What is Plastic?

A summary report exploring the potential for certain materials to be exempted from the Single-Use Plastics Directive

This report was authored by Eunomia Research & Consulting and published by Reloop Platform

With thanks to Richard McKinlay, Axion Recycling

January 2020

1.0 Introduction

In June 2019, Directive 2019/904, commonly referred to as the Single Use Plastics (SUP) Directive, passed into EU law with the aim of reducing the impact of 'certain plastic products' on the environment.[1]

Evidence of non-woven fabrics made from a random matrix of interlocking fibres—as opposed to a woven or knitted thread—impacting on flushed sewerage systems and the marine environment has led to the inclusion of wet wipes in the extended producer responsibility (EPR), labelling and behaviour change obligations under the SUP Directive.

Wet wipes are made from a single material or a combination of non-woven fabrics containing synthetic or natural polymers such as polyester, polypropylene, cotton or man-made cellulosic fibres (MMCFs). They are commonly used for personal hygiene and household cleaning, with wipes used for personal hygiene frequently flushed down the toilet.

The problems that arise from this are two-fold: firstly, in sewerage systems and waste water treatment facilities, wipes can result in significant blockages if they do not disintegrate sufficiently quickly. Secondly, wipes can contribute to marine pollution if they pass through waste water treatment facilities and into watercourses or bypass them entirely via sewage overflows or are littered on beaches or on land.

The SUP Directive excludes "natural polymers that have not been chemically modified" from the definition of plastic and therefore exempts them from regulation. In line with the intent of the Directive, exemptions for products made from some materials may be appropriate where these have substantially less impact on the environment than equivalents made from 'plastic'.

However, products made from unmodified natural polymers that *cannot* currently be shown to perform substantially differently in the environment would avoid regulation and this could severely undermine the effectiveness of the Directive. The question of which natural polymers are covered by the term 'plastic' and which may be exempt is therefore an important one as Member States work towards implementing the Directive.

In the context of wet wipes, the debate around exemptions has focused on two types of man-made cellulosic fibres; lyocell and viscose, both of which are effective substitutes for synthetic polymers. Manufacturers seeking to avoid the cost of regulation and to make green claims about their products may be driven towards these materials on a large scale.

Equally, consumers presented with apparently natural and environmentally benign wet wipes may feel that they can consume more wipes and be less careful regarding their disposal. It is conceivable that wet wipe consumption and flushing may even increase as a result of natural polymer wipes being given an environmental clean bill of health.

Similar substitution options may exist for other product categories covered by the Directive. As Member States begin enacting the Directive into their own law, consistent interpretation of the scope of products covered will be crucial if the integrity of the single market is to be maintained. This will be particularly evident for products subject to restrictions under Article 5, with the implication that products banned in some countries may remain freely available in others. However, inconsistency of product coverage for

EPR and most of the other instruments introduced by the Directive would have similar potential to substantially undermine the basis of free movement of goods within the single market.

2.0 What is Plastic?

The political motivation behind the SUP Directive stemmed from a concern about the impact of waste plastic 'leakage' into the environment, and in particular the marine environment. This has been a topic of considerable and increasing interest amongst citizens, civil society organisations and the media in recent years. The focus on plastic products relates to their durability and tendency to persist in the environment, in many cases for decades or even centuries. The focus on single-use items reflects a concern that the risk of leakage is highest where large volumes of low-value products are discarded after use periods of perhaps minutes or even a few seconds.

Based on the Recitals of the Directive, the primary intent of the legislators seems to be clear: to regulate certain single-use products that are perceived to have a disproportionate impact in driving persistent and damaging marine pollution, based on their prevalence in litter found on European beaches. The regulatory measures that are included vary by product category, with some being subject to outright bans while others will be regulated through measures such as EPR, product labelling requirements and consumption reduction requirements.

The focus on plastic products is understandable, both scientifically and politically. However, the reliance on the definition of *plastic* in determining which *single-use products* fall within the scope of regulation is potentially problematic, because single-use products of types that are in scope, but that are not 'officially' plastic, will be exempted from mandatory regulation under the Directive.

