the difference between "percentage of recycled content" and "percentage of CE reduction," as, if their purchasing decisions are based on environmental concerns, they need to understand which is more important. However, it is unrealistic to expect all consumers to understand this, which should put the onus on companies to be transparent in their messaging and should be their responsibility to promote the true benefit of new products which can be done by stating the CE reduction. However, again, this is not understood by all consumers, and is less intuitive to understand than percentage of recycled content. Companies are increasingly using

other means of communication to convey their efforts through promotional material that highlight CF reductions. This has often been done by comparing with the “equivalent number of trees saved” or the “number of plastic bottles not made,” that has equivalent CEs. Communicating in a perspective consumers can relate to helps them understand it more. If companies are undergoing sustainable projects for the right reasons, this should be easy to achieve as they will have the supporting data. For consumers, if a product is only being showcased with recycled content, it is not enough to determine the true CE benefit it actually has, and for those wanting to make environmentally conscious purchasing decisions, more information is needed.

Location

Another aspect to consider is the RP source location in relation to the manufacturing site. Sourcing materials close to the manufacturing site is the best option for reducing transport emission. However, determining what counts as “locally sourced” can be difficult, so it is important for the manufacturer to state the specific distance (Fontes, 2016).

LCAs

Many elements contribute to how environmentally friendly a material is, making it difficult to understand the full picture. For manufacturers exploring RP implementations, a life cycle assessment (LCA) can be used to assess the environmental impact of different RPs, which can include investigations into different recycling methods (Lazarevic *et al.* 2010). Huysveld *et al.* (2022) also detail the process for evaluating the substitutability of RMs for virgin materials. See section 5.4 for further information. However, it’s important for companies that when communicating the benefits of RP, it is simply not enough to state the recycled content, and more of an emphasis should be focused on “a reduction of carbon emissions.”

3.4 Injection moulding & recycled plastic

Use of RP is increasing as a method of achieving sustainability within the injection moulding industry, and with more sources of RP, the applications have led to great successes. A strong example is Dormer *et al.* (2013) who found CE reductions of 24% when increasing recycled content from 85% to 100% in plastic trays. To reduce emissions further they also explored the tray’s product design, by reducing the amount of material required, as well as the production energy required. Material density was also reduced through “foaming” which further reduced the product weight. These are good solutions that can yield great results by eliminating unnecessary features, however, this must be investigated on a case-by-case basis as some products are subject to more stringent testing.

3.5 Impact modifiers, additives & blends

The recycling process affects the mechanical properties of plastics, making it not always possible for a product to use 100% recycled content, which is important when performance is a key design element. Impact modifiers and additives can be used to improve properties, coming in a variety of forms like wood, glass fibres, talc, and other plastic blends (Satya & Sreekanth, 2020). They can be required where a higher recycled content is preferred on components with strict performance constraints.

Gu, Hall & Miles (2016) incorporated talcum powder and organically modified montmorillonite to RPP, finding a range of flexural strength improvements between the two. Impact strength improvements were observed with the addition of talc, however, improvements decreased when too much talc was

added, showing that “more is better” is not necessarily true for impact modifiers aiming to improve performance. Studies have shown that impact modifiers can increase impact strength by over 80%, however, results varied between PP composites (Kakroodi & Rodrigue, 2014). Similarly, tensile and impact strength has been improved by using elastomers with varying contents of styrene (Matei *et al.* 2017). It can still be difficult to achieve the same performance as virgin PP when using impact modifiers, as Ghahri *et al.* (2010) found ethylene vinyl acetate improved an RPP blends performance but not equivalent to virgin PP.

Impact modifiers affect mechanical properties both positively and negatively, and the use of which types will depend on the intended product application. Additionally, there are no fixed rules for which impact modifiers will work the desired way with which plastic variant. Again, a case-by-case analysis is required when investigating implementing such materials and leaning on the experience of suppliers to help with the investigation is beneficial, see section 5.9-10.

3.6 Introduction to next section

There are many aspects to consider when implementing RPs, and it is important to do the research into what is involved. The next section introduces the case study company, Sharpsafe, who manufacture single-use plastic sharps containers, to be used as the example throughout the subsequent sections that detail the sourcing, trialling, testing and implementation of RP into a manufacturing process.

4. Case study

4.1 Introduction to Sharpsafe

The following sections of this report aim to provide guidance for implementing RP into a company's processes. The sections focus on material sourcing, material trialling, I4.0 elements and continuous improvement, types of innovation, leading the market, and developing for global use. A case study will be used consistently throughout these sections to provide an example of how these elements were considered and addressed. It will also provide an analysis and highlight ways in which the process could have been improved. The company is Sharpsafe who manufacture injection moulded single-use sharps containers (SUSC) for the safe disposal of sharps and clinical waste.

Prior to the implementation, Sharpsafe containers were made from 100% virgin PP, with small doses of masterbatch to colour specific parts. The annual PP usage is 6000T. Containers are made up of two parts, a lid, and a base. All bases were yellow, with lid colours varying depending on the specific waste stream (UK only) or specific customer colours, including yellow, orange, purple, blue, white, and green.

Sharpsafe manufactures all containers at their facility in South Wales, and delivers across the world, including the UK, France, Germany, Spain, Portugal, The Netherlands, Italy, Japan, Australia, and Canada.

4.2 Project catalysts and problems faced

Several factors contributed in the decision to implement a RP into the production process.

First and foremost, the company was aware of the detrimental affect single-use plastics had on the environment and strived to reduce their impact as much as possible. Other initiatives were implemented across the business, but an LCA highlighted the company's highest CF was associated with virgin PP, making it the best option to reduce CEs.

As a large supplier to the NHS, whose goal to achieve carbon neutrality by 2050 was largely going to be achieved through suppliers, and as a key customer, Sharpsafe had to adapt to meet the new requirements.

While Sharpsafe has several competitors in the SUSC market, reusable sharps containers (RSC) are an increasingly popular solution for customers. With growing awareness on sustainability, the benefits of RSCs were increasingly becoming a worry for Sharpsafe. There are advantages and disadvantages to both product types, however, the perceived sustainability of RSCs against single-use, virgin containers were difficult to overcome.

Cost was also a factor as the UK PPT coming into effect in April 2022 (HM Revenue & Customs, 2021) meant any component of a packaging-classed product with <30% RP in, must pay a tax. By producing 22-23 million parts for the UK, this would be a substantial hit. Additionally, prior to project initiation, several sources of RP were cheaper than VP, with a cost saving to be obtained. However, this saving varied between available RPs and it was not certain the end material would be cheaper.

Cost played a big part in the decision, and while some may argue the primary reason should be to reduce environmental impact, the cost implications were a significant factor. If the company's net

profit is affected because of additional taxes and material price increases, this can lead to further drastic actions needing to be taken. Additionally, any cost increases could have either been absorbed by Sharpsafe, or passed onto customers through higher selling prices, however, as the following sections will detail neither of these options were sufficient.

4.3 Project outcome

The outcome of Sharpsafe's project was the world's first full range of significant recycled content SUSCs (Vernacare, 2022). Two RPs were implemented into the new range across sixteen container sizes.

The first material was added to the bases, with 100% RP in thirteen bases, and varied blends of RP/VP in the remaining three. Due to the larger containers putting more stress on the material during testing, the mechanical properties began to fail. The colour of the bases was less regulated, so a dark RP was implemented, which changed them from being yellow to grey.

The second material was added to the lids, with 20% RP in eight of the lids, and zero in the remaining eight. As there are strict colour requirements for lids, a clear RP was needed, however, this proved difficult to source, as all tested materials did not have the required mechanical properties.

4.4 Single-use vs reusable containers

The term "reusable" is increasingly becoming more preferred than "single-use" which can be seen within the sharp's container market. SUSCs are being evaluated against RSCs, which once full of disposed waste, are collected from hospitals, and taken to decontamination facilities for sterilisation before returning to a hospital. There are benefits to both, but the key elements are infection prevention and sustainability. Sharpsafe's priority is to provide safety and confidence for those using essential devices for patient treatment. Infection prevention is the priority, with sustainability following.

