WHAT IS PLASTIC?

A study exploring the potential for certain materials to be exempted from the Single-Use Plastics Directive, with particular focus on man-made cellulosic fibres

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1.0 Glossary

Cellulose	An organic compound and the primary substance which makes up cell walls and fibres of plants.
Degree of polymerization	Degree of polymerization, or DP, is the number of monomeric units in a macromolecule or polymer
Extraction process	The process by which a natural polymer (e.g. cellulose) is extracted from a natural material (e.g. wood pulp)
Lyocell	A natural polymer and man-made cellulosic fibre made by dissolving cellulose in wood pulp.
Man-made cellulosic fibre (MMCF)	Cellulosic fibres which have been manufactured by modifying the structure and properties of natural cellulose.
Natural environment	All living and non-living things occurring naturally as opposed to artificially.
Natural polymer	A polymer in which the polymerisation process occurred in the natural environment.
Nonwoven fabric	A fabric made from short and long fibres bonded together by mechanical, chemical, heat or solvent treatment.
Polymerisation	The chemical reaction that forms a polymer chain from a number of monomer molecules.
Single-use plastic	A product made wholly or partly from plastic which is not designed to fulfil multiple use rotations.
Synthetic fibre	Fibres made by humans through chemical synthesis.
Viscose	A natural polymer and man-made cellulosic fibre made by extracting cellulose from wood pulp.

2.0 Introduction

In June 2019, Directive (EU) 2019/904 was published by the European Parliament and Council with the aim of reducing the impact of 'certain plastic products' on the environment.[1] The Directive, referred to by many as the 'Single-Use Plastics (SUP) Directive' describes its objectives as:

> *"to prevent and reduce the impact of certain plastic products on the environment, in particular the aquatic environment, and on human health, as well as to promote the transition to a circular economy with innovative and sustainable business models, products and materials, thus also contributing to the efficient functioning of the internal market."*

Evidence of nonwoven fabrics, manufactured from both synthetic and natural polymers, impacting on flushed sewerage systems and the marine environment led to the inclusion of wet wipes in the extended producer responsibility (EPR), labelling and behaviour change provisions introduced by the SUP Directive.

Wet wipes are typically made from a nonwoven fabric containing either solely, or a mix of: polyester, polypropylene, cotton or man-made cellulosic fibres (MMCFs). They are commonly used for personal hygiene and household cleaning. Wipes used for personal hygiene are frequently flushed down the toilet.

The problems that arise from this are two-fold.

Firstly, in sewage systems and waste water treatment facilities, wipes can result in significant blockages if they do not degrade and disintegrate sufficiently very soon after flushing. Estimates suggest that UK water companies manage more than 366,000 sewer and drain blockages every year.[2] Further research attributes many of these blockages to bathroom products such as wet wipes and sanitary items which are incorrectly discarded down household toilets.

Secondly, wipes can contribute to marine pollution, for example if they pass through waste water treatment facilities and into watercourses or bypass them entirely via storm drains, 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. We understand the Directive to mean that it may be appropriate to exempt some products where these have substantially less impact on the environment than equivalents made from 'plastic'.

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[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] Jackson, L., and Tehan, R. (2019) Understanding behaviours causing blockages: Research with United Utilities to identify flushing habits in the North West of England, *Journal of Litter and Environmental Quality*, Vol.3, No.1, p.58

However, products made from unmodified natural polymers that *cannot* 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.

In the context of wet wipes, debate around exemption has focused on two types of man-made cellulosic fibres: lyocell and viscose, both of which are capable of substitution 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 if they can be considered as not plastic. 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-based wipes being given an environmental clean bill of health.

Before the market is driven towards such materials, the effects of these polymers on the environment should be more fully understood. Without this consideration, the Directive, which intends to address the environmental impacts of certain single-use products, is at risk of being undermined.

This report discusses the key issues surrounding this concern and considers whether a precautionary approach should be applied in order to ensure a higher level of environmental protection through preventative decision-taking.[3] The report is structured as follows:

I. **A scientific analysis of the definition of ‘plastic’** in the SUP Directive, focusing on the concepts of ‘not chemically modified’ and ‘natural polymers’ and examining how they could apply in the case of wet wipes made from lyocell and viscose.
II. **An analysis of the current science regarding the behaviour of MMCFs in natural environments**, focusing on the marine environment and in sewerage systems. This focusses on the concepts of, and standards and certifications for, biodegradability and flushability in relation to lyocell and viscose wet wipes.
III. **An analysis of the impact on the wet wipes market** of a potential shift to lyocell and viscose if these materials were to be exempt from the Directive. Also includes an examination of the environmental impacts of production of lyocell and viscose.
IV. **A summary of the findings and recommendations.**

[3] European Commission *The Precautionary Principle - Summary*, accessed 15 October 2019, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=LEGISSUM:l32042&from=EN

3.0 Defining ‘Plastic’ in the SUP Directive

The EU Single-Use Plastics (SUP) Directive focuses on reducing plastic pollution from single-use items, particularly in the marine environment. This necessarily requires a definition for plastic in order to determine which materials should be in scope. Presently, “natural polymers that have not been chemically modified” are exempt from the Directive. Plastic is defined under Article 3:

> *“ ‘plastic’ means a material consisting of a polymer as defined in point 5 of Article 3 of [REACH] Regulation (EC) No 1907/2006, to which additives or other substances may have been added, and which can function as a main structural component of final products, with the exception of natural polymers that have not been chemically modified”.*

This definition raises the need for clarity around the definitions of;

- a “natural polymer”; and,
- “chemically modified”.

A Natural polymer is defined by the European Chemicals Agency (ECHA)[4] as:

> *“Polymers which are a result of a polymerisation process that has **taken place in nature**, independently of the extraction process with which they have been extracted”*

This definition suggests two things:

1) **The polymerisation process must “take place *in nature*”**. “In nature” is a concept that may be open to interpretation. It suggests that the process cannot be carried out in industrial situations, even if it utilises the action of biological processes (e.g. microorganisms or enzymes). This implies that it is the natural process that matters, even when that natural process may be less efficient or have greater environmental impacts or unintended consequences.
2) **The process has taken place independently of the extraction process.** This suggests that the polymer must be completely formed prior to the extraction process. i.e. the extraction process cannot cause any degree of polymerisation. The definition for a natural polymer as stated above does not include any reference to modification of the polymer. If the extraction causes depolymerisation, then from this definition, it is still a natural polymer as the polymerisation took place in nature.

This is distinct from the definition in REACH Article 3 (39) of “substances which occur in nature”. As the term ‘natural polymer’ is used in the SUP Directive it can be assumed that the ECHA guidance is the best interpretation of this at present.

[4] Guidance for the implementation of REACH, Guidance for monomers and polymers, European Chemical Agency, April 2012, Version 2.0

However, "chemically modified" (from a "not chemically modified substance") must be interpreted directly from the definition in REACH (point 5 of Article 3) as this is specifically referenced in the SUP Directive. This defines it as:

> *"…a substance whose **chemical structure remains unchanged**, even if it has undergone a chemical process of treatment, or a physical mineralogical transformation, for instance to remove impurities"* [5]

In order to interrogate the definition, it is important to define the primary and secondary structure of a polymer:

- **The primary structure** encompasses the covalent bonds from the monomer units as well as the degree of polymerisation that builds up the polymer chain. In the case of MMCFs, the backbone is cellulose.
- **The secondary structure** is the way in which the polymer chains interact with each other and have an effect on the properties of the resulting polymer. Crystallinity is a function of the secondary structure.

The important parts of this definition are:

1) **The chemical structure must remain unchanged.** Chemical structure is the arrangement of atoms to form a molecule. For most molecules this can be easily defined; for example the chemical structure of water is H_2O. A change in chemical structure for a molecule is straightforward to determine if a bond has been broken or formed. If the combustion of methane is taken for example, the methane (CH_4) reacts with oxygen (O_2) to form carbon dioxide (CO_2) and water (H_20). This is a chemical change.

   The definition becomes more difficult with polymers. Polymers are macromolecular structures, with long chains made up of monomers. The physical properties of the polymer depend upon how many monomers are in a chain. The number of monomers can range from hundreds to tens of thousands depending on the polymer. It is currently unclear whether an extraction process that chemically modifies the secondary structure of the polymer should be considered in scope if it does not impact the primary structure, including its molecular weight. This is discussed further below.

2) "…***remains unchanged*** **even if it has undergone a chemical process or treatment".** This phrase can be open to interpretation. On one hand it could mean that providing the starting and end chemical structures are the same, what happens in-between is not important. In this interpretation a natural polymer could undergo several "intermediate" chemical changes, but providing it is returned to the same starting chemical structure, it would be exempt.

[5] 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),

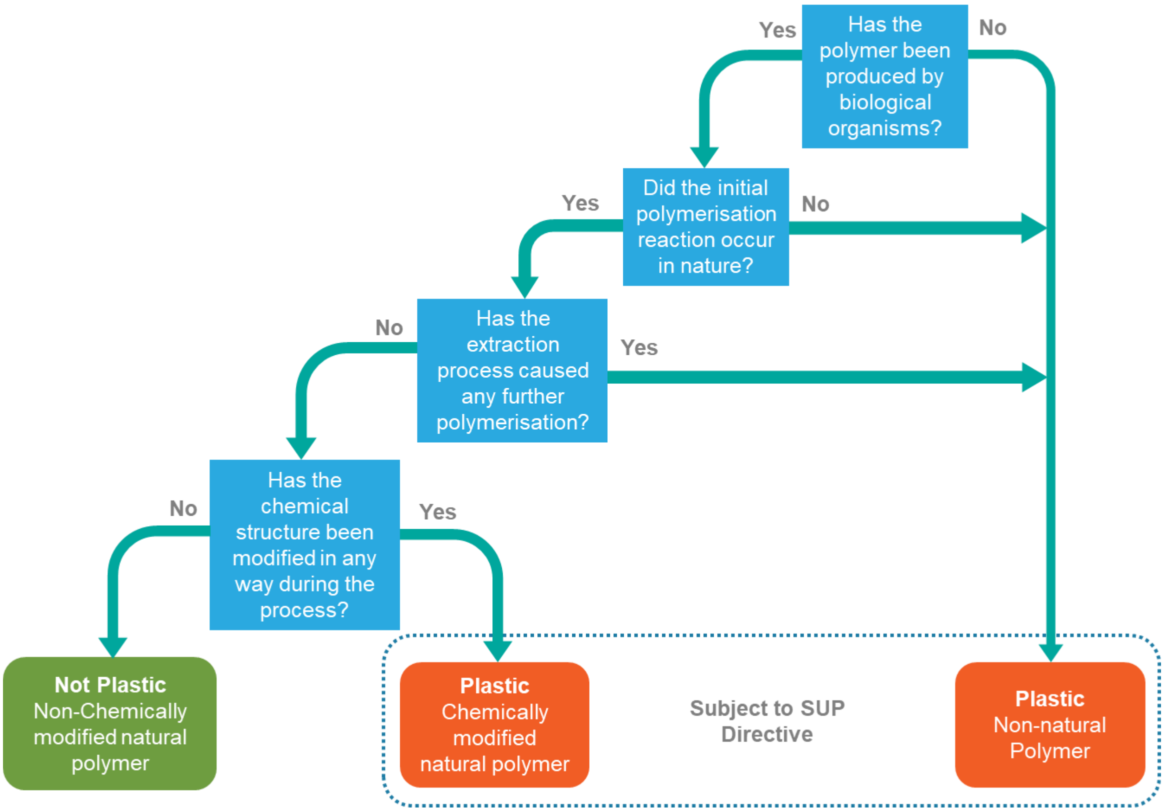
> A stricter interpretation is that that the natural polymer **cannot** be modified chemically as part of the conversion process **even if** the polymer has the same structure at the end as the beginning. This means the polymer "remains unchanged" through the entire process, and any "chemical process" used to treat or extract the polymer cannot interfere with the polymer itself but may be used, for example, to extract impurities that are not chemically bonded to the polymer.

A chemical process can be considered as the forming or breaking of covalent bonds. The earlier example of combustion of methane is an example of a chemical process. Polymerisation is also considered a chemical process. However, intermolecular forces such as hydrogen bonds are not covalent chemical bonds in the composition of the primary structure, but do play a major role in forming the aforementioned secondary structures that impart the polymer properties.

The "chemical structure" of a polymer should be defined not only by the detailed chemical composition, (e.g. the number and structure of carbon, hydrogen, oxygen atoms, and other elements), but also by the size/length of the polymer chains. For example, the composition of both candle wax and a polyethylene film is $(C_2H_4)_n$, but the structure also includes the numerical value of "n", as this value becomes critical to the understanding of its properties, such as strength or viscosity. Indeed, a polyethylene with an "n" value of 15-20 is candle wax, which has very different properties than a polyethylene fibre or film with an "n" value of 1,000. Moreover, any change in "n" involves a change in the covalent bonds of the structure.

Figure 1 shows a decision tree created by the authors of this report that can be used to determine, using the current definition of "plastic", whether a polymer can be considered exempt from the Directive. Firstly, it must be established whether or not the polymer can be considered a "natural" polymer. Secondly, it must be established whether or not the polymer has been chemically modified. If the polymer fails on any of these points, then it would be considered "plastic" and subject to the requirements of the Directive.

