Open-Bio
Opening bio-based markets via standards, labelling and procurement

Work package 3
Bio-based content and sustainability impacts

Deliverable N° 3.5:
A methodology for the indirect assessment of the renewability of bio-based products

Public

Version: 1
York, 20/10/2016

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The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° KBBE/FP7EN/613677.

Table of content

1 Summary ... 8
2 Introduction ... 10
3 Scope of the test method ... 12
4 Principle ... 13
5 Terms and definitions ... 19
6 General manufacturing and feedstock considerations ... 22
6.1 Design and development ... 22
6.1.1 Incorporating environmental aspects into product design ... 22
6.1.2 Components ... 23
6.2 Raw material selection and bio-based content ... 23
6.2.1 Feedstock choice and declaration ... 24
6.2.2 Bio-based content ... 24
6.2.3 Feedstock sustainability ... 25
6.3 Considerations for the manufacturing processes ... 25
6.3.1 Processes ... 26
6.3.2 Waste ... 26
6.3.3 Packaging ... 27
7 Product use (and reuse) phase ... 28
7.1 Use ... 28
7.1.1 Ecodesign ... 28
7.1.2 Fit for purpose ... 29
7.1.3 Business model ... 29
7.2 Reuse ... 29
7.2.1 Optimal lifespan (including repair) ... 30
7.2.2 Disassembly ... 31
7.2.3 Remanufacture ... 31
7.2.4 Reconditioning ... 32
8 End-of-life requirements ... 33
8.1 Recycling ... 33
8.1.1 Mechanical (physical) recycling criteria ... 34
8.1.2 Feedstock (chemical) recycling criteria ... 35
8.1.3 Organic (biological) recycling ... 36
8.2 Alternatives to recycling ... 37
8.2.1 Energy recovery ... 37
8.2.2 Total biodegradation in the environment ... 38
9 Reporting of recirculation characteristics ... 40
9.1 Reporting ... 40
9.1.1 Claims ... 40
9.1.2 Self-assessment ... 41

9.1.3 Communication 43
9.2 Case studies 46
9.2.1 Remanufactured casings 46
9.2.2 Mechanically recyclable PET packaging 47
9.2.3 Compostable PLA composite 53
9.2.4 Surfactant based domestic cleaning product 58
9.2.5 Chainsaw lubricant 60
9.2.6 Bio-based solvents 62
9.2.7 Multi-component product: carpet tiles 63
10 Feedback and recommendations 71
10.1 Open-Bio consortium feedback 71
10.2 Advisory partners and stakeholder feedback 72
10.3 CEN/TC 411 feedback 72
10.4 Ambitions towards the sustainability of bio-based products 73
11 Relevant initiatives and legislation 75
11.1 European initiatives 75
11.1.1 Registration, Evaluation, Authorisation & restriction of Chemicals (REACH) ...75
11.1.2 Critical raw materials 76
11.1.3 The bio-based product market 77
11.1.4 Waste framework directive 78
11.1.5 Ecodesign 78
11.1.6 The circular economy 80
12 The language of bio-based product recirculation 81
12.1 Current usage of the term renewable 81
12.2 Open-Bio definitions of renewability and related terms 81
13 Conclusion 84
14 Attempted calculation methodology 88
14.1 Explanation of the calculation methodology 88
14.1.1 Basis of calculation 88
14.1.2 Calculation and assessment 92
14.2 Examples of the recirculation calculation 93
14.2.1 Bio-based PET film 93
14.2.2 PET bottle with PP cap and label 95
14.2.3 Chemical recycling of PLA cutlery 99
14.2.4 Biodegradable food container 103
15 List of standards 111
16 References 114