Sustainability

Research argues that RSCs have lower CFs than SUSCs, largely due to them boasting an impressive 500 washes across one unit's life, compared to the one-time use of SUSCs. CE reductions have been found when hospitals switched from SUSCs to RSCs (Grimmond & Reiner, 2012), however, the validity of the results are questioned as the study focused on a hospital close to the manufacturing and sterilisation site of the containers, with more realistic transport emission distances unaccounted for. McPherson, Sharip and Grimmond's (2019) study also found reductions in hospital CEs when using RSCs. However, bias and a conflict of interest can be attributed to these reports as they were funded by an RSC manufacturer and were a client of one of the authors. Arguably, the same could be said of any report conducted by a SUSC manufacturer, so it is important to understand the possibility of biased information.

Another factor misrepresented by research favouring RSCs is that their available container sizes are quite large, the smallest size being 14L, which is unsuitable for many hospital wards. In the market, mid-range sizes are the most popular, with Sharpsafe's 4L and 7L containers being the biggest sellers. In reality, it's observed that hospitals using RSCs also have a second supplier of SUSCs. The above research does not consider this, and only compares the CF of RSCs vs SUSCs, rather than the reality of a shared distribution.

Infection control

The increasing promotion of reusable products can be seen across a range of industries, however, due to the potential spread of infectious diseases, alongside the additional logistics required for reusables, evidence indicates that clinical settings are increasingly using single-use devices (Medical Technology, 2020). When considering single-use or reusable devices, patient safety must be the main factor (BMP Medical, n.d.), suggesting that SUSCs will always be needed, and “reusable” is not always the most suitable option.

Additionally, Runner (2007) found bacteria present on RSCs after they had been sterilised. Pogorzelska-Maziarz’s (2015) also found correlation between SUSC usage and lower C-difficile rates with hospitals compared to RSCs, however, there is a possible conflict of interest within this study due to it being sponsored by a SUSC manufacturer.

These points are highlighted to indicate that while sustainable practises are important, the ability and appropriateness to implement them must be weighed on a case-by-case basis depending on the product. Whilst creating a reusable product may seem the best option initially, it may not always be feasible or appropriate.

4.5 Introduction to next section

Several factors led to Sharpsafe’s RP implementation, which was going to impact their production, product design, logistics, communication, and company strategy. As only a material change for an existing product, it can be said that the full scale of the impact was not anticipated at the beginning of the project, and many challenges were faced throughout that were not pre-empted which could have been avoided if considered early on.

The following sections address the many areas of consideration when implementing RPs, aiming to provide manufacturers with guidance, with the hope to avoid the challenges that Sharpsafe faced. For each section, an explanation of how Sharpsafe managed the specific subject will be explained to provide a constant comparative case study throughout.

5. Material sourcing

5.1 Finding the right material

Finding the right RP is essential to create a successful product and having a close link between designers and procurement activities is advised. Several factors should be considered when exploring possible RPs to implement: the link between technical performance and material specification; environmental performance; and economic performance (Field *et al.* 2001).

Two areas cover the material sourcing process:

- 1) Identifying materials that meet technical and sustainability needs, considering product technical and quality performance; elements of what a RP is; sources of plastic waste; the variety of recycling techniques and reprocessing steps; transportation distances; and total CEs (Singh *et al.* 2017). Conducting an LCA is recommended to compare these elements (Alhazmi, Almansour & Aldhafeeri 2021).
- 2) Identifying and liaising with suppliers to develop successful partnerships, with considerations in operation metrics; strategic dimensions and capabilities; quality management; process capabilities; design and development; cost reduction capabilities in the decision-making process (Talluri & Narasimhan, 2003, p.236). RP suppliers should also be evaluated against a range of metrics including material availability; level of integration; processing capabilities; environmental footprint of recyclers; alignment of two closed loop strategies; and auditing process and quality certification (Saravanan, 2018).

5.2 Product technical performance & material specification

During the plastic recycling process, mechanical properties are affected, usually resulting in poorer product performance (Hopewell, Dvorak & Kosior, 2009; Schyn & Shaver, 2020). Studies comparing mechanical properties of RPs against their virgin equivalents have found reductions in tensile strength, impact resistance and hardness (Satya & Sreekanth, 2020). However, between the RPs evaluated, there are differing levels of characteristic performance, of which the importance would vary depending on the materials intended application.

The importance of the mechanical property performance depends on the type of product the RP is being implemented into. For example, medical devices are subject to stringent testing where high product performance is essential due to the possible risks associated with a product failure. Whereas products like disposable cups that do not require rigorous testing, the reduced mechanical properties of RP will have little impact on the required product performance.

Deterioration in RP mechanical properties usually occurs with mechanical recycling, whereas chemical recycling results in a material with comparable properties to its virgin origin. This, however, has an impact on environmental performance, see section 5.3.

Having an early understanding of what product performance and material characteristics are required is essential to limit the material investigation's scope, which usually precedes a trialling and testing phase.

5.3 Environmental performance of recycled plastics

As section 3.3 detailed, there are environmental considerations when sourcing RP, such as recycling processes, sources of material, CE differences between materials, and blending implications.

Recycling process

Several recycling processes are available for different plastics, all having their own environmental impact. Whilst many processes result in less landfill waste and require less resource to produce than VP, there are new energy, collection, and processing emissions associated with RP to consider. Additionally, different processes result in different mechanical properties, so consideration for what is valued higher is required, either technical or environmental performance. For example, can a mechanically RP's properties meet the product technical requirements, or is a chemically RP more suitable. If so, the increased environmental impacts of chemical recycling must be considered. Defining what is most valuable is important early on to help set the scope of the investigation and provides more direction for further exploration.

Source of material

Additionally, the source of material will impact environmental performance. Post-consumer and post-industrial (pre-consumer) waste both have environmental implications, with some materials being more readily available than others but have a weaker environmental performance. Several options can address this, and environmental performance requirements will depend on the application and scale. For example, a more readily available post-consumer RP (reduced environmental performance) can be implemented across a wider range of products, or a less readily available post-industrial RP (higher environmental performance) across a smaller range. The benefits and balance of both options should be measured to determine what is feasible while still providing the optimum outcome for the manufacturer.

Carbon footprint of different materials

All materials have different CFs, and the goal of RP is to reduce this as much as possible. Choosing which RP based on CF can be challenging, and communication from companies can become clouded when promoting a new recycled content product based on their choice of wording.

For example, a company promoting their new 75% recycled-content product can be seen as a significant improvement. However, if another RP with lower CF was used but with less content, then overall this could be better. When implementing a RP, benefits should be measured by the reduction in CF, as this is the true value. Comparing the difference in the original products CF and the new recycled-content product can achieve this. It is recommended that a product be marketed by having "X% less carbon footprint than the original," as it provides the most relevant information.

5.4 Life cycle assessment

LCAs are used to assess the environmental impact of a product or process, incorporating all inputs and outputs, providing an overview of upstream and downstream impacts (Mabee, 2020). This enables companies to fully understand their environmental impact and can help identify the worst offenders which can be focused for improvement.

The process

LCAs focus on the product lifecycle, of which there are several concepts, but, using the cradle-to-grave concept, consists of five phases: raw material extraction; manufacturing & processing; transportation; usage & retail; waste disposal. Lots of data is required to conduct a comprehensive LCA that will provide accurate results and can be broken down into four stages: Goal and scope; Inventory; Impact assessment; Improvement assessment (BPF, n.d.).

Who they are conducted by

The ability to generate accurate LCAs has improved over the years, however, it's common for outside experts to run LCA projects for companies, with internal teams providing the required information. While Schilling (2017) supports the value of external expertise, this can be costly and time-consuming to implement. However, software tools are available for companies keeping the assessment internal (Quist, 2019). This can be cheaper than sourcing externally, however, interpreting results and recommending improvements can be difficult to do well, so internal teams must be confident in their ability to execute.