Figure 1: Decision tree for determining if a polymer is classed as plastic



3.1 Evaluation of Lyocell and Viscose

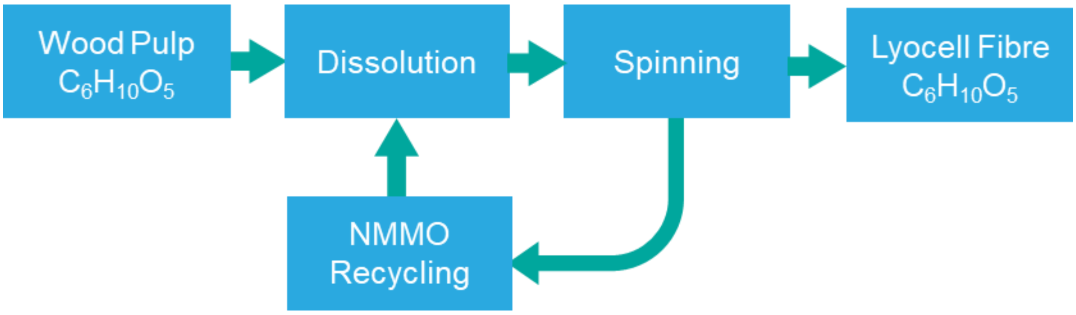
There are two polymers which are the focus of this study; lyocell and viscose. Both are produced from cellulose, usually extracted from wood pulp.

Lyocell

In the production of lyocell, wood pulp is mixed with a solvent N-Methylmorpholine-N-oxide (NMMO) to dissolve the cellulose polymer chains to enable extraction. The dissolved polymer is then regenerated (brought out of solution and solidified), and the polymer chains aligned to form the fibre.[6] Figure 2 shows a simplified process flow for the manufacture of lyocell.

[6] Chen.J (2015). 'Chapter 4- Synthetic Textile Fibers' in Sinclair. R. (ed.) *Textiles and Fashion*, Woodhead Publishing, pp 79-95.

Figure 2: Simplified lyocell manufacture process



From the description of the manufacturing process found in literature, it can be deduced that, in the case of lyocell, there is no ***intentional*** chemical reaction, change in chemical structure of the cellulose polymer chain or change in the degree of polymerisation.

However, it is well documented that chemical reactions that involve the breaking and forming of covalent bonds do occur.[7] These are "side reactions" caused by the NMMO solvent, which is a strong oxidant, and at the operating temperatures used during lyocell production (in the area of 100ºC), this will lead to several unintended reactions involving the cellulose polymer.

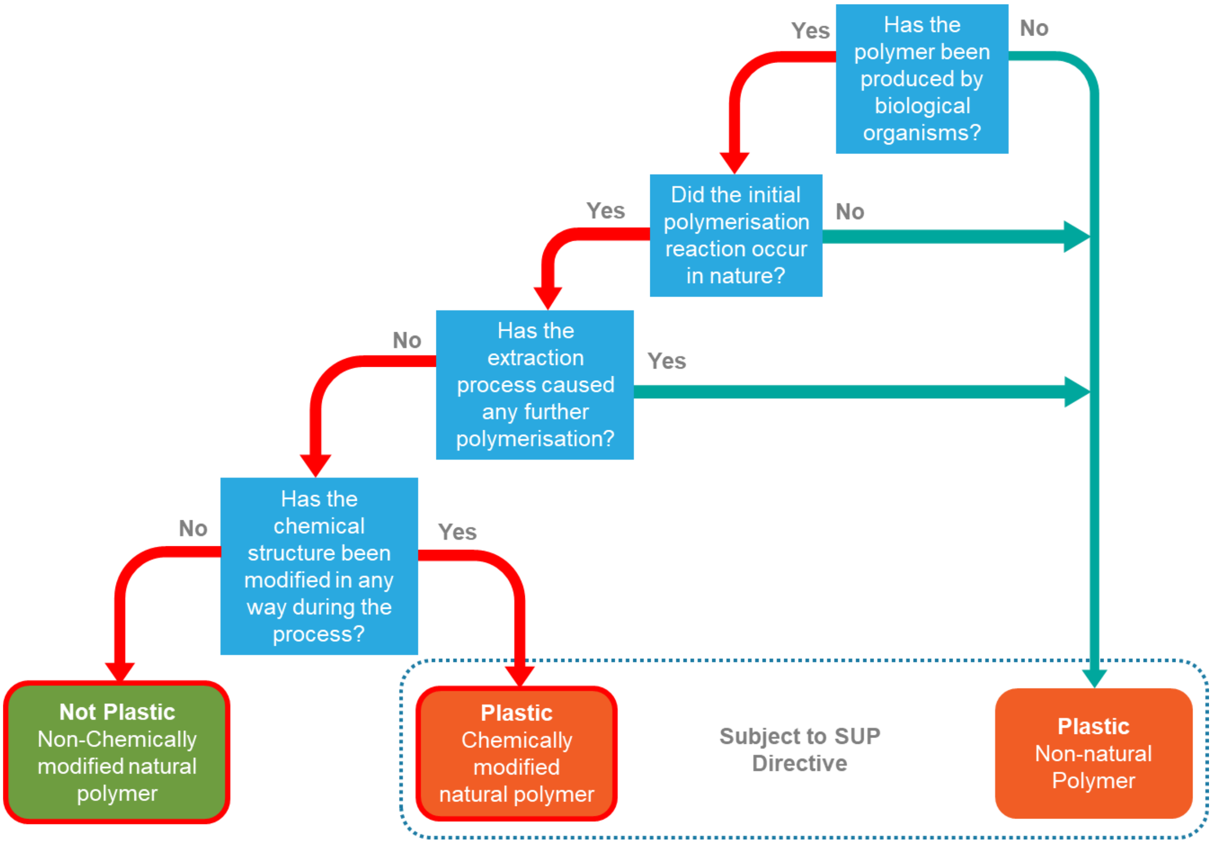
These reactions are described in more detail in Appendix A.1.0 which clearly shows there is the potential for chemical modification in the lyocell process. However, as these reactions are a function of the operating conditions, and since they can be reduced through the use of stabilisers, it is unclear as to the degree they occur in modern, commercial facilities. The wider literature details many possible reactions, which occur under specific conditions, and there is the potential that modern processes can eliminate the vast majority of these reactions.

In addition, the level of chemical change may be such that, fundamentally, the cellulose could be considered not to be chemically modified. Having said that, it could also be concluded that *some chemical changes will occur* in the cellulose due to the presence of NMMO. The current definition in the SUP Directive is insufficiently clear to categorically conclude whether lyocell should be exempt or covered.

Using the decision tree in Figure 3 (following the red arrows) it can be demonstrated that the categorisation of lyocell depends on whether the chemical structure has been modified and, as discussed above, the certainty around either assertion is mixed.

[7] Rosenau, T., Potthast, A., Sixta, H., and Kosma, P. (2001) The chemistry of side reactions and byproduct formation in the system NMMO/cellulose (Lyocell process), *Progress in Polymer Science*, Vol.26, No.9, pp.1763–1837

Figure 3: Decision Tree for Lyocell



Viscose

The production of viscose uses a different series of processes to lyocell, and is a more complicated situation[8]. The initial raw material is still wood pulp, however the cellulose is processed in a different way.

Firstly, the wood pulp is initially treated with sodium hydroxide which forms "alkali cellulose" from the cellulose in the pulp. **This is a chemical change** in which the structure (and therefore the chemical formula) is altered from $[C_6H_{10}O_5]_n$ to$[C_6H_9O_5Na]_n$.

The alkali cellulose then goes through an aging process in which the alkali cellulose is ***depolymerised*** using oxidative depolymerisation. Here, individual covalent bonds, specifically the glycosidic bonds between monomer units, are broken and the molecular weight is decreased. Depolymerisation itself can occur in two ways:

- Depolymerisation from the chain end, or the so called 'peeling' reaction, in which a single monomer is lost from the end of the polymer, resulting in a modest overall change in chain length or degree of polymerisation; or

[8] Faruk, O. (2018) *Viscose Fiber, Viscose Rayon Production, Properties of Viscose Rayon*, accessed 21 January 2020, https://textilestudycenter.com/viscose-rayon-production/

- Chain scission, or the so called ‘cleavage’ reaction, where the polymer chain is cut in more randomised points within the chain resulting in a more rapid and greater increase in the degree of polymerisation.

Depolymerisation can be considered to be a chemical reaction resulting in a change in chemical structure because covalent bonds are broken. When the polymer is broken down, it exposes end groups of atoms that must be reacted to form a stable molecule. This could potentially be considered a chemical change depending on the change in degree of polymerisation.

The viscose production process both intentionally and irreversibly reduces the length of the original cellulose material. In his chapter on “The Viscose Process”, Andrew Wilkes describes how the starting pulp with a DP of 750-850 is reduced to a DP of 270-350 to enable a material with a sufficient viscosity to form a fibre. [9] This means the **viscose has undergone a chemical change.**

The process then goes on to add Carbon Disulphide (CS_2) which transforms the alkali cellulose into cellulose xanthate using the below reaction:

$$[C_6H_9O_4\text{-}ONa]_n + n\underline{CS_2} \rightarrow [C_6H_9O_4\text{-}OCS_2Na]_n$$

This is a significant chemical change but is temporary and the cellulose xanthate is eventually transformed back into cellulose by precipitation in a sulfuric acid solution. The resulting viscose has the same chemical composition as the starting cellulose material (aside from the depolymerisation) using the below reaction.

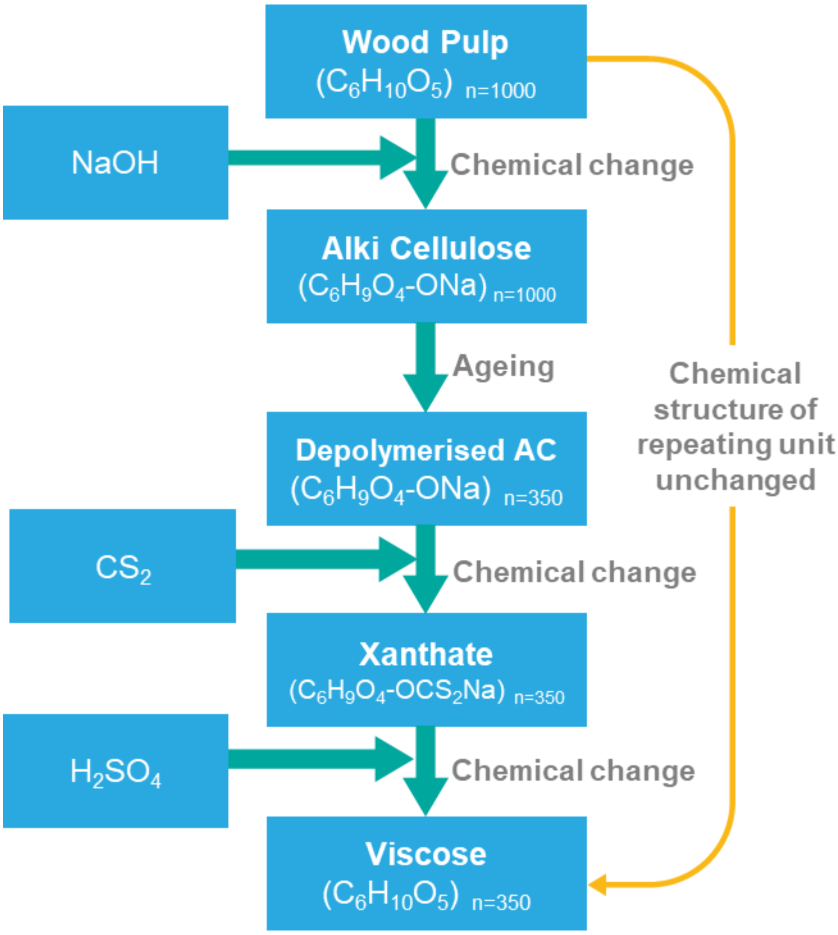
$$[C_6H_9O_4\text{-}OCS_2Na]_{2n} + nH_2SO_4 \rightarrow [C_6H_9O_4\text{-}OH]_{2n} + 2nCS_2 + nNa_2SO_4$$

However, if ‘remains unchanged’ indicates that the chemical composition can never change during the process, viscose does not meet the criteria of a polymer whose chemical structure must “remain unchanged”.

Figure 4 below shows a simplified diagram of the chemical changes the cellulose undergoes to be transformed into viscose. The final repeating unit of the viscose is the same as in cellulose, although depolymerisation has occurred.

[9] Wilkes, A.G. (2001) The viscose process. In Woodings C. (ed.) *Regenerated cellulose fibres*, Cambridge, England, Woodhead Publishing.

Figure 4: Chemical changes in viscose production

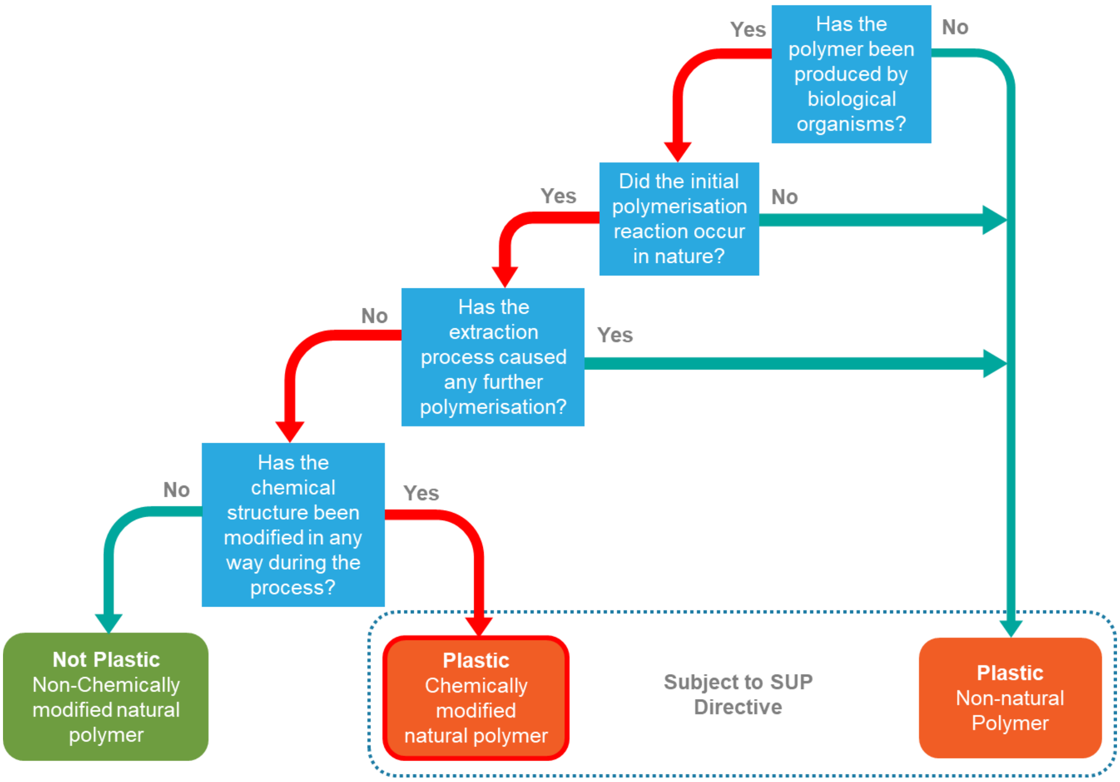


It therefore appears that viscose fails in the definition of "natural polymer that has not been chemically modified" in two ways:

- There are significant changes to the chemical structure to the cellulose during the production of viscose. Although the chemical structure (aside from polymer chain length) of the final product is the same as the original cellulose, changes have occurred. This means the cellulose does not "remain unchanged"; and
- There is a significant change in the degree of polymerisation during the ripening process. This should be considered a fundamental change in the chemical structure as is it caused by the breaking of a number of covalent bonds.