Recital 11 addresses the scope of the Directive and provides the context for the definition of plastics found in point 1 of Article 3. It states that the purpose of the exemption for "natural polymers that have not been chemically modified" is to exclude certain natural polymers from regulation. Exemption for some natural polymers is clearly important, as otherwise materials such as cotton and paper could have been inadvertently brought into the scope of the Directive, with wide-ranging unintended consequences. The question therefore is what should the cut-off be, accepting that materials such as cotton and paper were clearly intended to be excluded and synthetic polymers such as polypropylene, polyethylene terephthalate and polystyrene included.

From an 'intent of the Directive' point of view, one might expect that the only natural polymers exempted would be those proven to have characteristics in terms of a persistence in the environment that are so substantially different to plastics as to allow them unregulated access to the market in the products in question. For example, when used in a wet wipe, this might mean that they are proven to disintegrate very soon after entry into the waste water system or the marine environment or when discarded as litter on land and thereafter, to fully biodegrade within a short period of time.

However, the approach taken by the Directive is to rely entirely on the definition of plastic in governing which products should and should not be regulated. So how robust is

the exemption for “natural polymers that have not been chemically modified” in the context of the intent of the Directive?

In order to answer this question, it is necessary to separately consider the meanings of both “natural polymers” and “not chemically modified”. Recital 11 cross-refers to two important definitions within the framework of European regulation of chemicals known as REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals). One defines polymers and so is important in understanding the meaning of “natural polymers”; and the other defines “not chemically modified substance(s)”.

2.1 Natural Polymers

The European Chemicals Agency (ECHA) is the EU agency that oversees the operation of REACH. ECHA’s Guidance for Monomers and Polymers states that “natural polymers are understood as polymers which have formed as a result of a polymerisation process that has *taken place in nature*, independently of the extraction process…” (emphasis added).[2] Although the definition itself is clear that the Guidance is non-statutory and caveated by a legal notice, the phrase “…are understood as…” also somewhat weakens confidence in it.

However, taking the definition at face value, “taken place in nature” seems to exclude materials where polymerisation (the chemical reaction that forms a polymer chain from a number of monomer molecules) takes places through artificial processes or in an industrial setting. Under this reading, polymers derived from artificial fermentation processes such as polylactic acid (PLA) and polyhydroxyalkanoates (PHAs), even where they rely on naturally occurring microorganisms or enzymes, would not be considered as natural polymers, because the polymerisation process itself does not occur in nature. “Substances which occur in nature” are also helpfully defined in REACH in such a way as to exclude polymers where the polymerisation process has not taken place in nature.

However, this definition of natural polymers *would* encompass cellulose-based materials such as viscose and lyocell amongst many others, as the polymerisation process takes place in nature in the development of the plant material from which cellulose is extracted. As such, determining whether a particular cellulose-based material is one of the ‘certain natural polymers’ that should be exempted will come down to whether or not it has been chemically modified.

2.2 Not Chemically Modified Substances

The question of which natural polymers qualify as being ‘not chemically modified’ is less clear-cut. The language of the Directive implies a restrictive and precautionary approach, with the terms ‘unmodified’ and ‘not chemically modified’ (Recital 11) leaving no room for degrees of chemical modification; a natural polymer is either chemically modified or it is not. Unfortunately, defining the precise boundary of chemical modification in natural polymers is not entirely straightforward; and not subject to scientific consensus.

The SUP Directive relies on the REACH definition of a ‘not chemically modified substance’ as “a substance whose *chemical structure remains unchanged*, even if it has undergone a chemical process or treatment, or a physical mineralogical transformation, for instance to remove impurities” (emphasis added).[3] This definition therefore hinges on the meaning of ‘chemical structure’ and ‘remains unchanged’ in the context of natural polymers.

In terms of their basic chemistry, polymers are large molecules composed of repeating covalently bonded subunits known as monomers. Covalent bonds are chemical bonds that involve the sharing of electron pairs between atoms. It seems likely that 'chemical structure' in the context of polymers must address both composition (the monomers and reactants forming the polymer) and degree of polymerisation (molecular weight, driven primarily by the number of monomer units bound together). This assumption is consistent with the definition of "polymer" in REACH.