Who they are used by

LCAs can be used by several departments for varied reasons. Specifically for this topic, Design, and the possible product modifications to reduce environmental impacts; and Procurement, to identify each raw materials environmental impacts, are the most relevant reasons (Quist, 2019).

Limitations

There are, however, some limitations of LCAs, whereby normal operations are considered rather than considering instances where incidents occur; the quality of available data which determines the assessments validity; the reliability of results can be dependent on the skill of the person carrying out the assessment; and, because LCAs often take too long to complete, investment decisions can be delayed (BPF, n.d.). Experts can help alleviate these issues by identifying potential problems and determine the study's feasibility.

Some research claims that environmental impacts related to transportation are minor in comparison to the wider material production, however most LCAs still includes transportation (Voulvoulis *et al.* 2021).

Communication

It's recommended that LCAs be conducted on the various RPs being investigated to understand their CF, however, in many cases, suppliers may have already done this, so obtaining theirs may provide all necessary information. It's also recommended to conduct an LCA on the overall product, as LCAs can be great tools in communicating sustainability efforts to customers. Providing data driven evidence can enable customers to feel confident in the claims, thereby creating a deeper level of trust within the customer-manufacturer relationship.

5.5 Material contamination & quality consistency

As sources of RPs often originate from general waste where a range of materials are sorted before processing ready for supply, there can be contamination and quality consistency issues.

Contamination

Contamination can occur from the technical capabilities of recycling facilities which must have the proper equipment to sort and wash the materials to achieve high quality recycle. This is difficult with hard-to-identify plastics on sorting lines, where different materials that look similar are added to the wrong stream. This can negatively affect the expected properties, causing problems at the end-user's production process (Clarke, 2021).

Previously less of an issue, as only low-end products used RP, however, today more RP is being used in high-end specialised products that demand high quality material with good mechanical properties (Holmes, 2015). This shows the importance of quality assurance-testing to ensure that a material will consistently provide the desired performance, and new quality standards for post-consumer RP by the ESA aims to reduce contamination and bring consistency to output quality (Smulian, 2022).

Testing equipment and capability

RP suppliers should have a range of equipment to perform quality-assurance testing that guarantees the material is contamination free (Holmes, 2015). However, suppliers with such capabilities are in the minority, so it's important when working with suppliers, to check they have this equipment as it ensures the quality and consistency of the material will be as expected. Failure of a supplier to provide evidence would need careful consideration if progressing.

RP suppliers should also provide Declarations of Conformity, validating the quality of each batch of material, thereby providing confidence the batch received has been tested and confirmed to be as expected. Additionally, customers can do further incoming goods checks to ensure the characteristics align with a predetermined specification, however, such equipment can be costly. If such equipment is required, it should be factored into the initial business case to avoid unnecessary surprises.

5.6 Current vs future availability & cost

The increasing trend of RM usage (IMARC Group, 2021) has put future availability at risk, which can cause issues if commitments have been made to customers for RP-content products (Brooks, 2020). The increasing cost of RP (Hesselink & Duuren, 2021) is another consideration when exploring materials, and it's advised these factors are considered in the business case and when reviewing future forecasts. It is important to understand the future availability and cost parameters from the supplier, and have agreements solidified to avoid unwanted surprises.

5.7 Colour limitations & performance

Colour limitations must be considered as most RP comes from post-consumer waste (Plastics for Change, 2021), mixing a range of colours and, when recycled, results in a less bright colour than VP due to the pigments of the previous application remaining (OECD, 2021). However, while not yet commonplace, colour sorting processes are improving making this less of an issue in the future (OECD, 2021). Using masterbatches to colour RP, hiding undesirable colours is an option (Holland Colours, 2021), however, if a light colour is required this can be difficult to achieve.

Finding a clear RP with strong properties can be challenging, as darker plastics are more widely available. This is important if sourcing large quantities, and the supplier must confirm they have the volumes to supply. Research suggests brand owners must be prepared to change their design,

including colours, to adopt a RP (Hesselink & Duuren, 2021). Engaging with marketing teams for the preparation of launch to communicate the change, ties in with the need for multidisciplinary teams.

5.8 Multidisciplinary teams

Implementing new materials is no simple feat and isn't covered by a small team within a company. Multidisciplinary teams with regular meetings to discuss ongoing progress and make key decisions is essential for a smooth implementation (Saravanan, 2018). Activities cover all departments including actions of material trialling and product testing (R&D/Operations), cost evaluations (Purchasing/Finance), buyers agreements (Procurement), BOM set up (Engineering/Quality), quality procedures (Quality/Production), and promotional activities (Sales & Marketing/Graphics). This is a brief list among the multitude of actions, so having regular contact with key departments helps track project progression and ensures no key actions are missed.

5.9 Liaising with suppliers & strategic sourcing

RP suppliers should be experts in their materials properties and can help determine whether a material is suitable for a desired application, and it's encouraged that companies tap into this knowledge (Schilling, 2017). Research shows that including suppliers during development results in projects being completed to a higher quality and in less time (Birou & Fawcett, 1994).

Strategic sourcing methods can ensure successful supply chain management, as incompetent suppliers may affect company sustainability targets, product quality and spend (Saravanan, 2018). A material may be suitable but if the supplier doesn't perform as required, then accommodating potentially changing demands of the customer will be difficult (Talluri & Narasimhan, 2003). These risks indicate that trust within strategic alliances is important (Trott, 2021, p.269), with recommendations that partnerships partly be determined by previous professional or social knowledge (Liebeskind & Oliver, 1998). So, using the recommendation of trusted associates can help avoid unfit suppliers.

The principles of strategic sourcing and liaising with suppliers is not limited to RPs, and other changes to production equipment should follow the same principles.

5.10 Value of external expertise

There are also other types of external expertise to lean on. With increased sustainability consciousness, there are schemes, initiatives, NGOs, and companies available to help with initial sourcing investigations with funding opportunities. This can reduce the sourcing phase leadtime as they may have the contacts and knowledge to get quicker results. Outsourcing for innovation is widely recommended as good practice (Schilling, 2017; Trott, 2021; Tidd & Bessant, 2020), but can be applied for investigative purposes as well. Outsourcing can also alleviate limited internal resource issues.

5.11 Sharpsafe

Finding the right material

Finding the right materials was not a straightforward process for Sharpsafe, however, the initial material investigation was improved through collaboration with WRAP Cymru. They helped identify

possible suppliers and materials, however, it took trialling twenty-nine different blends of materials before confirming the outcome. Several suppliers and materials were explored, which was a long, costly, and challenging process to test, but highlights the benefit that leaning on external expertise has. Without WRAP Cymru this phase would have taken a lot longer.

Product technical performance & material specification

Due to the risks associated with SUSC product failures, finding a RP with required mechanical properties was essential to guarantee high performance. Over Sharpsafe's 50 years of manufacturing, many materials had been tested and PP has been the optimum material. Straightaway this provided direction for material sourcing, as materials with similar properties to virgin-PP were explored first. This narrowed the search, however, it soon proved difficult to find RPs that met these properties, so materials with different properties were explored as material blending to improve the properties was acceptable.

Knowing the material specification at the start was essential and helped define the scope of the search, saving time. If this was unknown, the initial investigation would have taken longer, with more materials to trial, interfering with production scheduling, and requiring more resource. Where RP implementations involve existing products, this should be straightforward, however, new products will take more time to understand.

Environmental performance

The two materials implemented were sourced from different suppliers, but were both post-industrial mechanically recycled waste, requiring no additional sorting process, with no contamination from other materials, resulting in lower CFs than VPs.

The base material, accounting for 80% of the plastic usage, was sourced locally within twenty miles from Sharpsafe, which helped reduce transportation costs and CEs. Alternatively, the lid material was sourced from Northern Ireland requiring transportation to South Wales. This had increased transportation CEs, however, as previous research claimed, transportation emissions are relatively small in comparison to material emissions. However, there is a continued effort to source an alternative material more locally to further reduce this impact.

Finding a "local" supplier was important as it tied in with Sharpsafe's sustainable messaging, however, it's not always possible for manufacturers. While there should be efforts to find local suppliers, it shouldn't compromise product quality or safety.