Using the decision tree in Figure 5, viscose should be classed as a chemically modified natural polymer. The red arrows indicate the pathway for viscose.

Figure 5: Decision Tree for Viscose



3.2 Other Polymers

In an open letter to DG Environment, issued in September 2019, the Nova Institute identified several other substances which it believed are “natural polymers” and should be exempt from the provisions of the SUP Directive.[10] One notable polymer on this list was Polyhyroxyalkanoates (PHA), classed under “natural Polymers produced via biosynthesis in bacteria”. The polymer is produced by a biological organism, but the commercial production of the polymer does not take place in nature.[11] As such, based on the ECHA guidance, it directly contradicts one of the conditions of being considered a natural polymer (‘Did the initial polymerisation reaction occur in nature?’), and thus it appears that it could not be considered exempt from the SUP Directive. In addition, the production of PHA depends upon the nutrients added to the culture, reinforcing that the polymer is not being produced “in nature”.

An argument might therefore be made that anything produced on an industrial scale using vessels, controlled cultures and other artificial means does not conform to the definition. The same polymer, but where the polymerisation took place in nature would be exempt, although it seems unlikely that such material could be used in the production

[10] Nova Institute (2019) Open Letter to DG Environment: Which polymers are “natural polymers” in the sense of the single-use plastic ban?

[11] Chen, Guo-Qiang, (2009), Industrial production of PHA, Plastics from Bacteria: Natural Functions and Applications

of anything other than very low volumes of single-use items. However, the meaning of "in nature" is not clearly defined by the ECHA and the definition of a natural polymer relies on non-statutory ECHA guidance that is worded somewhat ambiguously, so this interpretation lacks complete certainty. Assuming that this reasoning is sound, the same process should also be applied to other 'natural polymers', with responsibility falling to the manufacturer to prove that the polymerisation has taken place in nature.

3.3 Summary

The key factor for both lyocell and viscose is whether the chemical structure can be considered to have been modified in any way during the production process. For viscose, the chemical structure is the same at the beginning as at the end, but undergoes several chemical changes during this process. This leads to the conclusion that viscose should be considered a plastic under the SUP Directive.

For lyocell, the situation is less clear, as it might be argued that direct chemical changes do not occur, although several 'side reactions' are known to take place. The extent to which these reactions occur and whether they legally constitute chemical changes of the lyocell fibre is unclear. Currently, therefore, it is possible to argue the case for an interpretation of the SUP Directive definition that lyocell could be either a plastic or a non-chemically modified natural polymer.

4.0 Behaviour of MMCFs in the Environment

The SUP Directive forms part of the European Commission's strategy to tackle marine litter. Indeed, the Directive states that 80-85% of marine litter in the Union measured in beach litter counts, is plastic, with single-use plastic items representing 50% of the total.[12] 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 being used for periods of only minutes or perhaps even a few seconds.

With the objective and ambition to reduce marine litter, the SUP Directive focuses on the single-use plastic products most commonly found on beaches in the European Union, as well as fishing gear containing plastics and products made from oxo-degradable plastic. The primary intent of the legislators in enacting the Directive therefore 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.

To be consistent with the intent of the SUP Directive, a single-use product within the categories 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, consideration ought to be given to the end of life impacts of wipes discarded into the wastewater system or the open environment.

This section of the report aims to understand the state of the evidence regarding the environmental impacts of MMCF based wet wipes, with a particular focus on the marine environment. It is important to explore this in order to determine whether there is evidence that might justify exemption from the SUP Directive for some materials. The main grounds for this would be that the materials do not persist in the marine environment and would be relatively benign whilst there.

The evidence regarding two key material properties that would influence this— biodegradability and 'flushability' — is explored, before discussing lyocell and viscose specifically. The methods and limitations of testing for biodegradation and flushability are examined, and whether these limitations may result in uncertainty around the behaviour of MMCF-based wet wipes in the wider environment.

4.1 The Evidence for Biodegradability of MMCFs in the Marine Environment

Speed and extent of biodegradability are key determinants of the degree to which MMCF products are likely to persist in the environment. Conventional synthetic plastic

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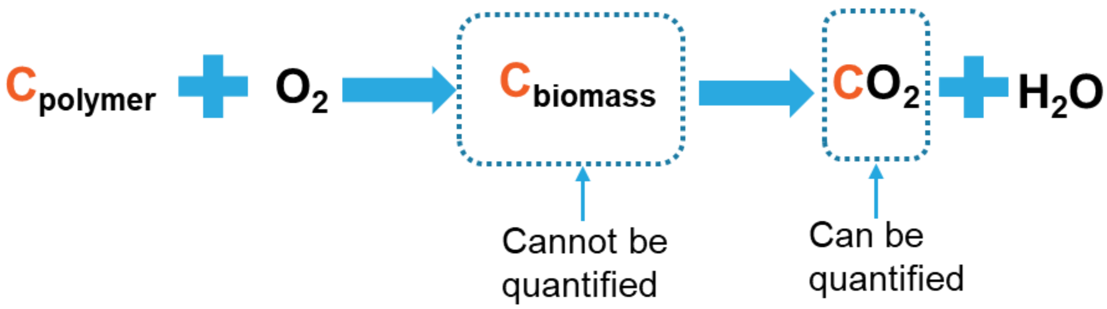
[12] European Parliament and Council (2019) Directive (EU) 2019/ of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment, *Official Journal of the European Union*

wipes are likely to persist for many years, either as a whole product or broken down into individual fibres. MMCFs are often described to consumers as biodegradable; the following section looks at the strength of the current evidence that may support this assertion, with specific focus on the marine environment.

4.1.1 The Biodegradation Process

As biodegradation is the degradation caused by biological activity, the material must be capable of being assimilated by microorganisms. The aerobic process in Figure 6 shows how microorganisms use oxygen to metabolise (biodegrade) the carbon in a polymer which is then mineralised into CO_2 and water.

Figure 6: Biodegradation Chemical Equation



Source: Adapted from Chinaglia et al.[13]

The microorganisms secrete enzymes which break down (cleave) the polymer chains to a size which makes them able to be assimilated by the organism. This biodegradation process takes place on the surface of materials, as the enzymes cannot penetrate the polymer. This means that the carbon in the core of the material is unavailable until the outer is metabolised, causing thicker material to biodegrade more slowly.

The consumption of oxygen or the production of CO_2 can be measured in order to track this process. Biodegradation percentage is often calculated as the ratio between the CO_2 produced and the theoretical CO_2 (tCO_2) if all of the carbon in the material was oxidised. A method has yet to be a developed that can be reliably used to measure the transfer of carbon into biomass. As such, it is only *mineralisation* that is directly measured rather than biodegradation itself.

4.1.2 Testing for Biodegradability in the Natural Environment

Before considering various tests for biodegradability, it is useful to understand the scientific methods and conditions under which biodegradability is examined. There are two principle research methods to investigate the biodegradability of a material;

[13] Chinaglia, S., Tosin, M., and Degli-Innocenti, F. (2018) Biodegradation rate of biodegradable plastics at molecular level, *Polymer Degradation and Stability*, Vol.147, pp.237–244

1) Research conducted 'in the field' or 'in situ' conducted using real-life, natural scenarios; and,
2) Research conducted in a laboratory, where variables can be strictly controlled and results gathering is more precise.

The former is used to determine the environmental fate of a material, but it is difficult to study in detail and to control for every potential influencing factor. The latter is used to demonstrate unequivocal evidence of biodegradation, but cannot accurately simulate the natural environment.

It is difficult however, to create the evidence base that links the two together in order to develop standard tests for which materials can be certified. The scientist needs to be confident that, if a standard test is passed, the material will also behave in a predictable way in the environment. This is particularly challenging given the diverse conditions and biology of the marine environment.

These are important caveats to keep in mind when considering the results from each of the testing conditions discussed below.

4.1.3 Testing in the Marine Environment

In the context of the growing challenge of plastic pollution in the oceans, marine-specific tests are important. There are significantly fewer standard tests for marine, as opposed to terrestrial, biodegradability. A 2015 EU report stated that there were only five marine-specific standard tests, all of which simulate aerobic conditions, and with only one measuring disintegration.[14]

Open-Bio for example, was a six-year EU funded project which ended in 2016. The project included one work package aimed at testing in-situ biodegradation and developing draft test methods and specifications on the marine degradation of bio-based materials.[15,16] This was considered *pre-normative research,* paving the way for standard specifications to be developed.

As part of the same Open-Bio project, a number of tests were also conducted off the coast of Greece and Italy. These measured the disintegration of various bioplastics, (although not man-made cellulosic fibres), in the intertidal beach zone, sublittoral zone (seafloor) and the pelagic zone (water column), which can be seen in Figure 7. The test samples were held in metal frames in the different scenarios. Sensors attached to the

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[14] Weber, M., Lott, C., and HYDRA Institute (2015) Open-Bio: Opening bio-based markets via standards, labelling and procurement. Deliverable N° 5.5: Review of current methods and standards relevant to marine degradation

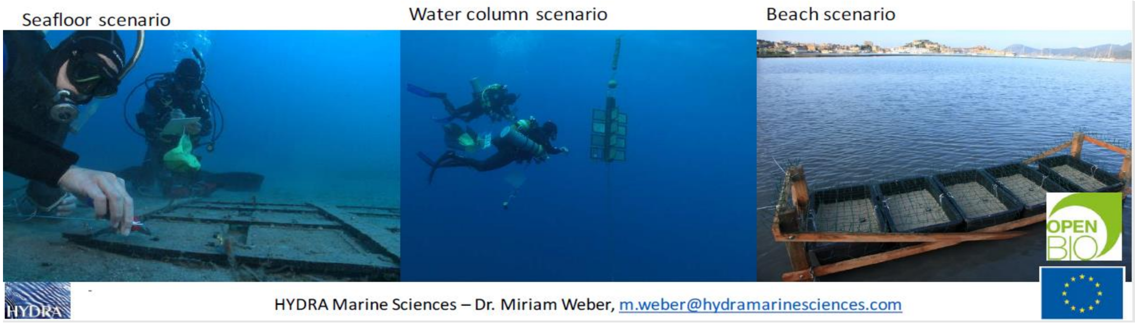
[15] Weber, M., Makarow, D., Unger, B., et al. (2018) Assessing Marine Biodegradability of Plastic—Towards an Environmentally Relevant International Standard Test Scheme, *Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea*, pp.189–193

[16] *Open-Bio: Opening bio-based markets via standards, labelling and procurement*, accessed 17 October 2019, https://www.biobasedeconomy.eu/projects/open-bio/

frames recorded the surrounding conditions, such as temperature, and regular samples were taken from the test materials for analysis.[17] The disintegration of the materials was measured and combined with the results from the laboratory tests, which measure CO_2 production and O_2 consumption for the same materials. This is important, as in-situ experiments for degradation in the marine environment cannot directly measure biodegradation (i.e. the CO_2 produced by microorganisms), but must rely on inferences such as disintegration, mass loss or molecular weight reduction.

This is problematic as mass loss may occur due to physical rather than biological processes. Examining direct/in-situ and indirect measurements of biodegradation together, allows conclusions to be drawn about the methods that are required to accurately measure the rate of biodegradation.[18] This development of effective methodologies is ongoing and is likely to continue for some time.

Figure 7: Development of standards for water biodegradation claims



Credit: Weber (2018) [19]

Since 2015, several other marine tests have been developed, including ISO 19679 and ISO 18830, created in 2016. Both provide a specified, laboratory-based methodology to test the rate and degree of aerobic biodegradation of plastic materials when settled on marine sediment. The former does so by measuring carbon dioxide evolution, the latter by measuring oxygen demand.