As such, any type of covalent bond formation or cleavage would constitute a 'change in chemical structure'. In the case of MMCFs, the well-recognized reduction in molecular weight during the viscose and lyocell processes, as well as the formation of oxidative by-products associated with this molecular weight reduction, arguably disqualifies these materials from being considered "not chemically modified".

It can also be argued that the term "remains unchanged" requires that the structure of a substance is not changed at any point in the production process, meaning that any sequence of chemical modifications that change the structure and then change it back during the process would not meet the test of 'remaining unchanged'. If so, the conversion of cellulose into cellulose xanthate as an intermediate step in the viscose process would disqualify viscose from being considered "not chemically modified", even though this modification is effectively reversed by the end of the process.

Taking a strict interpretation of chemical modification could also mean that the various side reactions that have been observed in lyocell production caused by interactions between cellulose and N-Methylmorpholine N-oxide (NMMO) would disqualify lyocell from being considered "not chemically modified", even though these reactions are unintended and their effects are minimal in an industrial context.

It is also worth noting that viscose and lyocell are often regulated quite differently to 'unmodified' cellulose. For example, 'regenerated cellulose'—the term used to describe material obtained by both the viscose and lyocell processes—has different FCM (Food Contact Material) and CAS (Chemical Abstracts Services) designations and is treated differently from cellulose by the "European Commission Regulation 10/2011 on plastic materials and articles intended to come into contact with food".

So, although there are most likely reasonable interpretations of the definition of 'plastic' in the SUP Directive that would bring materials such as viscose and lyocell into scope, there is considerable uncertainty regarding whether these interpretations are legally 'correct'. This will ultimately be determined through the testing in the courts of the legislative measures adopted in each Member State, in the context of the Directive and the implementing acts and guidelines produced under it.

How important this uncertainty is in creating 'loopholes' in the Directive will vary from material to material and product category to product category and in each case on the relative impact on the environment of products made from those materials, combined with the extent of their market adoption.

3.0 MMCFs and the Environment

To be consistent with the intent of the SUP Directive's Recitals, a single-use product within a category covered by the Directive should only be exempt if it has a substantially reduced impact on the environment relative to a regulated plastic alternative. In the context of wet wipes and man-made cellulosic fibres, this should consider the end of life impacts of wipes discarded into the waste water system or the open environment, as well as giving some consideration to upstream production impacts.

Wet wipes made from synthetic plastic (e.g. polyester or polypropylene) are likely to persist in the environment for many years, either as a whole product or broken down into fragments or individual fibres. Wipe structure will tend not to physically disintegrate when flushed down the toilet and into the waste water system. They can then become key structural components in sewerage system blockages (sometimes known as 'fatbergs'). As well as representing environmental problems in their own right, these blockages can lead to the release of waste water into watercourses and the marine environment during periods of heavy rainfall, sometimes via storm drains (either intentionally in the case of combined sewers, or unintentionally).

In order to pose a substantially reduced risk of sewer blockage, a wet wipe would need to disintegrate rapidly in a typical sewer environment, in a similar way to toilet paper. Once released into the open environment, either via the waste water system or via littering, full biodegradation would have to take place rapidly, before the whole product, fragments or individual fibres are able to have any significant impact on aquatic or land-based life or habitats.

3.1 Biodegradability and Flushability

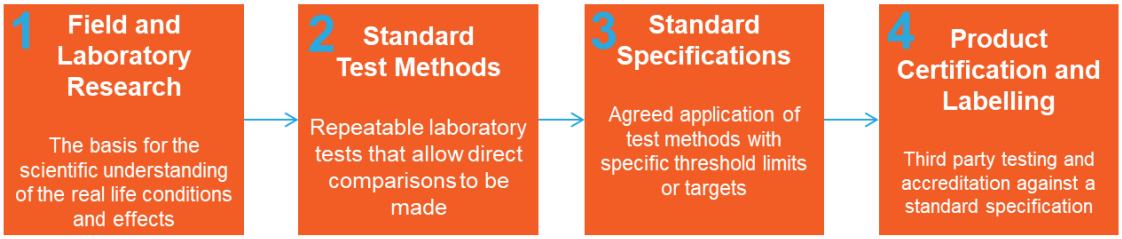
In the case of wipes made from MMCFs, readiness of biodegradability is a key determinant of how persistent these products are likely to be in an open environment.