LCA

Sharpsafe hired a PhD student, more knowledgeable than anyone internally, to conduct an LCA. This provided an accurate product and process analysis, with confidence to communicate the data to the market. Marketing campaigns elevating you higher than competitors require accurate data, as it can expose companies to scrutiny, so Sharpsafe needed confidence in the data to back up their claims. Overall, the project resulted in CE reductions of 2,500kgCO₂e which is a phenomenal improvement (Vernacare, 2022).

While Sharpsafe could have performed the LCA themselves, there is always risk that something may be missed. With the new range being first to market and changing the landscape of SUSCs, competitors could refute their claims. If something was missed and identified, it could damage the reputation of Sharpsafe and their products. If companies have the expertise to conduct accurate LCAs internally, it will be cheaper and quicker, however if not, sourcing external expertise is recommended.

Material contamination & quality consistency

Material quality is crucial with products that pose potential harm to users. Sharpsafe were awarded funding through the WRAP Cymru collaboration, and equipment was installed to test all material batches, to ensure consistent quality material is being delivered. As the RPs were post-industrial, there was less opportunity for contamination, however, one material proved challenging since the launch whereby traces of metals from the recycling process have been found. This results in batch rejections and additional resource required to deal with supplier corrective actions. This has only been a problem for the small-volume material and fortunately, strong agreements were in place that should contamination be found the supplier would recall the batch free of charge.

Without testing equipment, this contamination could have been missed and material used in production, possibly affecting product performance. It's important, where product quality is essential, that manufacturers are confident in their suppliers, or can test materials themselves. This material and supplier should have been more thoroughly investigated, as it was the material where only 20% content was possible, it didn't provide the ideal results anyway. However, it was perceived that any content of RM was better than none. In hindsight, Sharpsafe should have strived to source an alternative material for the initial launch or continued searching after launch as continuous improvement, showing a continued commitment to sustainability.

Current vs future availability & cost

Future cost and availability are challenging factors during procurement activities. Sharpsafe mitigated these challenges to the greatest extent by finding suppliers that guaranteed sufficient supply for the foreseeable future. Sharpsafe also became the primary customer of one supplier with priority over other customers should the volumes continue to increase.

One material was originally cheaper than VP, however, due to global economic issues (Business Wire, 2022), original cost-benefits became obsolete, proving difficult to mitigate. Additionally, good supplier relationships cannot always be relied on, and it's important to continue searching for equivalent materials that could be used interchangeably. There are always elements of uncertainty with suppliers whereby they may go into liquidation at any moment, leaving the manufacturer with no material supply. Having a secondary supplier is encouraged and once materials have been identified, that does not mean the search is over.

Colour limitations & performance

Due to SUSC lids requiring specific colour coding, finding clear RPs with required mechanical properties was challenging. As a result, the lid material is only 20% RP with the other 80% being VP to balance the mechanical properties. This is far from ideal as it doesn't hit the 30% threshold for the UK PPT.

As mentioned, having 20% was perceived to be better than nothing, so the material was implemented leading to subsequent issues. The challenge was due to regulations of lid colours. However, Sharpsafe changed the base colour which has less requirements. Initially met with market opposition, the justification and benefits were communicated to customers, who eventually understood and accepted the change. Where colour is less important, manufacturers should be prepared to change if it improves their CF, as this suggests customers will accept it. Exemplified by Sharpsafe as a medical product, if customers are accepting of such a drastic change, then less regulated products should be faced with less dispute.

Multidisciplinary teams

As the implementation was such a big undertaking, having key stakeholders involved throughout the project was essential. Depending on the stage of the project, weekly meetings were held to review actions and agree next steps. This ensured regular communication between key stakeholders, and helped address issues when they arose, ensuring everyone was in alignment on timings and actions.

Value of external expertise

The project started in collaboration with WRAP Cymru which expedited the initial material investigation. They helped identify possible materials and conducted initial searches and conversations with suppliers. This resulted in a quicker project and provided more clout to the claims and story that were promoted. WRAP also created their own promotional materials, further promoting the Sharpsafe range, hopefully leading to more awareness and thereby sales. If there is opportunity to utilise external expertise, it should be seized.

5.12 Introduction to next section

The next section explores testing potentially viable materials, which covers product performance requirements, appropriate sample quantities, material manufacturability and blending options. It's important to note that this section and the next are not linear processes, and one does not always follow the other. Often projects can be in several stages at once where the development and findings of one area requires the project to readdress a previous area.

6. Material trialling

To determine whether a RP is suitable for a specific application, besides sourcing activities, a range of testing is required to determine whether the products can actually be manufactured and perform as required.

6.1 Product performance criteria

Prior to any trialling, it's important to understand the performance criteria required of the moulded parts. Although the first challenge will be material manufacturability trialling (section 6.3), it's important to know the product performance requirements. If implementing RP into existing products, replacing VP, this criterion should be well-established, however if not, then spending time to fully understand what would be required is key.

For many products, performance requirements may be derived from standards or regulation governing the safety and quality of products within that industry. Alternatively, companies may set their own testing requirements. Regardless of the origin, some level of testing is required, whether stringent requirements for high performance products like medical devices or machinery components, or more relaxed testing for more benign products.

The affected mechanical properties of RPs may reduce product performance. Modifying injection moulding tools, without compromising the product's design, can be a suitable option to improve the performance. Strengthening failing areas, such as sharp corners, thin-walled areas, and other high-stress areas can yield great results. However, if more drastic modifications are required it's advised that careful consideration is given prior to any changes due to the impact on the product's design and the possible increase in weight, and thereby cost.

Additionally, if the products being trialled require external regulatory approval, it is recommended that there is utmost confidence in the product and materials performance prior to sending samples.

6.2 Appropriate sample quantity

Once product performance requirements are determined, an appropriate sample quantity to validate the testing must be defined. For confidence that results are accurate and reflective of actual production, determining the pass/failure rate is also required, however, this may be governed by regulatory guidance. Referencing ISO2859:2020-Sampling Procedures for Inspection by Attributes can help define this.

Larger sample quantities provide a greater understanding of the possible material and product performance variability; however, this leads to more cost and time to analyse the results. Thirty is often considered a suitable sample size, but this varies depending on product application, and the risks associated with the product testing should be considered (Maetrics, 2015). Knowing this beforehand will help determine; how much material is required from the supplier; how much interference there will be with production scheduling; and how much time resource is required from Quality technicians.

6.3 Material manufacturability

Injection packing pressure, injection time, packing time, mould temperature, injection speed, screw speed, and cooling time must be determined in preparation for future production, partially to ensure consistent manufacture of quality products without defects, but also as they influence productivity, quality, cost, and energy usage of the moulding process (Satya & Sreekanth, 2020; Bharti & Khan, 2010). These must be factored into business cases when comparing the feasibility of new materials.

Trial-and-error processes are common practice with moulders as they usually have experience of machines to make on the spot parameter adjustments, however, Bharti & Khan (2010) argue this is no longer good enough, and other approaches that validate samples through hardness, impact strength, flexural and thermal properties are more reliable. For example, the Taguchi Method details methods for designing processes that operate consistently and optimally (Kiatcharoenpol & Vichiraprasert, 2018).

If moulding internally, manufacturers should have sufficient experience to efficiently determine the correct parameters, however, blending RPs with VPs introduces more challenges. Additionally, if using an external mouldshop, it's recommended that someone who knows the products is present during trialling, as even if a material appears to produce quality parts to the moulders, there may be aspects not acceptable to an internal Quality person.

If a material has been identified as meeting cost, availability, and CE requirements, it is time for trialling. If a material cannot successfully mould a product, or if the cycle time to make a product is too long, increasing cost, then it should not be considered.

6.4 Material blends

As mentioned, implementing 100% RP into a product may not be feasible, and may require a RP/VP blend. This could be due to material availability and not having enough volume to satisfy 100% content across an entire product range, or due to RPs negatively affected mechanical properties.