A common criticism of laboratory testing is that it does not adequately represent field conditions.[20] For instance, the lack of natural variability in such testing is critiqued, as is the use of different biodegradation agents (inoculum) between tests, potentially causing

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[17] HYDRA Institut für Meereswissenschaften (2015) *Plastic in the Sea - Research Project OPEN-BIO*
[18] Lott, C., Weber, M., Makarow, D., and Unger *Open-Bio: Opening bio-based markets via standards, labelling and procurement. Deliverable N° 5.8: Marine degradation test field assessment*

[19] Dr. Miriam Weber (2018) Current state of field tests on biodegradable plastics in the marine environment, *HYDRA Marine Sciences*, 11 March 2018

[20] Harrison, J.P., Boardman, C., O'Callaghan, K., Delort, A.-M., and Song, J. (2018) Biodegradability standards for carrier bags and plastic films in aquatic environments: a critical review, *Royal Society Open Science*, Vol.5, No.5, p.171792

different results. [21] One such test that has been subject to critical review is the OECD 306 test which describes two methods for biodegradability in seawater. Ott *et al.* (2019, 2020) have produced two papers evaluating and improving on the OECD 306 biodegradability in seawater test. The first paper outlines a number of limitations of the test protocol, as listed below:

- There is a significant source of variability introduced through the origin and low concentration of microbial cells in the test;
- Inadequate sampling of seawater and the degrading organisms within;
- Inadequate replication of the complex marine environment; and
- Environmentally unrealistic conditions, including chemical concentrations used, light and temperature amongst others. [22]

The second paper seeks to improve on the standard test by increasing the biomass concentration in the test substance/solution, the result of which was a reduction in the number of false negatives reported.[23]

In addition, standard tests are *accelerated tests* conducted under 'optimal conditions' not designed to precisely replicate the natural environment. Standard soil tests are generally conducted at around 25°C and marine at 30°C, both significantly higher than the average temperature found in the equivalent natural environments. This is due to the commercial requirement that the tests be completed in a reasonable timeframe.[24]

For environments where the average temperate is lower than specified in the tests—which would be the case for the majority of the marine environment outside of the very surface of the ocean or the beach sediment in summer in a temperate region—the implication is that biodegradation might still take place, but it would be considerably slowed. Time is a particularly important aspect. The longer the material remains in the environment, the greater the chances that it will cause negative impacts, such as ingestion by organisms. The scale of such impacts and what might be an acceptable timescale have yet to be established.

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[21] Pagga, U. (1997) Testing biodegradability with standardized methods, *Chemosphere*, Vol.35, No.12, pp.2953–2972

[22] Ott, A., Martin, T.J., Whale, G.F., Snape, J.R., Rowles, B., Galay-Burgos, M., and Davenport, R.J. (2019) Improving the biodegradability in seawater test (OECD 306), *Science of The Total Environment*, Vol.666, pp.399–404

[23] Ott, A., Martin, T.J., Snape, J.R., and Davenport, R.J. (2020) Increased cell numbers improve marine biodegradation tests for persistence assessment, *Science of The Total Environment*, Vol.706, p.135621

[24] SCU (Ed) (2019) 'Science for Environment Policy': European Commission DG Environment News Alert Service, The University of the West of England, Bristol

Furthermore, wet wipes made from MMCFs tend to sink in water and therefore are more likely to end up on riverbeds and the sea floor, and buried in sediments.[25,26] The lyocell and viscose fibres themselves are also negatively buoyant in water and will sink even when the wipe has disintegrated. Polypropylene and polyethylene are positively or neutrally buoyant which results in a tendency to float until the fibre becomes bio-fouled and sinks. However, the exact pathways that plastics will take once in the marine environment are not fully understood, but far more is thought to enter the oceans than has been found floating on the surface.[27,28]

Upper layers of sediments vary greatly in the level of available oxygen. Factors such as available dissolved oxygen in the water, amount of organic carbon in the sediments and the degree of turbulence within sediment taking place from movement of benthic and sediment-dwelling organisms may affect this. Therefore, aerobic conditions are not guaranteed for biodegrading sunken wet wipes.[29] The lack of test methods that reflect anaerobic conditions is problematic in this regard.

It is also important to note that the rate of biodegradation of materials in a marine environment, while limited to a degree by oxygen, is also heavily limited by nutrient availability e.g. nitrogen, phosphorus and iron. Nutrient quantities vary depending on location and depth, as well as temperature. The further down the stratifications of marine sediment, the less dense the populations of micro-organisms become, changing to micro-organism communities able to survive in anoxic environments.[30] This demonstrates the challenging nature of studying this field and the difficulties in replicating this environment in laboratory tests.[31]

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[25] Franz, P. (2015) *Aerobic Biodegradation of Third generation Mater Bi under marine condition*, 2015, https://ec.europa.eu/environment/ecoap/sites/ecoap_stayconnected/files/etv/vn20150004_verification_report_novamont.pdf

[26] Thames21 (2017) *4,500 wet wipes found in one patch of Thames foreshore*, accessed 7 November 2019, https://www.thames21.org.uk/2017/04/17995/

[27] Lebreton, L., Slat, B., Ferrari, F., et al. (2018) Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic, *Scientific Reports*, Vol.8, No.1, p.4666

[28] Jambeck, J.R., Geyer, R., Wilcox, C., et al. (2015) Plastic waste inputs from land into the ocean, *Science*, Vol.347, No.6223, pp.768–771

[29] National Oceanic and Atmospheric Administration *DeepCCZ: Why Does the Oxygen Penetration Depth Vary in Different Sediments?*, accessed 8 November 2019, https://oceanexplorer.noaa.gov/explorations/18ccz/logs/june13/june13.html

[30] Salomons, W., and Stigliani, W.M.(1995) *Biogeodynamics of Pollutants in Soils and Sediments: Risk Assessment of Delayed and Non-Linear Responses*, Berlin, Heidelberg: Springer Berlin Heidelberg

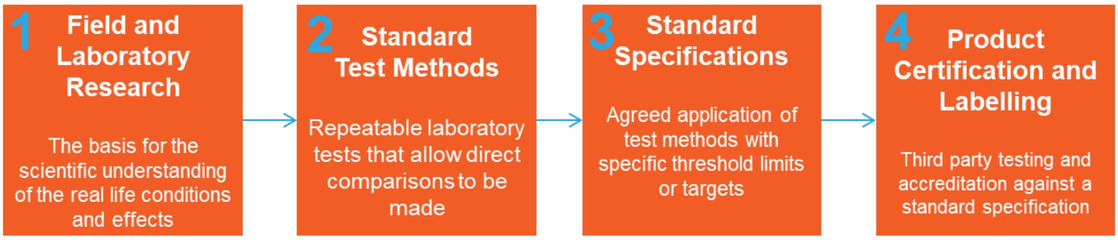
[31] Hassanshahian, M., and Cappello, S. (2013) Crude Oil Biodegradation in the Marine Environments, in Chamy, R., (ed.), *Biodegradation - Engineering and Technology* (14 June 2013) InTech

Given these limitations, considering results from a wide range of test scenarios will be paramount to building a picture of how biodegradable a material is.[32]

4.1.4 Biodegradability Standard Specifications and Certifications

Figure 8 depicts the simplified process used to understand biodegradation of plastics in the marine environment and how this can lead to product certifications. A great deal of research has taken place at stage one which has led to several test methods at stage two. However, 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 are harmless in the environment.

Figure 8: Process for Assessing Biodegradation in the Marine Environment



Standard specifications define compliance criteria, including pass/fail thresholds for producers to be able to test their products against. For instance, producers can test and declare their product compostable if it is in accordance with EN 13432. In addition to standard specifications, certifications from third parties are often available which test to these standards. The advantage of this is that certification often comes with a label to be displayed on products, which helps consumer confidence with purchasing decisions.

Examples of certifications include those from TÜV Austria, called "OK Biodegradable WATER" and "OK Biodegradable MARINE" for materials in freshwater and marine environments respectively. However, the MARINE certification prohibits the use of the associated label on products that are not meant to be used in or around the marine environment. This means that wet wipes may obtain the certification but would not be able to openly advertise this on packaging or promotional materials.

The American ASTM standard specification for biodegradable plastic in aerobic sea water — ASTM D7081[33] — was withdrawn in 2014 and has yet to be replaced. This standard specification required testing aerobic biodegradation in sea water using test method

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[32] Kjeldsen, A., Price, M., Lilley, C., Guzniczak, E., and Archer, I. A review of standards for biodegradable plastics, p.33

[33] *ASTM D7081-05: Standard Specification for Non-Floating Biodegradable Plastics in the Marine Environment,* accessed 9 November 2018, https://www.astm.org/DATABASE.CART/WITHDRAWN/D7081.htm

ASTM D6691[34] at a temperature of 30 +/- 2 °C for up to six months. The specification required a minimum of 30% biodegradation to pass (measured as a conversion of carbon to CO_2). This is one of the reasons that the specification was withdrawn as it is a particularly low threshold when compared with those used in other environments (often 90%). As our 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 was required.

The MARINE certification draws on the standard test method ASTM D6691 but requires a higher threshold for biodegradation than ASTM D7081 of 90%.[35] The material also needs to pass a disintegration test, which requires 90% of the material to pass through a 2mm sieve after 84 days. To obtain the MARINE certification, a substance must also pass the OECD 202 toxicity test which exposes small planktonic crustaceans to the material for 48 hours.[36] However, this test was adopted in 2004, just as the potential ecological issues around microplastics were beginning to see scientific focus. It is therefore unlikely to fully represent the risk to organisms.

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 something of an outlier, lacking the solid scientific underpinning necessary to remove doubt that products bearing its marque are truly better than the alternatives.

4.1.5 Biodegradability of Lyocell

There is very limited published scientific evidence for the biodegradability of lyocell in marine environments, including in sediments.

Currently, the only lyocell product to obtain the OK Biodegradable MARINE certification has been Lenzing's Tencel.[37] This means the product passed the tests described in 4.1.4. Although this shows that one lyocell product is biodegradable *under certain conditions*, as previously established, the certification itself does not fully encompass all of the potential risks to the environment.

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[34] *ASTM D6691 - 17 Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum*, accessed 21 October 2019, https://www.astm.org/Standards/D6691.htm *ASTM D6691 - 17 Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum*, accessed 21 October 2019, https://www.astm.org/Standards/D6691.htm

[35] TÜV AUSTRIA (2019) OK biodegradable MARINE : Initial acceptance tests

[36] OECD (1984) OECD guideline for testing of chemicals

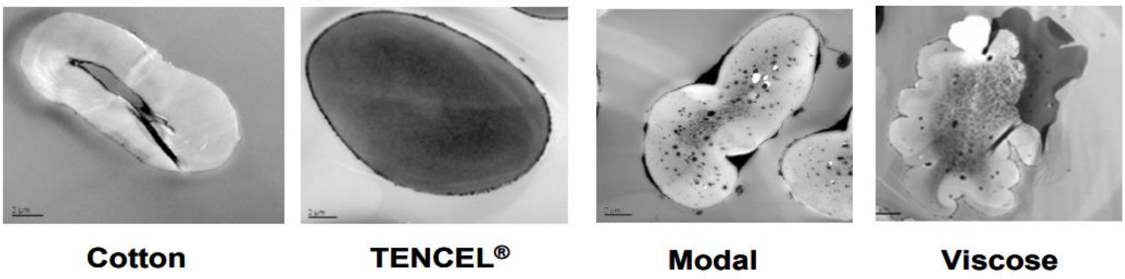
[37] TUV-AT (2020) *Certified Products*, accessed 20 November 2019, http://www.tuv-at.be/green-marks/certified-products/

While marine biodegradability tests for lyocell are scarce, some published soil-based research does exist. For instance, a 2009 soil burial test comparing Tencel lyocell, rayon (viscose) and cotton, concluded that Tencel fibre was the slowest to biodegrade; taking 94 days to decrease in mass by 50%.[38] However, it is difficult to draw conclusions from this study alone, given that the level of disintegration was not characterised and that mass loss can only infer biodegradation.

In the absence of direct biodegradability tests for lyocell, there are identifiable properties of the material which can help to indicate its behaviour in the environment. Lyocell's high molecular weight, higher degree of crystallinity compared to viscose and relatively hydrophobic properties are possible indicators that the fibres are less easily biodegraded in an open environment.[39]

Indeed, a paper by Firgo *et al.* (2006) outlines this resistance of fungal and bacterial growth on Tencel.[40] As demonstrated in Figure 9, water is absorbed by the Tencel fibres and distributed evenly between microfibrils and very thinly around the outer surface, whereas viscose has larger dark spots showing where water has accumulated. The paper states that the water distribution within Tencel makes it more difficult for bacteria and fungi to grow on the fibres. This can result in a tendency for Tencel to resist biodegradation.

Figure 9: Transmission Electron Micrographs of Cotton and Semi-synthetic Celluloses



Source: Firgo et al (2006)

In addition, lyocell has also been referred to by some as anti-bacterial.[41] [42] It is possible that the resistance of lyocell to microbial biodegradation will also result in resistance to

[38] Warnock, M., Davis, K., Wolf, D., and Gbur, E. (2009) Biodegradation of Three Cellulosic Fabrics in Soil, p.5

[39] Nam, S., Slopek, R., Wolf, D., et al. (2016) Comparison of biodegradation of low-weight hydroentangled raw cotton nonwoven fabric and that of commonly used disposable nonwoven fabrics in aerobic Captina silt loam soil, *Textile Research Journal*, Vol.86, No.2, pp.155–166

[40] Firgo, H., Schuster, K.C., Suchomel, F., Männer, J., Burrow, T., and Abu-Rous, M. (2006) The functional properties of Tencel® - A current update, p.10

[41] Kumar, P.S., and Suganya, S. (2017) Introduction to sustainable fibres and textiles, in Muthu, S.S., (ed.), *Sustainable Fibres and Textiles* (2017) Woodhead Publishing, pp.1–18

[42] Simplifi Fabric *lyocell*, accessed 30 October 2019, https://www.simplififabric.com/pages/lyocell

more general biodegradation in the environment. Further study would be required to confirm this link.

4.1.6 Biodegradability of Viscose

As with lyocell, there is a sizable gap in the scientific research regarding the biodegradability of viscose in natural environments.

Three viscose brands have been given the OK Biodegradable MARINE certification (Lenzing's viscose, Kelheim Fibres' VILOFT and Aditya Birla Group's Birla Viscose).