Although both viscose and lyocell are sometimes found to be biodegradable in lab conditions and some published research does exist regarding soil biodegradability, very limited published scientific evidence exists regarding their biodegradability in marine environments. A soil burial test comparing lyocell, viscose and cotton concluded that lyocell fibre was the slowest to biodegrade.[4] This may be explained by lyocell's high molecular weight, higher degree of crystallinity compared to viscose and relatively hydrophobic properties, which are possible indicators that biodegradation of fibres in an open environment could be inhibited.

In order to ascertain whether the exemption of lyocell and viscose wet wipes would be consistent with the intent of the Directive, established and certified testing and product labelling standards should exist, backed by robust and independent scientific evidence.

Figure 1 shows a simplified process for achieving that situation and reflects work currently being undertaken by scientists, industry and certification bodies to establish standards for biodegradation of plastics in marine environments that should ultimately lead to development of product certifications.

Figure 1: Process for Assessing Biodegradation in the Marine Environment



A great deal of research has taken place at stage one, which has led to some test methods at stage two. Nevertheless, there is a long way to go to develop a standard specification that draws on enough test methods and develops appropriate thresholds in a robust way so as to be certain that products that meet these requirements will have no more than an acceptable level of impact if released into the environment.

Standard specifications define compliance criteria, including pass/fail thresholds for producers to be able to define their products. For instance, producers can test and declare their product 'compostable' if in accordance with EN 13432.

The American ASTM standard specification for biodegradable plastic in aerobic sea water — ASTM D7081 — was withdrawn in 2014 and has yet to be replaced. This standard specification required testing aerobic biodegradation in sea water at a temperature of 30 +/- 2 °C for up to six months with a minimum of 30% biodegradation to pass.[5] This low threshold is one of the reasons that the specification was withdrawn, as it is particularly low when compared with those used in other environments (often 90%). As the understanding of the impacts of plastics on the marine environment has increased it was recognised that stronger evidence was needed for a standard and therefore moving back to stage one—further field and laboratory research— was required.

In addition to standard specifications, third-party certifications are often available which either provide verification of testing to standard specifications or to their own standards. An example of the latter is "OK Biodegradable MARINE" from TÜV Austria for materials in marine environments. This is very similar to the withdrawn ASTM D7081 but requires a higher threshold for biodegradation of 90%.[6] It also prohibits the use of the associated label on products that are *not meant to be used in or around the marine environment*, recognising the risk of encouraging irresponsible disposal if consumers are led to believe a product will biodegrade in the sea. This means that whilst this certification may be obtainable for wet wipes, this should not be openly advertised on packaging or promotional materials. However, several material suppliers do seem to openly promote their material as having passed this certification in reference to products which would not be suitable for consumer promotion in this way.[7,8]

The overwhelming majority of the scientific community recognises that there is still much to be learned regarding marine biodegradability. As such, the OK Biodegradable MARINE certification is an outlier, lacking the solid scientific underpinning necessary to remove doubt that products bearing its marque are truly better than the alternatives.

In recent years, the term 'flushability' has emerged as an attempt to classify whether a particular product is suitable or not for disposal through the toilet and waste water treatment system. This is in response to an increasing number of blockages attributed to bathroom products such as wet wipes and absorbent hygiene products which are

incorrectly discarded down household toilets. There is no one agreed industry definition of flushability, with the term currently seeming to be more marketing rather than science driven. However, standards have been developed by EDANA and INDA, the European and North American industry bodies representing the non-woven fabric industry, as well as by a number of water utilities associations.

The scientific legitimacy of flushability claims in respect of lyocell and viscose wet wipes is uncertain, with a dearth of scientific evidence on the topic. It is difficult to make confident claims on flushability generally, as different standards have different requirements. Also, flushability standards are of limited use in assessing whether a product will biodegrade in the environment and none addresses the prospect of wipes or fibres entering waterways and oceans and their impacts in these environments. This means that the current flushability standards cannot (and do not seek to) provide confidence that materials that meet them will not have a similarly detrimental impact on the environment as a synthetic plastic product.