Studies confirm the benefits of using blends, whereby Cox (1995) found blends of 20% recycled polyhydroxyalkanoate with 80% virgin equivalent were optimum for their application. Rahimi *et al.* (2014) found using a blend of 20% recycled ABS had little impact on the impact strength, making it a suitable option. Roy & Li (2014) found most polymers can handle a 10-30% recycled blend ratio with virgin equivalents with little impact on mechanical properties. However, other factors such as product design and testing requirements may impact this, so should be looked at on a case-by-case basis.

The specific material blend required for a specific application may be unknown, so a trial-and-error process may be necessary which may be guided by a company's own green targets for carbon reductions, or regulatory conditions. For example, a company may go directly to testing a 30/70%-RP/VP blend to avoid the UK PPT and depending on the results, they may be able to increase the RP content or must reduce it.

Regrind

Once plastic has been through at least one processing method, such as moulding, it can be ground or chopped for reuse. This is called regrind and comes from wasted material during the manufacturing process (Bozzelli, 2010). Studies suggest the similarities between VP and regrind mean similar product performance and energy consumption can be obtained from regrind at any blend ratio, however, different processing times may impact energy outputs (Vassallo, Rochman & Refalo, 2020).

Manufacturers can utilise regrind material as an additional sustainable solution, while benefitting the cheaper cost due to utilising waste material, however it cannot completely replace VPs, as moulding VP generates the regrind, so additional sources of RP must be explored.

6.5 Sharpsafe

Product performance

Sharpsafe have existed for many years, so product performance requirements were known, and testing procedures established. While analytical tests on material properties can provide useful insights, the crucial testing is conducted on product samples. These tests were derived from procedures laid out by regulatory bodies that govern SUSC safety across different regions:

Standard	Description
ISO 23907-1:2019	Sharps injury protection — Requirements and test methods — Part 1: Single-use sharps containers
UN 3291	Clinical Waste (Bio Medical Waste or Regulated Medical Waste) / European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)
AFNOR NF 302	Packaging for potentially infectious clinical waste with perforation risk

Knowing the testing requirements meant trialling could begin as soon as material samples were received. If implementing RP into a new product with new testing procedures, then it's advised that sufficient testing and trials are done to ensure the test methodology is appropriate for the application leaving no room for user error or variability. Additionally, knowing the performance requirements plays a crucial role in determining material requirements, and thereby material specifications, so understanding early will help define the scope of the material search. Additionally, knowing whether external validation is required is important to factor in the costs and leadtimes into the business case and planning.

Appropriate sample quantity

All containers are manufactured onsite, so Sharpsafe had the capability to schedule samples with minimal interference to production, enabling testing of enough samples to be confident in the results. For each material and/or blend, 50 samples were taken for each test and each product variant. The aforementioned standards require between 10-20 containers when validating, so testing 50 samples guaranteed confidence that results were accurate, reducing the risk of possible external failure.

However, Sharpsafe has a large production facility with 41 injection moulding machines and a relatively small technical team, resulting in challenges obtaining technical resource to perform the trials. This should be considered if working to strict time constraints, as using external mouldshops may have the capacity to complete the trials quicker. Planning and working with other departments can ensure that the production trialling and quality testing is conducted efficiently.

Material manufacturability

With onsite manufacturing, the technical team efficiently determined the required process parameters for each blend of material. Suppliers were initially advised for optimum parameters which were trialled, but the internal team adjusted the settings if these did not provide the desired output. Several materials provided quality samples, however, cycle times and moulding inconsistencies

prevented them from being viable solutions. This emphasizes the need for expertise during the moulding and trialling process, as the supplier's recommendations may not always be the best option depending on the product being made.

Material blends

Of all the materials and blends that were trialled, only two were identified as suitable solutions. One material was able to be 100% of the content for the specific part, whereas the other material could only be 20% of the total content.

One factor not considered at the start was the mixing process of materials to create a blend. This was performed by hand during trialling which, for small production runs sufficed, however would not be suitable for production. Consequently, additional mixing equipment was procured to achieve the desired blend, however it was not included in the initial business case and had a long leadtime which threatened the launch date. This was not a major issue but shows that all possibilities must be considered and factored into initial planning.

6.6 Introduction to next section

Implementing new materials does not only involve sourcing and testing various materials. While those aspects are important, projects often involve additional production work to enable the use of such materials, or there may be technological advancements to improve the development process. The next section discusses areas of improvement on product design and operations, which can be influenced or improved through use of I4.0 technologies.

7. Industry 4.0 & continuous improvement

Continuous improvement can incorporate I4.0 elements, as to how RP products can be trialled. Technologies can help with prototyping; soft tooling for production samples without large tooling investments; and software identifying areas of improvement for design. These technologies are not essential for RP implementations and are discussed to provide information on the possibilities that are available to companies to enable continued efficiencies and improvements. If within a company's means, by implementing these technologies manufacturers can remain competitive and not be left behind (Amaral, Jorge & Peçasc, 2019; Niemeyera *et al.* 2020).

7.1 Identifying areas of improvement

Manufacturing is changing with the development of I4.0 technologies (Renjen, 2018), such as additive manufacturing; augmented reality systems; big data analytics; Internet of Things; and simulations, which collectively have improved efficiencies in decision making times; testing and design optimisation; sharing information through real-time device connections (Rüßmann, 2015). Regarding RP implementations, these technologies can improve product quality, guarantee consistent material quality, and help streamline operation and production management. Additionally, technologies can help improve the product design by identifying stress areas, facilitating higher recycled contents and incorporate rapid prototyping to inform decisions without the need for large investments.

7.2 Advanced trialling

If not within scope to use an existing design or tool when implementing RP, a full or partial redesign may be required. New injection moulding tools may be required for trialling new products, which can be time-consuming, costly, and risky as the design may not be feasible with an RP. Fortunately, technological advancements mean it is no longer essential to have production tooling to test a new product. Additive manufacturing includes the development of "soft tooling" for trialling, which is quicker and cheaper (Gilchrist, 2016). Studies comparing the mechanical properties of parts moulded from additively manufactured soft tools against production tools found the parts performed comparably (Simpson *et al.* 2019), however other studies have shown issues in tensile strength due to the additively manufactured tools roughness (Kampker *et al.* 2019). While not appropriate for production, this enables the testing of samples, validating the design is right.

Soft tooling can expedite the trialling period, however, this relies on having a designed tool available. Where tool design is needed, simulation technologies can digitally trial tools before physically making any. Injection moulded tools are costly and time-consuming to manufacture, requiring thorough design consideration, aiming to avoid as much touch-ups as possible after first trials. Studies show that warping, shrinkage, and cycle times can all be improved through simulated testing (Ye, 2020; Özdemir & Akar, 2017).

Neither of these are essential for RP implementations and they do come with additional costs, but they have been mentioned to show the possibilities if an initial design does not yield satisfactory results from RP trialling. While replacing VP with RP is the focus throughout this report, it's not always initially possible, and companies must adapt and investigate fully before concluding that it is not possible.

7.3 Advanced operational equipment

Introducing I4.0 technologies does not require manufacturers to become smart factories with large scale investment (Bosch Rexroth, 2015). Companies can make incremental changes to improve current practices, which requires less cost and resource, and carries less risk than implementing several technologies at once (Amaral, Jorge & Peçasc, 2019).

Making sure the right blend and/or materials is used in the right products is essential and must include ensuring the material is right from suppliers. Tinius Olsen (2022) provides a range of automated quality testing solutions for polymers, ranging from automated systems that requires operator cooperating, up to systems that are operator free. Fully automated inline technologies can test surface quality, weight, and dimensional properties of moulded parts, without much human interference, ensuring that only quality products are reaching customers (Aminabadi *et al.* 2022).