Again, certain chemical properties of viscose could indicate susceptibility to biodegradation. For instance, the manufacturing process for viscose results in the creation of cellulose fibres that are shorter, less crystalline and relatively amorphous when compared to lyocell. Such properties are likely to be more favourable for microbial biodegradation.[43,44]

Furthermore, the same 2009 soil burial test mentioned in section 4.1.5 concluded that viscose biodegraded more quickly than both cotton and lyocell.[45] Another 2016 study also showed that viscose degrades rapidly in soil – this study showed an 80% loss in fabric weight within 28 days, still outperforming cotton.[46]

4.1.7 Persistence of MMCFs in the Marine Environment

Several studies have identified the presence of man-made fibres in marine environments and in the digestive tracts of various marine animals. A 2019 study analysing 'synthetic' materials found in amphipod digestive tracts from six different deep-sea trenches around the pacific ocean[47] showed that, of the 15 different fragments analysed by Fourier-transform infrared spectroscopy (FT-IR), six were the MMCFs described as lyocell and rayon.[48] This indicated that these fibres are found in the deep sea and are entering

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[43] Arshad, K., and Mujahid, M. (2011) *Biodegradation of Textile Materials*, dissertation submitted for Degree of Master in Textile Technology, at The Swedish School of Textiles, Sweden, 2011

[44] Nam, S., Slopek, R., Wolf, D., et al. (2016) Comparison of biodegradation of low-weight hydroentangled raw cotton nonwoven fabric and that of commonly used disposable nonwoven fabrics in aerobic Captina silt loam soil, *Textile Research Journal*, Vol.86, No.2, pp.155–166

[45] Warnock, M., Davis, K., Wolf, D., and Gbur, E. (2009) Biodegradation of Three Cellulosic Fabrics in Soil, p.5

[46] Nam, S., Slopek, R., Wolf, D., et al. (2016) Comparison of biodegradation of low-weight hydroentangled raw cotton nonwoven fabric and that of commonly used disposable nonwoven fabrics in aerobic Captina silt loam soil, *Textile Research Journal*, Vol.86, No.2, pp.155–166

[47] Amphipods are an order of small crustaceans which inhabit almost all aquatic habitats, including the deepest parts of the ocean. They are usually scavengers and detritivores, eating a diverse range of particulate matter floating in the sea.

[48] Jamieson, A.J., Brooks, L.S.R., Reid, W.D.K., Piertney, S.B., Narayanaswamy, B.E., and Linley, T.D. (2019) *Microplastics and synthetic particles ingested by deep-sea amphipods in six of the deepest marine*

into the food chain of such organisms with unknown effects. Similar results have been found in studies of various other organisms, from Mediterranean invertebrates and fish in the English Channel, to Chinese terrestrial birds.[49, 50, 51]

Another study analysing the types of synthetic polymers found in the Atlantic Ocean found that 63% of the 499 FT-IR analysed samples consisted of rayon fibres, collected from 76 samples of 2,000 litres of seawater from various sites along the west coast of Europe and Africa.[52] The paper also discusses multiple other studies which identified high levels of MMCFs in a range of aquatic and terrestrial settings. Rayon was found to comprise 56.9% of fibres found in deep-sea sediment and coral samples studied in a 2014 paper, making it twice as abundant as polyester fibres.[53] Fibres have similarly been found in sediments in the Mediterranean and off the northern Spanish coastline; 79.7% of 202 fibres found were cellulose; either dyed cotton and linen or reported as rayon, despite plastic-based synthetic fibres comprising 65% of the textiles market.[54]

It is worth noting the limitations associated with such studies. It has been argued for instance, that fibre contamination from inside the laboratory may lead to false results and that MMCFs are sometimes difficult to distinguish from other cellulose fibres such as cotton and flax.[55] On the other hand, most recent studies now mitigate extensively to avoid contamination and FT-IR remains one of the best analysis methods for distinguishing different fibres. It could also be argued that the presence and persistence of any cellulosic fibre type in the marine environment is still cause for concern, given that they are not expected to behave significantly differently from one another.

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ecosystems on Earth, accessed 11 November 2019, https://royalsocietypublishing.org/doi/pdf/10.1098/rsos.180667

[49] Remy, F., Collard, F., Gilbert, B., Compère, P., Eppe, G., and Lepoint, G. (2015) When Microplastic Is Not Plastic: The Ingestion of Artificial Cellulose Fibers by Macrofauna Living in Seagrass Macrophytodetritus, *Environmental Science & Technology*, Vol.49, No.18, pp.11158–11166

[50] Lusher, A.L., McHugh, M., and Thompson, R.C. (2013) Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel, *Marine Pollution Bulletin*, Vol.67, Nos.1–2, pp.94–99

[51] Zhao, S., Zhu, L., and Li, D. (2016) Microscopic anthropogenic litter in terrestrial birds from Shanghai, China: Not only plastics but also natural fibers, *Science of The Total Environment*, Vol.550, pp.1110–1115

[52] Kanhai, L.D.K., Officer, R., Lyashevska, O., Thompson, R.C., and O'Connor, I. (2017) Microplastic abundance, distribution and composition along a latitudinal gradient in the Atlantic Ocean, *Marine Pollution Bulletin*, Vol.115, Nos.1–2, pp.307–314

[53] Woodall, L.C., Sanchez-Vidal, A., Canals, M., et al. (2014) The deep sea is a major sink for microplastic debris, *Royal Society Open Science*, Vol.1, No.4, p.140317

[54] Sanchez-Vidal, A., Thompson, R.C., Canals, M., and de Haan, W.P. (2018) The imprint of microfibres in southern European deep seas, *PLOS ONE*, Vol.13, No.11, p.e0207033

[55] Comnea-Stancu, I.R., Wieland, K., Ramer, G., Schwaighofer, A., and Lendl, B. (2017) On the Identification of Rayon/Viscose as a Major Fraction of Microplastics in the Marine Environment: Discrimination between Natural and Manmade Cellulosic Fibers Using Fourier Transform Infrared Spectroscopy, *Applied Spectroscopy*, Vol.71, No.5, pp.939–950

Moreover, even if a proportion of these cellulosic fibres are misreported as man-made, they are still identified as present in a wide range of natural habitats and in the digestive tracts of a range of animals.

Furthermore, another characteristic of cellulose is its tendency to adsorb heavy metals such as arsenic, copper, cadmium, chromium, lead, iron, mercury, zinc and nickel.[56] Cellulose in various forms, including lyocell, is commonly used in wastewater treatment to adsorb such harmful chemicals and prevent them from entering the open environment.[57,58] This means that wet wipes made from cellulosic fibres have a strong potential to adsorb harmful metals present in the environment, concentrating them onto the material and potentially increasing the harm to animals that ingest them.[59]

4.1.8 Summary

In summary, there is a lack of evidence around the biodegradation of lyocell and viscose. There are no current specifications or established frameworks which certify biodegradation in the marine environment. Although some test methods exist, they do not fully encompass all categories of marine environment and it is not yet possible to quantify the impacts of a material in the marine environment over time. There are significant knowledge gaps which limit the extent to which in-situ testing and laboratory testing can be linked, thus restricting the development of concrete standards.

Ultimately, current scientific knowledge regarding the behaviour and impacts of MMCFs in the marine environment, and other environments, is not sufficient to determine that all hazards are removed, and there are no reliable tests or certifications to prove this at present. As such, there is a risk that the original intent and effectiveness of the Directive could be undermined.

4.2 The Evidence for Flushability of MMCFs

In recent years, the term ‘flushability’ has developed which attempts 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 sanitary items which are incorrectly discarded down household toilets. This has been recognised as a particular problem in the UK

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[56] Gaballah, I., and Kilbertus, G. (1998) Recovery of heavy metal ions through decontamination of synthetic solutions and industrial effluents using modified barks, *Journal of Geochemical Exploration*, Vol.62, Nos.1–3, pp.241–286

[57] Jamshaid, A., Hamid, A., Muhammad, N., et al. (2017) Cellulose-based Materials for the Removal of Heavy Metals from Wastewater - An Overview, *ChemBioEng Reviews*, Vol.4, No.4, pp.240–256

[58] Bediako, J.K., Wei, W., Kim, S., and Yun, Y.-S. (2015) Removal of heavy metals from aqueous phases using chemically modified waste Lyocell fiber, *Journal of Hazardous Materials*, Vol.299, pp.550–561

[59] Brennecke, D., Duarte, B., Paiva, F., Caçador, I., and Canning-Clode, J. (2016) Microplastics as vector for heavy metal contamination from the marine environment, *Estuarine, Coastal and Shelf Science*, Vol.178, pp.189–195

where the water industry has expended considerable resources in identifying and quantifying the problem. Estimates suggest that UK water companies manage more than 366,000 sewer and drain blockages every year.[60] It has also been noted that around 80% of blockages are caused by these items combining with fats disposed of into the sewer system, which solidify and cause larger, 'fatberg' blockages.[61]

A 2017 study by Water UK found that baby wipes accounted for 75% of identifiable products by weight in sewer blockages.[62] Surface wipes, cosmetic removal wipes and feminine hygiene products accounted for approximately 20% by weight of identifiable products. In total, wet wipes made up around 93% of the material causing the sewer blockages which the study investigated. It is a term developed by industry, rather than a scientific term, however the aforementioned Water UK study found that the majority of blockage material recovered comprised of 'non-flushable' wipes disposed of via the toilet, implying that the flushability of a wet wipe was of high importance[63].

4.2.1 Testing for Flushability

The methodology for testing the flushability of a wet wipe closely aligns with its journey from disposal via the toilet, through the sewer system, and subsequent behaviour in a waste water treatment facility. There is not one agreed industry definition of flushability—which in itself is largely a marketing term at the current time. However, various standards have been developed by bodies representing the waste water services industry and the nonwoven fabric industries. These address the ability of a wet wipe to;

- Pass through the toilet and drainage system to see whether the chance of causing a blockage is sufficiently low;
- Sufficiently disintegrate in the toilet bowl, drain and sewage system;
- Settle adequately enabling removal in a waste water treatment facility, and;
- Disintegrate and biodegrade sufficiently in environmental conditions similar to waste water treatment facilities.

In recent years, three flushability standards have become particularly prominent:

- EDANA/INDA—Guidelines for Assessing the Flushability of Disposable Nonwoven Products, also known as GD4;

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[60] Jackson, L., and Tehan, R. (2019) Understanding behaviours causing blockages: Research with United Utilities to identify flushing habits in the North West of England, *Journal of Litter and Environmental Quality*, Vol.3, No.1, p.58

[61] Dyson, R. (2016) FOG: An increasing problem and opportunity, *Foundation for Water Research Newsletter*

[62] Andy Drinkwater, and Frank Moy (2017) *Water UK: Wipes in Sewer Blockage Study - Final Report*, October 2017, https://www.water.org.uk/publication/wipes-in-sewers-blockage-study/

[63] Andy Drinkwater, and Frank Moy (2017) *Water UK: Wipes in Sewer Blockage Study - Final Report*, October 2017, https://www.water.org.uk/publication/wipes-in-sewers-blockage-study/

- International Water Services Flushability Group (IWSFG)— Publicly Available Specification (PAS) 1: 2018 Criteria for Recognition as a Flushable Product; and
- Water UK— The Water Industry Specifications (WISs).

EDANA and INDA are the European and North American industry bodies representing the non-woven fabric industry, and their members include the largest MMCF manufacturers in Europe. Their guidelines are the industry standard used by manufacturers throughout Europe and members are required to display a "Do Not Flush" symbol on products that have "significant potential to be flushed" and do not pass the tests in the guidelines. As such it is useful to explore the testing methods used in these guidelines.

There are seven separate tests within GD4.[64] Three of these test the ability of a product to successfully clear the toilet water and household drainage without causing a blockage. In testing, products are flushed through a toilet system and must meet a number of criteria. For example, only one in 10 products tested may cause a blockage requiring the use of a plunger. One test measures the ability of a wet wipe to settle at the bottom of a waste water treatment facility, so as to be captured in the process and not expelled to the environment, stipulating minimum sinking velocities of the test products. Critically, from the perspective of the marine environment, many wet wipes simply pass straight through the facilities, or bypass facilities via combined sewer overflows.

A product's ability to disintegrate or biodegrade is assessed under conditions designed to mimic those found in waste water treatment facilities. Disintegration levels are tested by measuring the quantity able to pass through a 1mm sieve after 14 days in conditions similar to waste water treatment facilities, with 95% being the minimum threshold.

The OECD testing methods 311 and 301B are used to test anaerobic and aerobic biodegradation respectively.[65, 66] In order to pass the OECD 301B test for aerobic biodegradation, a minimum average level of 60% of the theoretical level of CO_2 production must be achieved by a product held in aerobic conditions within a 28 day testing period. The GD4 guidelines test anaerobic biodegradation using the OECD 311 testing methodology, but set their own pass criteria. They require a minimum average level of 70% of the theoretical level of CO_2 production to be achieved by a product held in the test conditions within a 28-day testing period. The 70% limit is not justified in the GD4 guidelines, but the OECD advise that predictions based on the testing for anaerobic biodegradability are weaker. They also warn that the test is not applicable to the assessment of anaerobic biodegradability in different environmental conditions.