3.2 Production Impacts

Alongside their potential impacts on the environment at end of life, some consideration should be given to the wider environmental costs and benefits of a shift from synthetic to lyocell or viscose wet wipes in the event that they are exempt from the SUP Directive.

In terms of direct manufacturing impacts, the lyocell and viscose processes both utilise a range of chemicals. In the case of lyocell, the NMMO solvent used to dissolve the cellulose in wood pulp is non-toxic and easily recovered for recycling, at a rate of around 98%.[9] The viscose process uses sodium hydroxide, carbon disulphide and sulfuric acid and its production produces hydrogen sulphide as a by-product, all of which can have severe negative effects on ecosystems and human health if released into the environment. Although an appropriately managed viscose process should capture these chemicals and neutralise or recycle them after use, there have been several recorded incidences of significant chemical leakage. [10, 11]

A shift from synthetic to cellulose-based materials would also impact on raw material demand, away from primary fossil hydrocarbons and towards cellulose. Cellulose is typically derived from hardwoods, softwoods and sometimes bamboo, with an estimated 150 million trees felled globally every year to meet current demand for MMCFs.[12] There is evidence of an increasing move by lyocell and viscose producers towards certified sustainable sources of cellulose;[13] and water, fertilizer and pesticide consumption can be significantly lower in lyocell and viscose than in the production of cotton. However, the issues associated with loss of biodiversity, land use competition, water abstraction and application of chemicals in crop production are highly complex, making simple comparison of very different materials highly problematic.

As a broad conclusion on relatively similar materials, lyocell is likely to present a lower risk of direct environmental impact compared with viscose due to the chemical processes employed. Synthetic polymers generally have higher greenhouse gas emissions associated with production than MMCFs, but a wholesale move towards cotton, for instance, is likely to result in a significant increase in other environmental impacts relating to the material's cultivation.

4.0 Market Implications

Under the SUP Directive, Member States are required to ensure that EPR schemes are established for wet wipes which cover at least the necessary costs of consumer awareness raising measures (including on re-usable alternatives); the costs of cleaning up litter resulting from those products; and the costs of data gathering and reporting.

It may be the case that Member States consider the flushing of non-flushable wet wipes as littering. Whilst the term *littering* is not defined, there are various references in the Directive to "littering or of other inappropriate means of disposal of the product", with flushing likely to at least be considered as 'inappropriate disposal'. Subject to the non-statutory guidelines on SUP Directive implementation to be published by the Commission in 2020, this appears to leave flexibility to include the direct costs of clearing sewer blockages attributable to wet wipes within EPR schemes.

It is clearly not straightforward to directly attribute pollution/clean-up costs to wet wipes, but taking the UK as an example, wet wipes are reported to cause 93% of sewerage blockage, costing €117 million per year to clear according to research by Water UK.[14] Based on the number of wet wipes sold across Europe in 2016 (around 40.37 billion packages),[15] it can be estimated that around 7 billion wet wipes were sold in the UK in 2018.[16] If blockage removal costs attributable to wipes in the UK are therefore €109 million per year, this equates to about 1.6 Euro cents per wet wipe. As a European average, the UK data is likely to provide an overestimate, as UK citizens seem to be particularly heavy users of wet wipes. However, this estimate excludes the highly uncertain costs of consumer behaviour change initiatives and contributions towards wider litter clean-up, as well as scheme administration, data gathering and reporting. So, whilst these figures present a very rough estimate, they hint at the price factors large enough to drive future market behaviour.

Currently, lyocell costs producers around 25-30% more than other raw materials, although unit lyocell production costs could fall due to economies of scale if demand were to increase significantly.[17] But at these assumed costs, if an average wet wipe weighs 6.7g, the raw material cost per lyocell wipe might be around 1.5 Euro cents compared to 1.1 Euro cents for a PET wipe. Adding a 1.6 Euro cents EPR cost to a synthetic wipe would result in a 145% increase in material cost. This would clearly be enough to affect competitiveness versus an exempt lyocell wipe, perhaps to the point where synthetic wipes became unviable in the market place. A wholesale shift to lyocell would be likely to marginally increase the consumer price to some extent and this might lead to some reduction in consumption. However, if EPR costs of this order were to be applied to all wet wipes, the higher level of increase in consumer prices, combined with awareness raising measures regarding reusable alternatives, may be enough to significantly shift demand away from single-use wipes in the long term.