Technologies benefiting injection moulding facilities includes digital twin simulations that replicate physical objects using sensors and real-time data monitoring, which predict system behaviours and failures, improving cycle times and reducing order leadtimes (Kenett & Vicario, 2021; Tan *et al.* 2019; Zhang *et al.* 2017). The same sensors can be used for data collection and analytical processing to illustrate what the equipment is doing. This can learn to predict future maintenance issues, eliminate inefficiencies, and avoid unplanned issues (Lazaro *et al.* 2019). Cognitive computing abilities involving analysing historical data and self-learning are only improving as technology continues to develop and has benefits in avoiding unforeseen maintenance costs, keeping tools in production for longer (Rousopoulou *et al.* 2020; Lenz, 2018); and improving efficiencies through fault identification (Kozjek *et al.* 2017; Zhang *et al.* 2015). However, using the correct data is essential for successful use of these technologies whose analytical algorithms can be time-consuming and costly to configure (Farahani *et al.* 2019), so companies must be prepared to invest the time and resource to achieve this successfully.

Many technologies could be discussed, however, they all require their own dedicated literature. Again, they have only been mentioned here to provide further direction on possible improvements. Although, if a business model is already successful there is not always a need to implement such technologies (Gilchrist, 2019, p.237), but there are tools available that can help prepare for such implementations if required (Genest & Gamache, 2020).

7.4 Downsides of I4.0

There are many benefits that can be achieved through I4.0, however, it's important to note the possible risks and consequences of such implementations.

With increasing development of the Internet of Things (Gilchrist, 2016), comes possible cyber security risks. With 50 billion devices connected to the internet, this threat continues to grow, and if technologies are implemented, companies must be prepared to implement high-end security systems (McKinsey & Company, 2019, p.25). While expensive and time-consuming, the consequences of not doing so pose greater risks (Banafa, 2018, pp.78-79).

Another impact of I4.0, is the subsequent job loss as human roles are replaced with autonomous robots and systems. Modern technologies will disrupt the workforce, some believing large scale unemployment will occur, whereas others believe it will create shifts in competency requirements (Schwab, 2019, p.38; Nascimento, 2018, p.611). As such, current studies suggest only 25% of companies believe they have required skillsets for future technologies (McKinsey & Company, 2019; Renjen, 2018), so it is recommended that companies invest in upskilling their workforce in preparation for new technologies. These technologies may change a worker's role, however, there is hope it will

enable workers to focus on other worthwhile tasks, and not be stuck working on issues or maintenance that would have otherwise occurred if not for the technologies.

A big obstacle preventing companies implementing I4.0 is cost. Many long-term benefits can be seen in productivity improvements, future cost savings, improved quality output, faster cycle times, and reduced machine downtime, however, the large investment required can build quickly, making it difficult for smaller companies to transition. However, as mentioned, smaller incremental steps can obtain good results. There are ways to reduce costs such as exploring low-cost automation (Erbe, 2002), using subscription-based architecture to avoid hosting (Chan, Lu & Wang, 2018), and possible funding opportunities for smaller companies (Villa & Taurino, 2019). Ideally, the incremental changes made, and the cost-benefits obtained will lead to future investment opportunities.

7.5 Sharpsafe

Sharpsafe's RP implementation involved little I4.0 technologies. The material trialling phase utilised existing injection moulding tools of current products, which initially provided varied results, and different outcomes were observed across the product range. Smaller containers performed well with most materials, whereas bigger containers subject to heavier impact testing, didn't perform as well with high recycled content. Fortunately, only minor tool modifications were required to improve the performance with desired content, which was done by the internal toolroom. However, two containers were not able to pass even after minor modifications. Consequently, Sharpsafe utilised an external company to perform Finite Element Analysis on the products with desired materials who identified and proposed design changes. Using software and utilising external expertise enabled Sharpsafe to incorporate RP into these products, which would have otherwise been difficult to accomplish, showing the benefits such technologies can provide.

Through WRAP Cymru's funding, Sharpsafe invested in new equipment to test all incoming batches of RP. This provided confidence that materials being used on production were high quality, but also helped identify contaminated batches, as previously discussed. Test equipment included an automatic tensile machine, Charpy tester, precision scales and a melt flow indexer, and while not specifically I4.0, the equipment was expensive and without the funding provided by WRAP, Sharpsafe would not have been able to implement the RP. This shows benefits of working with external companies and exploring the possibilities of funding.

Cyber security was not an issue for this implementation, as there were no I4.0 technologies introduced, as well as no job losses as a result. It did however require the Quality technicians to be upskilled with the new equipment, which is in line with the discussed research (McKinsey & Company, 2019; Renjen, 2018). Other I4.0 technologies could have been implemented into Sharpsafe's production, such as RFID tags on injection moulded tooling (Oberle, 2015), predictive maintenance (Lazaro *et al.* 2019), and autonomous robots (Gilchrist, 2016) which would all help improve efficiencies, however, was not the purpose or requirement of this project.

7.6 Introduction to next section

Ensuring the right material has been identified and the required manufacturing equipment is prepared for implementation is essential, however there are other, more commercial conversations that must be had, and should form part of the whole company strategy for what they want to achieve over the next several years.

8. Commercialisation & strategy

8.1 Leading the market

Many believe that to be innovative you must shock and surprise with first-to-market products. As RM is increasingly being implemented across industries, the opportunities to be first to market with a unique recycled product are declining, however, there are still some products that may be yet to transition. Research shows companies with first-to-market products benefit from “first mover advantages,” such as influencing customer expectations, shaping how customers evaluate other new products; setting and establishing distinctive quality standards; suggesting evaluation criteria customers should follow; and developing greater understandings in manufacturing and distribution elements (Trott, 2017, p.468).

However, there can be downsides with being first to market. Developing new products is expensive and time-consuming, whereas competitors can quickly copy a newly launched product, even improving on the design, making their version better (Goffin & Mitchell, 2017). This is exemplified by Gillette and their first-of-a-kind three blade precision razor. Developed at a high cost, it was the first of its kind within the shaver market, however, it was quickly copied by Boots and several other companies, who spent a fraction of the development costs. Another downside for new products, is there may be several regulatory or marketing challenges that can be arduous to overcome, whereas a competitor will not have to deal with such challenges as these would have already been addressed with barriers broken.

All possibilities must be considered prior to development as “hidden” development and post-launch challenges can greatly impact the long-term success of products. Companies must ensure that new products are good enough for long term to be first to market, and that enough resource is available to achieve such an undertaking. However, companies must consider whether they can afford to be second, third or even last to market. Decisions like this must be justifiably made and the more knowledge of a subject, the more calculated decisions can be made. Such knowledge to make these decisions can be obtained through market research, competitor analysis and trendspotting (Tidd & Bessant, 2020).

8.2 Innovation

Each RP implementation for each company will differ. Some may be introducing 100% RP into an entire product, whereas others may be introducing 20% into a small component of a larger product. All have sustainability benefits, but vary in development priority, required resource, and cost. Understanding the type of innovation such a project would be, can be important in informing a company whether it's strategically the right project to undertake at that time.

Types of innovation

Innovation comes in several forms and there is an abundance of research discussing exactly what it means to be innovative and what it involves (Tidd & Bessant, 2020; Trott, 2021; Satell, 2017; OECD/Eurostat, 2018). However, two core principles are relevant for this research topic. Trott (2021) summarises the research on innovation and explains that it can be broken down into incremental and radical innovation.

Incremental innovation utilises internal expertise and capabilities of existing technologies with modest changes to existing practices, leading to the enhancements of competencies with products remaining

competitive. Whereas radical innovation requires new knowledge, leading to technological advancements, often making current products uncompetitive.

Many believe incremental innovation lacks excitement and impact, and more efforts should be focused on radical innovations, however, both are important, and companies should strive to develop both incremental and radical innovations (Satell, 2017). Radically innovative products often lead to substantial market share by stealing the market from pre-existing competitors, however, more resource, time, investment, and knowledge is required to succeed. This may be possible for larger organisations, but smaller companies may find it more challenging, and comes with significant risk if the efforts are unsuccessful. Wherever there is change, there is always risk.