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[64] INDA and EDANA (2018) Guidelines for Assessing the Flushability of Disposable Nonwoven Products

[65] OECD (1992) *Test No. 301: Ready Biodegradability*, Paris: Organisation for Economic Co-operation and Development

[66] OECD (2006) *OECD GUIDELINES FOR THE TESTING OF CHEMICALS*, accessed 25 November 2019, https://www.oecd-ilibrary.org/docserver/9789264016842-en.pdf?expires=1574698612&id=id&accname=guest&checksum=8FD048C605C074183A7C5A581B390315

In recent years, several bodies representing the waste water services industry have released their own flushability standards. Whilst there are similarities to the EDANA GD4 guidelines, these standards are more focussed on aspects of flushability relevant to the waste water treatment process rather than characteristics such as biodegradability. Two of these standards are outlined below:

1) **International Water Services Flushability Group (IWSFG)- Publicly Available Specification (PAS) 1: 2018 Criteria for Recognition as a Flushable Product.** This standard uses several of the GD4 test methodologies but uses stricter pass criteria. For example, whilst the GD4 toilet bowl clearance test allows one of 35 test wet wipes to cause a blockage requiring the use a plunger, the IWSFG requires a 100% pass rate. This highlights a greater emphasis on the potential to cause blockages in this standard. Crucially, the IWSFG does not require any testing for biodegradation and simply uses the EDANA disintegration tests. Therefore, none of the IWSFG criteria test a product's ability to biodegrade.[67]
2) **Water UK- the Water Industry Specifications (WISs).** As of October 2019, only two products have achieved this standard, and neither of these products contain man made cellulosic fibres or synthetic fibre.[68] In order for brands to advertise their products with the Water UK 'Fine to Flush' logo, their products are assessed against nine criteria that are said to simulate the conditions found in the UK waste water treatment system more accurately than the GD4 and place different emphasis on different aspects of flushability.[69] For example, out of 40 tests, in the WISs, no products are allowed to cause water to overflow the toilet bowl, whilst in the GD4 guidelines, one of 35 tests are allowed to cause a blockage requiring the use of a plunger.[70]

   Notably, there are no biodegradation test requirements so it cannot be inferred that a product that meets this standard will biodegrade if dispersed into the environment. Instead, the product is subjected to a dissolution test in bleach solution. This is designed to determine whether the material contains synthetic or organic material; the presence of the former leading to a test failure. This may provide an indication towards a material's likelihood to biodegrade, but is in no way a substitute for testing under specific environment conditions.

Of the three widely used flushability standards only EDANA's GD4 guidelines incorporates biodegradability testing into its assessment criteria. The WISs and the PAS both test a product's ability to pass through the waste water treatment system without

[67] *IWSFG Flushability Specifications – International Water Services Flushability Group*, accessed 11 October 2019, https://www.iwsfg.org/iwsfg-flushability-specification/

[68] Water UK (2019) *Waster Industry Specification: Fine to Flush*, 2019, https://www.water.org.uk/wp-content/uploads/2019/01/Fine-to-flush-WIS-4-02-06-January-2019.pdf

[69] *Leading retailers not embracing wet wipe 'flushability' standard*, accessed 11 October 2019, https://www.mcsuk.org/news/wet_wipe_score_card

[70] Water UK (2019) *Waster Industry Specification: Fine to Flush*, 2019, https://www.water.org.uk/wp-content/uploads/2019/01/Fine-to-flush-WIS-4-02-06-January-2019.pdf

causing blockages, focusing on its ability to disintegrate but not necessarily biodegrade. Further, whilst the EDANA GD4 guidelines do involve limited biodegradability testing, the methods only test a product's ability to biodegrade in the conditions found in waste water treatment facilities.

4.2.2 Flushability of Lyocell

The Veocel Lyocell fibre produced by the Lenzing Group has been certified as 'fully flushable' according to the GD4 guidelines from INDA/EDANA. However, no evidence could be found that this product, or any other lyocell product, has been submitted for testing, or met the flushability criteria of either the IWSFG or the 'Fine to flush' standard from Water UK.

A recent report from Ryerson University, funded by the Municipal Enforcement Sewer Use Group of Canada, tested five products containing lyocell against the IWSFG standard. None of these passed, due to the failure to pass the disintegration and more stringent drain line clearance tests.[71] This provides evidence that the flushability of products containing lyocell is contested and highly dependent on the relevant standards tested against.

4.2.3 Flushability of Viscose

Similar to the lyocell fibres on the market, the Viloft fibre produced by Kelheim Fibres has been certified as 'fully flushable' according to the GD4 guidelines from INDA/EDANA.[72] No evidence could be found showing it had met the flushability criteria of either the IWSFG or the 'Fine to flush' standard from Water UK. Other products such as the Vernacare Conti Flushable Patient Wet Wipe contain viscose and have met the GD4 standard, and similarly, no evidence was found of them passing the IWSFG and Water UK standards.[73] In the aforementioned Ryerson University report, of the nine products tested containing viscose, none met the IWSFG standard, due to the failure to pass the disintegration and drain line clearance tests.[74] Similarly to lyocell, the flushability of products containing viscose is contested and highly dependent on the relevant standards tested against.

4.2.4 Summary

The degree of flushability of both lyocell and viscose is uncertain. At present, there is a dearth of scientific evidence on the topic. It is difficult to make confident claims on the

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[71] Anum Khan, Barry Orr, and Darko Joksimovic (2019) *Defining Flushability for Sewer Use - Final Report*, March 2019, https://www.iwsfg.org/wp-content/uploads/2019/07/Ryerson_Report_2019.pdf
[72] Fibre2Fashion (2006) *Kelheim brings specialty viscose fibre Viloft nonwoven for flushable wipes*, accessed 10 January 2020, https://www.fibre2fashion.com/news/textile-news/newsdetails.aspx?news_id=12919

[73] *Conti Flushable Cleansing Dry Wipes (15 Pack)*, accessed 25 November 2019, https://www.careshop.co.uk/patient-care/wipes/dry-wipes/conti-flushable-15x50.html

[74] Anum Khan, Barry Orr, and Darko Joksimovic (2019) *Defining Flushability for Sewer Use - Final Report*, March 2019, https://www.iwsfg.org/wp-content/uploads/2019/07/Ryerson_Report_2019.pdf

flushability of viscose and lyocell-based wet wipes, as the term is not standardised and different testing regimes have different requirements.

Furthermore, the laboratory testing methods used to assess the biodegradability of the products, means that flushability standards are of limited use in assessing whether a product will biodegrade in the environment. The strongest testing demonstrates biodegradation is possible within a wastewater treatment plant and the weakest has no requirement, or merely that the material be produced from organic matter. None of the tests address the very real prospect of wipes entering waterways and oceans and their impacts in these environments. This further increases the risk of undermining the effectiveness of the Directive.

Ultimately, the current flushability standards cannot provide confidence that materials that pass through sewage systems will not have a similarly detrimental impact on the environment 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.

5.0 Market Implications

This section presents an overview of current and future market trends for lyocell and viscose. The analysis considers the possible market impacts, at both global and European scales, if lyocell or viscose were to be exempt from the SUP Directive, as well as the potential implications for their modes of production.

5.1 Current Material Market Trends

The global market for wet wipes continues to expand. In 2014 the consumer wipe market grew to a value over $10.5 billion (€9.4 billion) and, to 2019, has experienced annual growth rates of around 7%.[75] The largest wipes segment using nonwovens is personal care wipes. It is estimated that personal care wipes consumed 763,700 tonnes of nonwovens globally in 2019, projected to reach 1 million tonnes valued at $12.5 billion by 2024.[76]

A number of factors drive this growth, including: cost, convenience, performance, hygiene, disposability and consumer-perceived aesthetics. Currently, the US and Western Europe are the largest markets for wet wipes, with Europe projected to be the fastest growing regional market in the near future, driven in particular by an increasing demand for more specialised types of wipe, such as more 'natural' wipes.[77] In 2016, overall EU consumption of baby and personal care wet wipes stood at 40.4 billion units per annum. Consumption has increased over the years recorded and is forecast to increase to around 76 billion units in Europe in 2030.[78] In Europe, the UK is the largest consumer of nonwoven wipes, with 24.9% of the Western European market.[79]

At present, the global fibre market for all types of fibre products is still dominated by synthetic fibres. Polyester is the leading material, accounting for over 60% of the world fibre market together with other synthetic fibres.[80] Recent studies also point to the relatively low price of oil in recent years as a significant influencing factor, thus making

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[75] Mango, P. (2014) *The Future of Nonwoven Wipes to 2019*, 2014

[76] Smithers (2019) *The Future of Personal Care Wipes in a Changing Retail Landscape to 2024*, accessed 10 January 2020, https://www.smithers.com/en-gb/services/market-reports/nonwovens/personal-care-wipes-in-a-retail-landscape-to-2024

[77] Grand View Research (2019) *Personal Care Wipes Market Size, Share, Industry Report, 2019-2025*, accessed 27 November 2019, https://www.grandviewresearch.com/industry-analysis/personal-wipes-market

[78] Eunomia (2017) Single-use Plastics and the Marine Environment - Leverage Points for Reducing Single-use Plastics, Final Report for Seas at Risk

[79] Mango, P. (2014) *The Future of Nonwoven Wipes to 2019*, 2014

[80] Engelhardt, A. (2019) *Rising investments in manmade fiber feedstocks*, accessed 7 November 2019, https://fiberjournal.com/rising-investments-in-manmade-fiber-feedstocks/

such synthetic materials more cost competitive. Cotton makes up about 25%, wood-based cellulose fibres around 6% and other natural fibres around 5% of the global fibre market.[81]

5.1.1 Cellulosic Fibre Market

The MMCF segment of the market has seen rapid growth in recent years, amid a wider growing market share for products which are perceived to be more sustainable, a trend fuelled by both government policy and consumer preference. Since 1990, the global MMCF production volume has increased from around 3 million metric tonnes, to around 6.7 million metric tonnes in 2017, representing about a 6.3% share of the total global fibre production volume.[82]

Whilst demand is still driven by the factors previously mentioned, environmental awareness, particularly regarding plastics and climate change, has grown amongst the public, especially in more affluent countries. This has combined with continued market recovery from the global economic downturn of 2008/9 and prosperity growth, to increase consumers' willingness to pay for what are typically more expensive products (lyocell is generally 15-20% more expensive than EU viscose).

Limited supplies of other natural fibres such as cotton are also contributing to the popularity of wood-based cellulosic fibres. Indeed, a recent market report indicates that the percentage of natural raw materials used in wipes is predicted to increase from 54% in 2013 to 59.2% in 2023.[83] This growth is predicated on the global consumer trend for more 'natural' or sustainable products. Although this trend has waxed and waned depending on regional and global economics, the overall direction has been growth.

5.1.2 The Lyocell Market: Trends and Forecasts

Globally, the market for lyocell fibre is expected to have a compound annual growth rate (CAGR) of 7-8% to 2025. The global market share of lyocell increased from around 3% in 2016 to around 4.5% in 2017, shown in Figure 10.[84] In Europe, the production of nonwoven fabrics for medical and automobile industries has expanded. By 2024, Europe is forecast to contribute more than 12% of the global lyocell fibre market, with the UK, Germany and France dominating demand.[85]

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[81] Lenzing (2019) *Factsheet: The Global Fiber Market*, accessed 7 November 2019, https://www.lenzing.com/investors/facts-and-figures/factsheet/

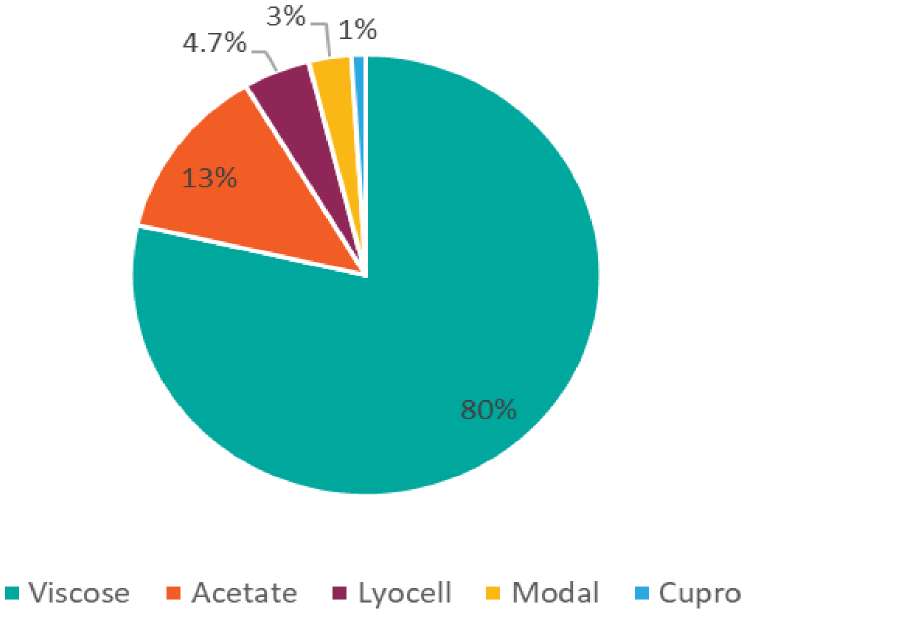
[82] Textile Exchange (2016) *Preferred Fiber Market Report 2016*

[83] Olivio, T. (2019) *Wipes Go Natural - Nonwovens Industry Magazine - News, Markets & Analysis for the Nonwovens Industry*, accessed 7 November 2019, https://www.nonwovens-industry.com/issues/2019-04-01/view_features/wipes-go-natural/

[84] Textile Exchange (2018) *Preferred Fiber & Materials: Market Report 2018*, https://www.ecotlc.fr/ressources/Documents_site/2018-Preferred-Fiber-Materials-Market-Report.pdf

[85] Global Banking and Finance Review (2019) *Lyocell Fiber Market to showcase significant growth from apparel segment over 2019-2024*, accessed 26 November 2019,

Figure 10: Approximate Global Market Share of MMCFs, 2017



Source: https://www.ecotlc.fr/ressources/Documents_site/2018-Preferred-Fiber-Materials-Market-Report.pdf

It is important to note that lyocell is increasingly used in apparel and textiles industries. Indeed, it is the apparel segment which leads lyocell fibre market growth.[86] The lyocell market is highly competitive, and particularly innovative, and is structured around a small number of key players, including:

- Lenzing AG;
- Hi-tech Fiber;
- Smart Fiber AG;
- Shangtex Holding:
- Aditya Birla Group; and
- Acelon Chemicals & Fiber Corporation.