5.0 Conclusions and Recommendations

A **strong argument can be made that viscose products do fall within the scope** of the SUP Directive provisions, based on the Directive definition of plastic and the scientific evidence relating to viscose production.

The situation with **lyocell is less clear-cut** and may depend on whether the unintended side reactions that have been observed in its production constitute modification in chemical structure and whether they are intrinsic to the industrial production of lyocell.

It seems likely that several other innovative **materials produced via biosynthesis such as PHAs would be covered by the Directive**, as they are unlikely to qualify as natural polymers since the initial polymerisation reaction does not occur in nature. However, other novel, unmodified natural (and therefore exempt) polymers may well enter the market in product categories regulated under the Directive. If these cannot be shown to be substantially better in environmental terms, this could have significant implications for any of the product categories targeted by the Directive.

Substitution of plastic with established unmodified natural polymers such as cotton and paper *would* exempt such products from the Directive. This is unlikely to give rise to serious concerns in most product categories, but may do in cases such as wet wipes (cotton) and cigarette filters (paper), where it is technically possible to manufacture highly functional products from these materials that may have poor environmental credentials in the context of the Directive's objectives.

Regarding lyocell and viscose, there is a **lack of evidence around the extent to which biodegradation will take place in the marine environment**. There are no currently available specifications or established frameworks for certification of biodegradability in the marine environment. Although some test methods exist, they do not encompass a wide range of marine environments. Flushability standards are primarily focused on sewer blockages and vary in how rigorously this is tested. They also provide a very limited indication of other environmental impacts, including biodegradation in the marine environment. This means that **current standards cannot provide confidence that materials that pass into the marine environment will not have a similarly detrimental impact as a synthetic plastic product**. Based on this, **there appears to be no justification on environmental grounds for an exemption for lyocell or viscose under the SUP Directive.**

The SUP Directive relies for establishing its scope boundaries on a criterial **concept of 'unmodified natural polymers' that is imprecise, highly technical and subject to a lack of clear scientific consensus**. It can only be interpreted with reference to multiple other regulations and guidance documents, some of which have no statutory status and themselves use imprecise language. Reliance on a definition of plastic with exemptions for unmodified natural polymers therefore gives rise to **the risk of exemptions that run counter to the intent of the Directive** as well as **inconsistent implementation by Member States that could undermine the integrity of the single market**.

5.1 Recommendations

Given the clear risk of unintended exemptions, as well as of inconsistent implementation leading to compromise of the operation of the single market, it is vital that the Commission takes decisive action to ensure absolute clarity of scope of the Directive:

1) As an immediate measure, the Commission's forthcoming guidelines to Member States on SUP Directive implementation should clearly state that:
    a. A restrictive and precautionary approach should be taken to the exemption of materials or products, applying a high burden of proof.
    b. Through this, it should be ensured that the *only* natural polymers exempted by legislation are those which are proven to have characteristics in terms of a persistence in the environment that are so substantially different to plastics as to allow them unregulated access to the market in the products in question.
    c. Natural polymers are polymers in which polymerisation has taken place in nature and that materials where polymerisation takes place in an artificial or industrial setting are not natural polymers, even if polymerisation relies on naturally occurring microorganisms or enzymes.
    d. Chemical modification is a binary process and either has or has not occurred. As such, there is no de minimis threshold or degree of modification that is to be considered too insignificant to consider.
    e. Modification of chemical structure at any point in the production process is to be considered a chemical modification, even if such a modification has been reversed by the end of the production process.
    f. When seeking to address the environmental problems related to the Directive such as littering, Member states should consider widening the scope of EPR schemes (in line with the 'polluter pays' provisions of Article 14 of the Waste Framework Directive), to other single-use products, irrespective of material.
2) To reinforce the current drafting of the Directive and reduce risk to the integrity of the single market, the Commission should incorporate the points set out in recommendations 1a to 1e into the implementing act to be adopted by 3rd January 2021 under Article 4 of the SUP Directive in respect of the calculation and verification of consumption reduction of single-use plastic products, as this clarity of scope will be required in order to facilitate the clear and consistent measurement of consumption of the relevant single-use plastic products.
3) The Commission should give serious consideration to an early amendment of the SUP Directive to address the risk to the operation of the single market that would still remain even after the implementation of recommendations 1 and 2. Such amendment might take the form of either:
    a. An amendment to the definition of plastic to exempt only those polymers that qualify as 'substances which occur in nature' under REACH, whilst making clear that materials such as paper and cotton are not plastics;
    b. Or preferably, to rule out unintended exemptions and ensure that the benefits of the Directive are secured and maximised, to move away altogether from a reliance on the definition of plastic and towards a set of clear single-use product definitions in respect of all product categories to be regulated under the Directive, irrespective of material.