Incremental innovation that is essentially “doing what we do, but better” (Tidd & Bessant, 2020, p.30), enables companies to remain competitive with less upfront investment. Hollander (1965, cited in Tidd & Bessant, 2020, p.30) also “suggest that the cumulative gains in efficiency are often much greater over time than those that come from occasional radical changes”. Whilst developing radical innovations involves significant risks, there are also risks by avoiding them, as a company’s competitors may launch a new radical innovation rendering the company’s existing products uncompetitive.

Managing innovation portfolios

Knowing a project’s innovation type is important, however it’s recommended that companies adopt tools for managing innovation portfolios to decide which projects to undertake. Portfolio management works by viewing all projects collectively where they are evaluated based on their fit for the overall company strategy (Trott, 2017). This helps justify where limited resource is used and aims to prioritise the most lucrative projects. Some companies find value in basing their portfolios according to resource commitment and availability, cash flow timings, and levels of risk (Schilling, 2017), and Trott (2017) details the balance criterion of portfolios can be newness, time of introduction, and market, by describing an example of a portfolio model that uses hierarchy of criteria and factors for evaluation.

Once the project portfolio has been agreed in line with the company strategy, additional tools for running projects are recommended. Cooper’s (2011) Stage Gate process or Tidd & Bessant’s (2020) Innovation Funnel are useful tools in delivering strong projects, by aiming to ensure all aspects have been covered, reducing uncertainty, and having key decision points. Actions within sections 5-9 are covered within these processes. However, these should be used as tools for guidance, not necessarily strict rules, as even if the portfolio is not balanced perfectly, there may be other drivers that require projects to start, such as regulatory changes, or supply chain issues.

8.3 Response to standards & legislation changes

While innovation efforts should come from a company’s own desires for growth and improvement, often innovation projects initiate out of necessity. Changes in government regulations can affect the innovation process, both positively and negatively, but are aimed at reducing costs, enhancing efficiency, improving safety, and stimulating innovation (OECD, 1997). The OECD details a three-fold typology of regulation, each focusing on different aspects: economic regulation, social regulation, and administrative regulation.

Typology

Regarding RP within this typology, economic regulation includes competition law, which influences companies into innovating beyond their existing practices by encouraging competition and the development of new innovations. Social regulation, encompassing environment, clearly linked to RPs, and changing legislation with minimum share recycled content, which can already be seen across several countries and shows no signs of slowing. Additionally, the rules implemented today may be expanded in the future. And administrative regulation, encompassing intellectual property, which can govern how well certain aspects of an innovation can be protected. For adding recycled content, this may include a novel feature that allows higher recycled content to be added to a product, or a creative method of material processing.

Pros and cons

Regulations can provide suitable conditions for innovation by maintaining openness and competition within markets and have also helped create new industries such as the “environment industry” (OECD, 1996). However, negative effects of regulation include barriers to new or improved product or process development by discouraging research by companies, limiting the choice of technologies that are investigated, and increasing development uncertainty and costs (OECD, 1997).

It’s also important to consider the regulatory differences between regions, as what may be applicable for one country may be different for another. See section 9.2.

8.4 Sharpsafe

Sharpsafe’s, first of its kind, full range of high recycled content SUSCs never intended to be a disruptive innovation, however, throughout development it became evident this was the case. Adding RP into SUSCs was initially an incremental innovation, but as the “world’s first,” there was substantial disruption in the market, requiring them to champion change in regulations and legislation, forever changing the landscape of SUSCs.

Origins

The project originated from several forces, one being the social obligation to improve the CF of plastic SUSCs. After evaluating possible projects, transitioning from VP to RP held the biggest possible improvements, however, the UK’s PPT further ignited the project. Sharpsafe could have accepted the tax and absorbed the additional cost, or past the cost onto customers through increased pricing making them less competitive, both options deemed unacceptable.

The target was to launch the new range when the tax came into effect in April 2022. It became evident that if Sharpsafe did not launch a recycled range, there was a strong possibility a competitor would, giving them a market advantage. The project’s success varied as detailed in section 5.11, whereby 100% RP was implemented into the bases, but only 20% RP in the smaller lids due to colour requirements, meaning there was additional tax to be paid. The lid material was implemented because Sharpsafe believed that any recycled content is better than none, however, as previously discussed this was not the best strategy.

Challenges

The challenges faced and outcome turned the project into a disruptive innovation. The first major challenge arose when the UK Department of Health, who set the requirements for colour-coded lids,

were hesitant of the change from yellow to grey bases. However, after much deliberation, the mandate was amended to allow container bases to be any colour, and more importantly, strongly advised that containers should have significant recycled content. Customers will heed this recommendation when making purchasing decisions, so if a competitor was first to market and helped make this change, then Sharpsafe would have been at risk of not meeting the new recommendations, and possibly losing out in new tenders.

Another major challenge arose when samples were sent for external validation, as it was the first time the regulatory bodies had seen grey SUSCs. Until this point, all sharps' containers were predominantly yellow. Sharpsafe is certified to three standards: The ISO23907-1:2019 and UN3291 standard had no reference to containers being yellow, however, the test houses for each standard were unable to validate the samples, requiring further clarification from the ISO committee and UN board respectively. This was challenging as initial feedback argued the high RP content may risk the containers performing poorer, although all internal and external testing passed the requirements. This took several months of deliberation before the containers were approved, which risked surpassing the deadline. This was an uncertain time for Sharpsafe as without this certification, the new range could not be launched.

A similar problem arose with the French standard, AFNOR 302, however it does specify that SUSCs must be "predominantly yellow". Several conversations were had, leaning on Sharpsafe's French distributors, which led to no agreed solution before the launch. This was frustrating as there were discussions on what constitutes "predominantly yellow", with no definitive answer given by AFNOR, meaning there was no way to actually test it. Such conversations included the percentage of the surface that was yellow and went into colour theory and whether grey is a shade or colour. Sharpsafe could not introduce the new range into the France at first launch, however, ongoing discussions and promotion of the benefits eventually resulted in AFNOR agreeing to use Sharpsafe as a trial for sustainable-grey-sharps containers, and if successful will result in a change to their standard. This is a promising result, and even though it came after the initial launch, it shows the value customers and regulatory bodies see in sustainable solutions.

Additional challenges came from the considerable amount of external validation that was required for the full range of sixteen containers. This proved challenging when working towards the deadline as once samples were sent for testing, the result leadtimes were varied and largely out of Sharpsafe's control, with some sizes not being approved until close to the deadline, causing uncertainty internally and with key customers. Preparing and planning to avoid stressful end-of-project deadlines is recommended.

Outcome

The changes in regulations, standards, and market acceptance, changed Sharpsafe's innovation from an incremental innovation to a disruptive one, changing the landscape of SUSCs. This was a crucial project and involved a great deal of time, investment, challenges, and uncertainty. While a strong project, and positive that standards were changed in line with sustainable efforts, the true effort of what was involved is unknown to customers. They may see Sharpsafe as the first to market of this type of product, but they may not understand the difficulties that were endured to get there. Since the launch, several competitors have launched equivalent ranges, avoiding the stressful and uncertain regulatory challenges faced, however, fortunately in this case, Sharpsafe's efforts resulted in a strong and well-received project launch.

External forces driving change

Another instance of making a change based on external forces, was a change in the ISO23907-1:2019 standard's test requirements. Prior to the 2019-version, all Sharpsafe containers passed the standard, however, the introduction of a new test meant several containers were no longer compliant. This resulted in product design and tool modifications, that otherwise would not have been required. This shows that as a company, being able to adapt to external forces as they arise is essential.

8.5 Introduction to next section

Addressing the areas that have been discussed in this section is, again, only one part of the whole picture, however, if a company wishes to expand further beyond their existing markets, they need to have a sound understanding of what is involved. Culture, business etiquette, regulations and import and export taxes vary between regions, so to develop products for global use, these must be explored prior to launch.

9. Developing for global use & market acceptance

Companies implementing RP into an existing product for existing customers will already know the market well. However, if striving to expand into new regions, it's important to consider the differences in culture, regulation, and resource, as these aspects will vary region to region.