With regards to lyocell consumption, China is a major lyocell consumer, absorbing 36.43% of global production in 2016.[87]

https://www.globalbankingandfinance.com/category/news/lyocell-fiber-market-to-showcase-significant-growth-from-apparel-segment-over-2019-2024/

[86] PRNewswire (2019) *Lyocell Fiber Market Analysis - Global Opportunities, Revenue, Demand and Geographical Forecast To 2023: Radiant Insights, Inc.*, accessed 12 November 2019, https://www.prnewswire.com/news-releases/lyocell-fiber-market-analysis--global-opportunities-revenue-demand-and-geographical-forecast-to-2023-radiant-insights-inc-300928314.html

[87] Market Watch (2019) *Lyocell Fiber Market Research Reports 2019 | Global Industry Size, In-Depth Qualitative Insights, Explosive Growth Opportunity, Regional Analysis by 360 Research Report*, accessed 7

Indeed, investments in this material process have already grown. In Europe, capacity for dissolving wood pulp sits across nine countries with a combined capacity of nearly two million tonnes. Two new mills are planned along with full-scale production from a previously closed Spanish plant, and greater investment in order to avoid bottlenecking.[88]

The majority of lyocell production in Europe is carried out by Lenzing, based in Austria. The company had an 18% global market share in 2017, and has optimistic growth projections. Lenzing has released expansion and investment plans in order to meet the increasing demand from downstream companies. Starting in early 2020, Lenzing plans to triple its production of Lenzing lyocell.[89]

5.1.3 The Viscose Market: Trends and Forecasts

As shown by Figure 10 in the previous section, viscose had around an 80% share of global man-made cellulosic fibre production in 2017.[90]

The viscose industry is concentrated in a small number of companies, with several owning all stages of production. The data on wood trade specifically for dissolving wood pulp production (and viscose), is not publicly available. However, the shape of the broader wood for pulp market is known. The industry is geographically clustered in:

- USA and Canada
- Sweden and Austria
- India, China and Indonesia
- South Africa and Brazil

Figure 11 shows the production share of the world's largest viscose fibre producing regions in 2015.

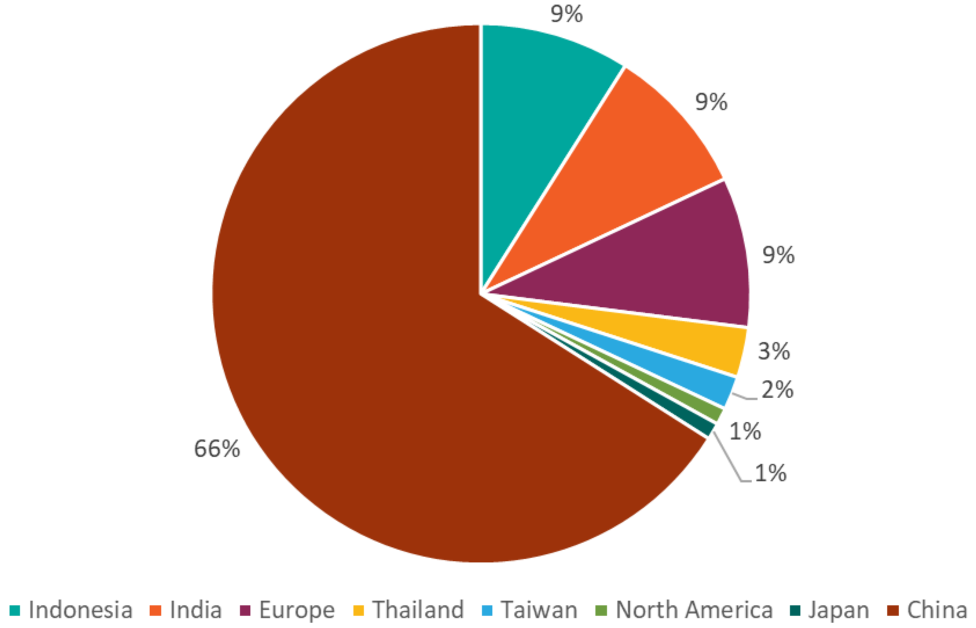
November 2019, https://www.marketwatch.com/press-release/lyocell-fiber-market-research-reports-2019-global-industry-size-in-depth-qualitative-insights-explosive-growth-opportunity-regional-analysis-by-360-research-report-2019-05-30

[88] Engelhardt, A. (2019) *Rising investments in manmade fiber feedstocks*, accessed 7 November 2019, https://fiberjournal.com/rising-investments-in-manmade-fiber-feedstocks/

[89] LENZING AG (2019) *Lenzing upgrades LENZING™ Lyocell Shortcut fiber offerings with increased production capacity and launch of new fiber grades*, accessed 12 November 2019, https://www.lenzingindustrial.com/NewsAndEvents

[90] Textile Exchange (2018) *Preferred Fiber & Materials: Market Report 2018*, 2018, https://www.ecotlc.fr/ressources/Documents_site/2018-Preferred-Fiber-Materials-Market-Report.pdf

Figure 11: World's Largest Viscose Fibre Producing Regions, 2015



Source: https://waterfootprint.org/media/downloads/Viscose_fibres_Sustainability.pdf

In Europe, Sweden and Austria are among the largest dissolving wood pulp producers in the world. Sweden mainly imports raw materials (roundwood) from Norway, Latvia and Russia, while Austria mainly imports for the Czech Republic, Germany and Slovakia. With regards to dissolving wood pulp production, 53% of global production was accounted for by only five companies: Sappi; Aditya Birla (operates in Sweden); Lenzing (operates in Austria and Czech Republic); Bracell; and Rayonier.

Lenzing and Aditya Birla are the top two viscose producers. One particular area of innovation is the production of 'recycled' man-made cellulosics from reclaimed materials, such as cotton byproducts and leftovers. One example is Lenzing's Refibra. Launched in 2017, it is the first lyocell fibre made from 20% post-industrial cotton residues.[91] During the first decade of the 21st century, global viscose fibre production capacity grew at an average annual rate of 7.7%, driven primarily by expansion in Asian countries. Notably, between 2007 and 2013, China more than doubled its viscose fibre production.[92] The global viscose fibre CAGR is forecast to be around 4.6% for the period 2019-2025.[93]

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[91] Textile Exchange (2018) *Preferred Fiber & Materials: Market Report 2018*, 2018, https://www.ecotlc.fr/ressources/Documents_site/2018-Preferred-Fiber-Materials-Market-Report.pdf

[92] Water Footprint Network (2017) *Viscose Fibres Production - An assessment of sustainability issues*, August 2017, https://waterfootprint.org/media/downloads/Viscose_fibres_Sustainability.pdf

[93] Market Watch (2019) *At 4.6% CAGR, Viscose Fiber Market Size Poised to Touch USD 17300 Million by 2025 - MarketWatch*, accessed 13 November 2019, https://www.marketwatch.com/press-release/at-46-cagr-viscose-fiber-market-size-poised-to-touch-usd-17300-million-by-2025-2019-10-22

5.2 Market Impacts

Under the SUP Directive, there are a number of costs which producers of certain single-use plastic products (including wet wipes) will be exposed to. If either, or both, lyocell and viscose are exempt from the SUP Directive, and therefore not subject to EPR cost requirements, this is likely to impact the competitive wet wipe market.

This section first outlines some possible EPR cost requirements under the SUP Directive, providing a high-level review of the potential impacts for wet wipe producers. The analysis then examines the implications which a market shift in material use may have for the cost and production of lyocell and viscose.

5.2.1 EPR Costs

Under Article 8(1) of the SUP Directive, Member States are required to ensure that EPR schemes are established for wet wipes. Article 8(3) requires Member States to ensure that producers of certain single-use plastic products (including wet wipes), cover '*at least the following costs'*:

a) The costs of the awareness raising measures regarding those products;

b) The costs of cleaning up litter resulting from those products and the subsequent transport and treatment of that litter; and

c) The costs of data gathering and reporting in accordance with point (c) of Article 8a(1) of Directive 2008/98/EC.

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"*. It is therefore likely that flushing would be considered as 'inappropriate disposal'. Importantly, the wording leaves flexibility for Member States to require producers to cover further costs, which may include:

- The cost of collecting and treating wet wipes in residual waste;
- The direct costs of clearing sewer blockages attributable to wet wipes; and
- Potentially the wider costs associated with Combine Sewer Overflow (CSO) spills caused by wet wipe induced blockages.

The most significant costs are likely to be associated with litter resulting from wet wipe disposal in the sewerage system. For instance, wet wipe manufacturers could be charged according to the proportion of wipes in litter counts on beaches or sewerage overflows. This could have an impact on the product price.

It is difficult however, to directly attribute costs such as pollution/clean-up costs to wet wipes. Taking the UK as an example, wet wipes are reported to cause 93% of sewerage blockages in the country, costing €117 million per year to clear according to research by

Water UK.[94, 95] It could therefore be argued that the wipes industry may be required to contribute €109 million per year. Furthermore, based on the number of wet wipes sold across Europe in 2016 (around 40.4 billion packages) and a compound annual growth rate of 4.34%,[96] it can be estimated the UK sold around 7 billion wet wipes in 2018.[97] If blockage removal costs are €109 million per year, this equates to about 1.6 Euro cents per wet wipe.

5.2.2 Price Impacts

If lyocell were to be exempt from the SUP Directive plastic definition and the market supply shifted to lyocell-based wipes, there is likely to be a price impact. Currently, lyocell is around 25-30% more expensive than other raw materials. As an estimate, if an average baby wipe weighs 6.7g, the cost per lyocell wipe are approximately 1.5 Euro cents compared to 1.1 Euro cents for a PET wipe. Adding 1.6 Euro cents to a synthetic wipe for EPR would result in a 2.5 times cost increase which would directly affect the sales price to the point where they may be uncompetitive and thus unviable in the market place (see Table 1). Any exempted product would therefore likely have a significant advantage. If the EPR costs are in this order of magnitude for all wet wipe products—regardless of material—the inevitable increase in price for the consumer may have a significant impact on the growth of the market in the long term.

Table 1: Wet Wipe Costs per Item

Product Material	Approx Cost (€ cents/wipe*)	Potential EPR Costs (€ cents)	Total Costs (increase)
Synthetic wet wipe	1.1	1.6	2.7
Lyocell wet wipe	1.5	n/a	1.5
(EU) Viscose wet wipe	1.4		1.4

(*) based on a baby wipe weighing 6.7g.

[94] Water UK (2017) *New proof that flushing wipes is a major cause of sewer blockages*, accessed 8 January 2018, https://www.water.org.uk/news-water-uk/latest-news/new-proof-flushing-wipes-major-cause-sewer-blockages

[95] Drinkwater, A., and Moy, F. (2017) *Wipes in sewer blockage study: final report*, https://www.water.org.uk/publication/wipes-in-sewers-blockage-study/ Drinkwater, A., and Moy, F. (2017) *Wipes in sewer blockage study: final report*, https://www.water.org.uk/publication/wipes-in-sewers-blockage-study/

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

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

5.2.3 Impacts on Production

If either lyocell or viscose are exempt from the SUP Directive and the market shifts in response, there will be a resultant impact on the production and manufacturing process of both materials. As noted previously, a single-use product within the categories covered by the Directive should only be exempt if it has a substantially reduced impact on the environment relative to a regulated plastic alternative. Having considered the impacts of wet wipes discarded into the wastewater system, this section highlights the predominant environmental impacts a potential shift in production to lyocell and viscose may have, both globally and at the European level.

5.2.3.1 Wood Supply

If there is a shift to a greater use of lyocell and viscose, this will impact the supply and demand of the raw materials from which they are made, principally wood. Lyocell and viscose fibre production depend upon wood as a source of cellulose, typically from hardwoods, softwoods and sometimes bamboo. An estimated 150 million trees are felled globally every year for the production of man-made cellulosic fibres alone.[98]

It is important to note that wood production and demand in Europe is not only fuelled by fibre production but also for the paper and board industry, woodworking industries and furniture industries. A study conducted by the Confederation of European Paper Industries (CEPI) showed that the supply of wood in Europe was being outpaced by the rate of consumption of paper, board and wood-based products.[99] The research concluded that this trend strongly indicated a gap between wood supply and demand in the future, highlighting the need to focus on sustainable wood production. Therefore, an increase in demand, combined with greater emphasis on sustainable wood cultivation, is projected to influence market growth.

Furthermore, a market shift would also put pressure on dissolving wood pulp, a key process in the production of lyocell and viscose fibres. The current global market for all types of wood pulp is around 600 million tonnes, with Europe responsible for around a third of this.[100] Total dissolved wood pulp is globally around 10 million tonnes with half of that used in textiles.[101] The global wood pulp market is predicted to grow at a CAGR of 2.1% 2019-2024.[102]

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[98] *CanopyStyle – Canopy*, accessed 30 October 2019, https://canopyplanet.org/campaigns/canopystyle/

[99] Galembert, B. de (2003) *Wood Supply for the Growing European Pulp and Paper Industry*, accessed 27 November 2019, http://www.fao.org/3/XII/0904-C1.htm

[100] CEPI (2011) The Forest Fibre Industry 2050 Roadmap to a low-carbon bio-economy

[101] Andritz Pulp and Paper (2017) Global Trends in Dissolving Pulp, *Spectrum*, Vol.36, No.2

[102] Mordor Intelligence (2018) *Wood pulp market - growth, trends, and forecast 2019-2024*, accessed 12 November 2019, https://www.mordorintelligence.com/industry-reports/wood-pulp-market

The European market for nonwoven personal care wet wipes was around 300,000 tonnes in 2017,[103] with 40% of this consisting of wood derived fibres. If the European wet wipe market were to move entirely to cellulosics, this would represent an increase in demand of around 1% for dissolved pulp. Although this is proportionally low, it is unclear what the precise consequences would be to the market.