References

[1] European Parliament and Council (2019) Directive (EU) 2019/ of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment, *Official Journal of the European Union*.

[2] ECHA (2012) Guidance for the implementation of REACH, Guidance for monomers and polymers. European Chemical Agency. Version 2.0. Available at: https://echa.europa.eu/documents/10162/23036412/polymers_en.pdf/9a74545f-05be-4e10-8555-4d7cf051bbed

[3] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).

[4] Warnock, M., Davis, K., Wolf, D., and Gbur, E. (2009) Biodegradation of Three Cellulosic Fabrics in Soil, *Summaries of Arkansas Cotton Research*, p.5.

[5] ASTM International (2005) *ASTM D7081-05, Standard Specification for Non-Floating Biodegradable Plastics in the Marine Environment* (Withdrawn 2014), ASTM International, West Conshohocken, PA. Available at: www.astm.org

[6] TÜV AUSTRIA (2019) *OK biodegradable MARINE: Initial acceptance tests*. [online] Available at http://www.tuv-at.be/fileadmin/user_upload/docs/download-documents/english/OK-compost-OK-compost-HOME-OK-biodegradable-SOIL-WATER-MARINE/20190403_Program_OK_12e_b_OK_biodegradable_MARINE_corrigendum.pdf

[7] Lenzing (2018) *Corporate Sustainability Update*. [online] Available at https://sustainability.lenzing.com/issue-03-2018/

[8] Kaneka (2018) *New Business Development: Biodegradable polymer- KANEKA Biodegradable Polymer PHBH™*. [online] Available at https://www.kaneka.co.jp/en/business/material/nbd_001.html

[9] Krysztof, M., Olejnik, K., Kulpinski, P., Stanislawska, A., and Khadzhynova, S. (2018) Regenerated cellulose from N-methylmorpholine N-oxide solutions as a coating agent for paper materials, *Cellulose*, Vol.25, No.6, pp.3595–3607.

[10] Changing Markets Foundation (2018) *Dirty Fashion Revisited: Spotlight on a polluting viscose giant*. [online] Available at: https://changingmarkets.org/portfolio/dirty-fashion/

[11] Hoskins, T. (2017) *H&M, Zara and Marks & Spencer linked to polluting viscose factories in Asia*, The Guardian. [online] Available at: https://www.theguardian.com/sustainable-business/2017/jun/13/hm-zara-marks-spencer-linked-polluting-viscose-factories-asia-fashion

[12] Canopy (2018) *CanopyStyle*. Canopy. [online] Available at: https://canopyplanet.org/campaigns/canopystyle/

[13] FSC (2017) *Market Info Pack 2016-2017*. FSC. [online] Available at: https://ic.fsc.org/file-download.fsc-market-info-pack-2016-2017.a-1728.pdf

[14] Drinkwater, A., and Moy, F. (2017) *Wipes in sewer blockage study: final report*. Water UK. [online] Available at: https://www.water.org.uk/wp-content/uploads/2018/11/Wipes-in-sewer-blockage-study.pdf

[15] ICF Consulting, and Eunomia Research & Consulting (2018) *Assessment of measures to reduce marine litter from single use plastics: Final report and Annex*. European Commission. Available at: https://ec.europa.eu/environment/waste/pdf/Study_sups.pdf

[16] On the basis that the UK has 16% of EU GDP, see https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20170410-1

[17] Hodakel, B. (2020) *What is Lyocell Fabric: Properties, How it's Made and Where*. Sewport. [online] Available at: https://sewport.com/fabrics-directory/lyocell-fabric