9.1 Culture differences

Each culture has different opinions of one subject to another, and understanding these before launching in a new market is important. New regions may not have the same infrastructure, methods of doing business, or even attitudes to products as existing markets. Consumer behaviour is influenced by cultural differences, and the success of a launch can be determined by how well these differences are addressed. Avoiding misunderstandings with foreign clients on a business level, and customers on a marketing level is key, and Seale (2015) describes cases of large companies that failed in this regard.

The nuance to culture within business is large, and it's advised to research prior to any development efforts. Smith (2021) summarises nuances involve cross-cultural challenges, such as low-context and high-context cultures; the varying degrees of nuance and directness in communication; understanding and observing interactions and gestures; workplace etiquette; organisational hierarchy; and negotiation style differences. New regions must be thoroughly researched. What is commonplace in existing markets, may be completely alien to another, and assimilating with the people to understand their needs and requirements is important (Dynamic Language, 2014). This is essential for NPD but also marketing campaigns to avoid cultural stereotyping and to be able to create meaningful messages. As mentioned previously Tidd & Bessant (2020) states that the more we know, the better decisions we can make.

Perceptions and value of sustainability

When introducing products into new markets and the unique selling point is sustainability-focused, companies must consider the cultural differences in how a specific region will perceive this apparent benefit. There are significant differences in sustainability consciousness (Berglund *et al.* 2019), environmental concerns and environmentally-friendly purchase behaviours amongst young consumers (Paço *et al.* 2012). Franzen & Vogl's (2013) two-decade analysis of environmental attitudes across thirty-three countries supports this. They found a nation's wealth correlates with their environmental concerns, whereby higher levels of concern are found amongst countries with improving economic conditions. This may be in part due to low economically developed countries having higher priorities than sustainability such as improving education, infrastructure, and hunger. While sustainability-focused products aim to improve the effect on the entire world, if sustainability isn't a priority for a specific region, they would unlikely pay a premium for sustainable products which is often the case.

It's important to understand and consider these differences before advertising in new markets, to avoid promoting the wrong message to the wrong region, leading to wasted efforts, resources, and costs.

9.2 Expansion considerations for new regions

Expanding into new markets can yield impressive results such as more sales and more profit, however, the decision must not be taken lightly, as the previous section has alluded to, there are many challenges to address.

Tariffs and export fees must be incorporated into financial planning. For example, companies supplying products into the UK must pay a PPT charge on all plastic packaging's using less <30% RP. There will be other rules and regulations within each region, so thorough research is required to avoid unplanned expenses.

The physical distance can be a big challenge and a major contributor to CEs, especially important if promoting a low CF-product. However, viable solutions to this could be investing in new tooling to send to new regions to manufacture locally. However, this could be costly and would require lots of resource to establish.

Addressing culture differences is important, however it's crucial to master marketing efforts for targeted regions as well. Buying processes and marketing campaigns can be run differently to local practices, and Dynamic Language (2014) suggests Transcreation of documentations and content must be done to ensure correct messaging is communicated.

9.3 Sustainable product vs feasibility & profit

Once these aspects have been addressed, a company may find the cost-benefits that can be obtained in existing markets may not be achievable within new markets. It's important to consider potential differences, and while efforts to develop, promote and launch new sustainable products in new markets may originally have been thought to generate new revenue, it ultimately may not be financially feasible. In this instance, directing efforts to existing markets would be recommended.

9.4 Sharpsafe

The initial launch of the Sharpsafe range did not target new markets. Due to the scale of the project, all effort was initially targeted on transitioning existing customers from original products to the new recycled-content range, which was a substantial task. However, since the successful launch with existing markets, efforts have now changed for ongoing expansion into new regions. This was the right process for Sharpsafe, as there was significant work involved with existing markets, to focus on expanding as well had the potential to overload the available resource, potentially leading to issues with existing customers. Sharpsafe found starting with existing customers then moving to expand enabled them to strategically focus their efforts and were also able to use the successful launch in existing markets as promotional evidence to new markets. Having a strategy for specific market launches is important and trying to accomplish everything simultaneously may not be the best option.

Throughout development, all existing customers were communicated to with discussions focusing on the CE benefits of the new products, who all understood the sustainability efforts. However, differences were observed. Some customers wanted raw CE data showing the change of the new products, whereas others wanted more marketing pieces that included buzz phrases like "equivalent to 1,000 trees per year" or "equivalent to 1,000 less bottles being made". Both methods of communicating the benefits have value, but their value is dependent on the customer. This shows that companies must be willing to adapt to specific customer requirements, and all communications, promotional activities, and marketing materials should be considered for the type of customer being targeted.

10. Conclusion & recommendations

10.1 Sustainable practices for manufacturers

This report has aimed to communicate the environmental uncertainty of the world, and the contribution from manufacturing processes, products, and practices. Manufacturers looking to improve their CF have a multitude of options, several of which have been discussed. Manufacturing and process changes, developing new sustainable products, or developing new products with reduced material weight may be feasible for a company. However, some companies may not have the ability to develop brand new products, so deciding to replace a VP with a RP to implement into an existing product can yield great CE reductions. However, while seeming like an easier solution, this report detailed the numerous challenges that would lie ahead for a successful implementation, especially when that change of material will be used as the unique selling point of said product. There are many aspects to cover, and it is essential that research and due diligence is done to ensure the right material, with the right characteristics is identified, and sufficient trialling is conducted to ensure that the products will perform as required. However, it's also important that companies understand they may not have the internal knowledge to conduct the project in the best way and that they do not have to endure these efforts on their own. Using external expertise from suppliers, test houses, funding schemes and more, can be paramount to taking the project to the next level. Additionally, the sourcing and trialling of materials are fundamental to the project, however, understanding the possibilities for manufacturing improvements, the consequences of leading a market, and where a company should be focusing their efforts on at the time are just as important, and should often be considered before the project begins.

Material sourcing and trialling were the primary focus, with other elements of a material implementation discussed. For companies using this document as a guide, it is highly recommended that the other sections are explored further as they are equally important as the sourcing and trialling phases. It's important to understand that each company and each product is different, and there is nuance to all these aspects. Researching and understanding best practice is important, however, a company must be able to apply the knowledge to their specific business which may not directly correlate with the research.

Additionally, future work for the author would aim to dive deeper into each of the topics discussed, providing further detail on useful tools, practices and discussions that must be had, with all information located within one document to be used as a more comprehensive guide for companies. The author would also aim to obtain cooperation from funding schemes, agencies, consultancies, and organisations that would be used as direct contacts for when companies are ready to begin such a project, however, this would be dependent on the region. Not all companies have the resource to explore sustainable practices, so providing a more comprehensive document will help more companies transition, thereby reducing CEs on a global, and hopefully greater, scale.

10.2 Sharpsafe's implementation

Sharpsafe's RP implementation was successful and changed the landscape of SUSCs for the foreseeable future. Challenging and changing regulations has resulted in 100% VP SUSCs soon to become a thing of the past, as since the launch, several competitors have released their own recycled

ranges. While deemed a success, the project faced many challenges that were not accounted for in the initiation phase of the project which resulted in higher costs, longer leadtimes, and uncertainty. Had all the aspects discussed in sections 5-9 been addressed, discussed, planned for, and agreed, the project would have run smoother and there were elements that could have been improved. This shows that the due diligence early in the project was not as sufficient as it should have been, highlighting this phase of the project is essential. While Sharpsafe's launch was successful, this may not be the case for other companies. Research, investigate, explore, and determine. Not everything will be known at the start, but addressing as many of these unknowns as possible will help avoid problems further throughout the project.

11. Limitations and further research

The limitations of this document acting as a guide for companies, is that it's important to understand there are nuances to each company. The research and information provided is to act as a guide only, and it is important for companies to understand their practices may not be directly in line with the research discussed. Each company has different resource, expertise, knowledge, budget, and quality requirements for their products, so using this information and determining ways to apply to their own process is important.

Additionally, the detail provided is to guide a company in their sustainable efforts, and is by no means a fully comprehensive document, and as such further investigation into each of the topics discussed is recommended.

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