With regards to the sustainable forestry industry, there is some indication of how this may be affected. For instance, at the global level, the number of Forest Stewardship Council (FSC) certified dissolving pulp producing sites doubled to 156 between 2015 and 2017. In the same time period, Europe has seen the greatest percentage increase (14%) in the number of FSC certified sites producing or processing fibres.[104] The Programme for the Endorsement of Forest Certification (PEFC) certified dissolving pulp and fibre producing sites also increased between 2015 and 2017.[105]

Additionally, between 2015 and 2018, the proportion of viscose producers with policies relating to endangered forest sourcing increased from 35% to 80% of the global market.[106] Lyocell has also been marketed as derived from sustainable wood sources, such as Tencel and Simplifi Fabric. It is claimed that Tencel only uses wood from sustainable eucalyptus plantations, a claim that was backed by an independent audit from the Rainforest Alliance in 2017.[107]

Ultimately, if demand for lyocell or viscose increases, there will be an impact on the production process and materials, spurring growth in both regional and international supply chains. This could present a competitive advantage to those European regions already involved in lyocell production, namely Austria, Germany, France, UK, Italy, Russia and Spain, as well as those companies already active in this niche market. However, a wholesale move to lyocell/viscose-based wipes in Europe may contribute to a squeeze on raw material supply in Europe.

5.2.3.2 Manufacturing

Increased demand for lyocell and viscose will not only have implications for production, but also for manufacturing of MMCF wet wipes. One part of the MMCF manufacturing

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[103] EDANA (2019) *Nonwovens markets*, accessed 15 January 2020, https://www.edana.org/nw-related-industry/nonwovens-markets

[104] FSC (2017) *Market Info Pack 2016-2017*, January 2017, https://ic.fsc.org/file-download.fsc-market-info-pack-2016-2017.a-1728.pdf

[105] Textile Exchange (2018) *Preferred Fiber & Materials: Market Report 2018*, 2018, https://www.ecotlc.fr/ressources/Documents_site/2018-Preferred-Fiber-Materials-Market-Report.pdf

[106] Textile Exchange (2018) *Preferred Fiber & Materials: Market Report 2018*, 2018, https://www.ecotlc.fr/ressources/Documents_site/2018-Preferred-Fiber-Materials-Market-Report.pdf

[107] Rainforest Alliance (2017) *CanopyStyle Verification and Guidelines Evaluation Report for: Lenzing Aktiengesellschaft in Lenzing, Austria*, May 2017

process which has the potential to cause significant environmental damage is the chemicals used.

The manufacturing processes for lyocell and viscose differ in the chemicals used. 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%.[108]

The viscose manufacturing process uses sodium hydroxide (NaOH), carbon disulphide (CS_2) and sulfuric acid (H_2SO_4); all of which can have a severe negative effect on ecosystems and human health if released into the environment. The toxic and corrosive gas hydrogen sulphide (H_2S) is also a by-product when cellulose is precipitated in CS_2. Although an appropriately managed viscose process should recapture these chemicals and neutralise or recycle them after use, there have been several incidences across the world where chemical leakage has occurred, causing severe damage to the environment and human health.[109,110]

Natural fibre-based wipes are often bleached to remove natural impurities and to achieve a white colour, for instance bleached or unbleached cotton wet wipes. Bleaching is typically a large-scale industrial process involving a significant amount of chemicals, energy and water. The procedure results in waste and by-products such as chlorine which, if improperly managed, can be damaging to the environment and human health.[111] Dyes used on lyocell and viscose have also been identified as potentially toxic to animals.[112]

Whilst dying is an uncommon practice in wet wipe manufacture, wet wipes are often impregnated with soaps, lotions or other chemicals to increase functionality. Wet wipes containing chemicals such as sanitizing agents, can be damaging to aquatic life if released into the environment.[113]

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[108] 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

[109] Changing Markets Foundation (2018) *Dirty Fashion Revisited: Spotlight on a polluting viscose giant*, February 2018, http://changingmarkets.org/wp-content/uploads/2018/02/DIRTY_FASHION_REVISITED_SPOTLIGHT_ON_A_POLLUTING_VISCOSE_GIANT-1.pdf

[110] Hoskins, T. (2017) H&M, Zara and Marks & Spencer linked to polluting viscose factories in Asia, *The Guardian*

[111] Ross, C.B. (2015) *Bleached Vs Unbleached Fabrics*, accessed 14 January 2020, https://www.the-sustainable-fashion-collective.com/2015/03/26/difference-between-bleached-and-unbleached-fabric

[112] Remy, F., Collard, F., Gilbert, B., Compère, P., Eppe, G., and Lepoint, G. (2015) When Microplastic Is Not Plastic: The Ingestion of Artificial Cellulose Fibers by Macrofauna Living in Seagrass Macrophytodetritus, *Environmental Science & Technology*, Vol.49, No.18, pp.11158–11166

[113] Kimberly-Clark Professional *Safety Data Sheet - KLEENEX Hand Sanitising Wipes*, https://www.kcprofessional.co.uk/media/209652619/7782-83-84__SDS_GB_EN_V13.PDF

Thus, if the market were to shift, and the manufacture of lyocell and viscose-based wet wipes were to increase, the implications and heightened risks to the environment of mismanaged chemical manufacture processes would need to be recognised.

5.3 Summary

Overall, if MMCFs were to be exempt from the SUP Directive, it is probable that these fibres would become a more popular material for wet wipes. The viscose-based wet wipe market is predicted to grow, driven by brands looking for alternatives to synthetic plastics. The lyocell market is also projected to increase, but at present lyocell wipes are more expensive for consumers due to higher costs for raw materials. As viscose fibres in Europe are currently 20-30% cheaper than lyocell, it will likely be a first-choice alternative. However, the relative competitiveness of these materials may well be determined by which are found to be exempt from the Directive. Future anticipated investment in both processes could also conceivably create the economies of scale required for cost reductions.

Ultimately, the level of EPR costs in Europe will be a significant factor influencing how interested brands might be in moving to alternative, ‘plastic free’ materials. An EPR cost of for instance >1-2 Euro cents per wipe would more than offset the higher raw material cost for MMCF based wipes, exerting a greater push towards these materials. These factors require attention in order to ensure that market competition is not distorted.

Finally, the wet wipe material market sits amidst a broader global shift towards non-synthetic based fibres across the apparel and textiles industries. Whilst the price of oil plays a key role in the fibre market, there is also growing awareness across the globe of the need for more responsible consumption of resources. Lyocell and viscose are both plant-based fibres with regional as well as global production chains. The impacts which lyocell and viscose production have on the environment differ according to their manufacturing processes. Consideration needs to be given to both the sourcing of raw materials as well as the management of industrial processes if production of these materials increases.

6.0 Conclusion 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**.

6.1 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

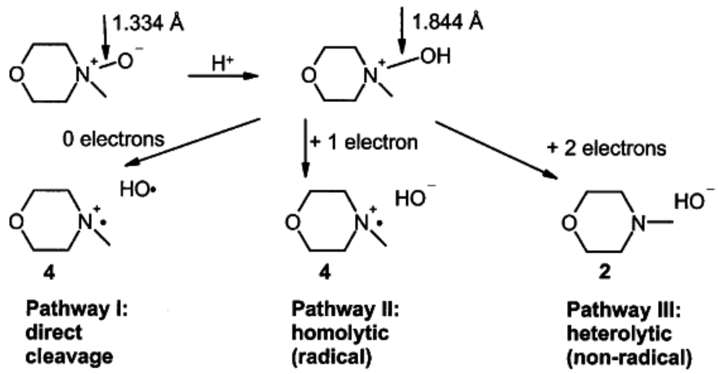
altogether from a reliance on the definition of plastic and towards a set of clear single-use product definitions in respect of all product categories to be regulated under the Directive, irrespective of material.

Appendix

A.1.0 Lyocell Process 'Side Reactions'

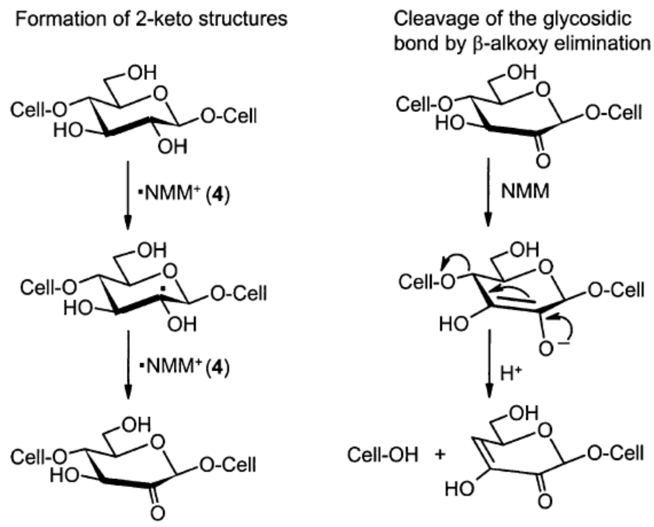
Side reactions during the process of creating lyocell are the result of the degradation of the NMMO, which is most commonly activated by the presence of a proton (hydrogen atom). The N – O bond is then broken. The most likely pathways are the homolytic and heterolytic (direct cleavage is very unlikely). The distinction is needed as the effect on cellulose is different for the homolytic and heterolytic process. The pathways are shown in Figure 12.

Figure 12: Degradation of NMMO



First considering the homolytic pathway, this results in the chemical changes as shown in Figure 13**Error! Reference source not found.**.

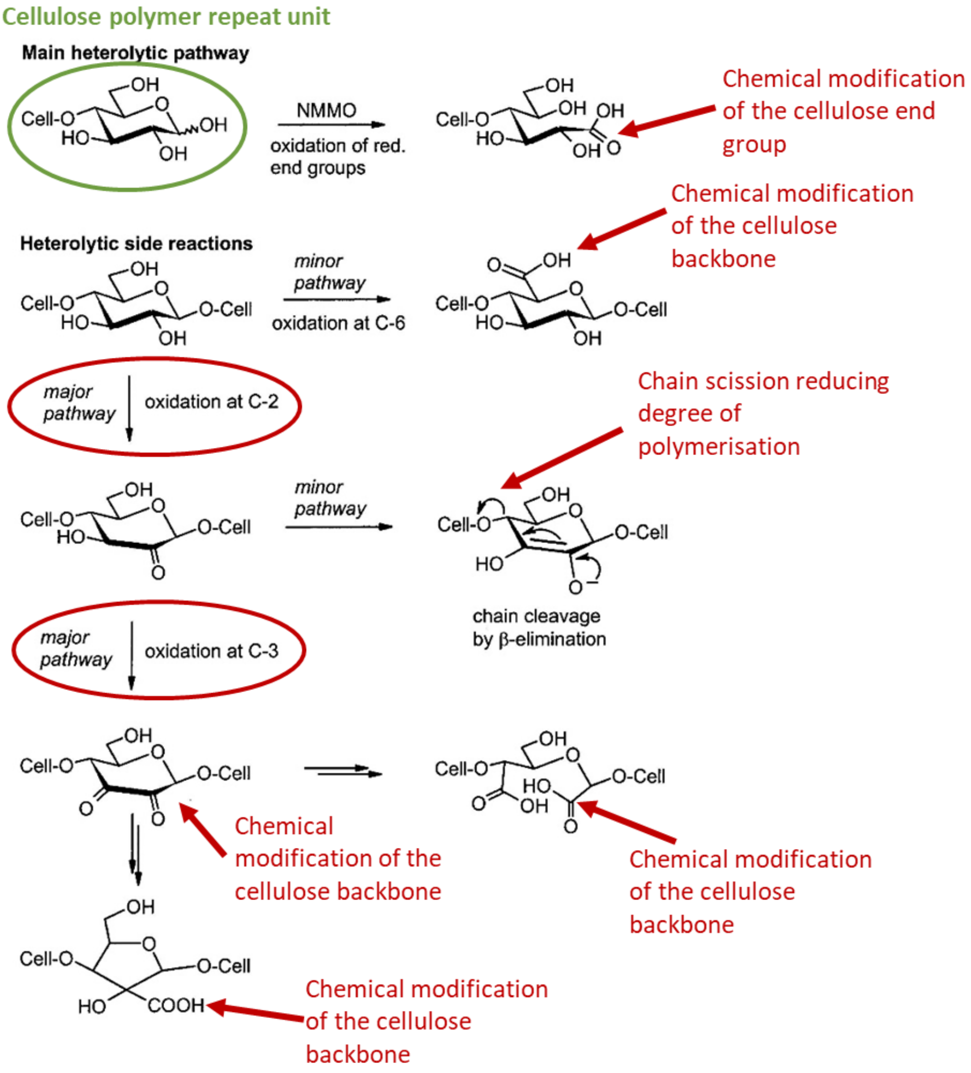
Figure 13: Chain scission caused by homolytic reactions



Here, the cellulose chain has been modified such that a keto group has been introduced into the backbone of the polymer structure. This leads to chain scission and the reduction in degree of polymerisation. The literature states that without stabilisers, the degree of polymerisation can be reduced by around 35% depending on conditions.

The reactions caused by the heterolytic pathway differ, as more reactions can occur at different points in the cellulose chain. The heterolytic reactions include oxidation of the end groups as well as oxidation in the backbone of the polymer. The reactions are shown in Figure 14[114] As can be seen from the reaction pathways, there is the potential for both chain scission and additional oxidation resulting in a variety of chemical modifications. It should be noted that the chain scission resulting from heterolytic reactions is negligible when compared to homolytic.

Figure 14: Chemical modifications of cellulose caused by heterolytic degradation of NMMO



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[114] These are not the only reactions that can occur