List of Figures

Figure 3-1 Product life cycle phases with recirculation loops indicated. 12
Figure 4-1 Product recirculation through examples of reuse, recycle, or feedstock renewal. 14
Figure 4-2 Schematic of a recirculated product‘s life cycle with different end-of-life treatments required for different components. The scope of different standards is also indicated. 16
Figure 4-3 Decision flow chart for bio-based products designed to recirculate (for every disassembled part). 17
Figure 4-4 The relationship between this work and other topics covered in Open-Bio and CEN/TC 411. 18
Figure 7-1 Reuse and recycling hierarchy (adapted from BS 8887-2). Assembly is not required for articles consisting of a single component. Recirculation routes fall within the shaded area. 30
Figure 9-1 Use of standards, test methods and communication templates to supply information on product recirculation. 41
Figure 9-2 The chemical structure of PET, with bio-based atoms circled in green, and fossil derived atoms emphasised with red circles. 47
Figure 9-3 The hydrogenation of cardanol and subsequent polyethoxylation to give a surfactant (n = 13). 58
Figure 9-4 Dimethyl isosorbide (left) and the ketal of acetone with glycerol, solketal (right), with fossil derived atoms in red. 63
Figure 12-1. The composition of articles. 81
Figure 12-2. Hierarchy of renewability definitions. 82
Figure 14-1 Recirculation requires substances to be treatable at end-of-life and either bio-based or alternatively made of other renewable feedstocks. 91
Figure 14-2 Chemical recycling recirculation scheme of bio-based ethylene glycol in PET...92
Figure 14-3 Plastic bottles with full wrap shrink labels. 96
Figure 14-4 A schematic of the allocation process for allocating the maximum recirculation in biodegradation processes. 104

List of Tables

Table 4-1 Recirculation strategies. 14
Table 6-1 Standardised bio-based content requirements for different categories of products. 25
Table 9-1 Blank data table for self-assessment of recirculation calculations. 42
Table 9-2 Reporting template for B2B communication of recirculation characteristics. 44
Table 9-3 End-of-life process selection justifications for each component. 45
Table 9-4 The use of claims in a B2C context. 46
Table 9-5 Information regarding the life cycle of PET. 47
Table 9-6 Self-assessment of a mechanically recyclable item of PET packaging 50
Table 9-7 Material balance data describing PET production (grey atoms are not present in the final product. 50
Table 9-8 Reporting template completed for PET packaging. 52
Table 9-9 End-of-life process selection for the example of PET packaging. 52
Table 9-10 Self-assessment of the recirculation of a PLA lined paper cup (mass scaled to represent a 1 kilogram batch). 56
Table 9-11 Reporting template for B2B communication of the recirculation characteristics of a PLA lined paper cup. 57
Table 9-12 End-of-life process selection justifications for a PLA lined paper cup. 57
Table 9-13 A self-assessment failing to demonstrate the recirculation of a partially bio-based surfactant made from fossil derived reactants. 59
Table 9-14 Self-assessment of lubricant recirculation. 60
Table 9-15 Reporting template for B2B communication of the recirculation characteristics of a lubricant. 61
Table 9-16 End-of-life process selection for a lubricant. 62
Table 9-17 Bio-based solvent characteristics relevant to recirculation 63
Table 9-18 Carpet tile self-assessment of recirculation. 64
Table 9-19 Reporting template for the B2B communication of the recirculation characteristics of a carpet tile. 67
Table 9-20 End-of-life process selection justifications for the bitumen backing component of a carpet tile. 69
Table 9-21 End-of-life process selection for carpet fibres. 69
Table 9-22 End-of-life process selection for a carpet tile adhesive. 70
Table 11-1 REACH substance data requirements. 75
Table 11-2 Bio-based product standards produced by CEN/TC 411 (as of September 2016). 77
Table 14-1 Recirculation calculation data for a PET product. 94
Table 14-2 Reporting template for a PET film. 95
Table 14-3 Component parts of a plastic bottle by mass. 96
Table 14-4 Recirculation calculation data for an inadequately designed PET bottle product. 97
Table 14-5 Recirculation calculation data for an improved PET bottle design. 98

Table 14-6 Communication of a PET bottle recirculation characteristics (with improved design). 99
Table 14-7 Composition of the PLA composite material (per 100 kg). 99
Table 14-8 Recirculation calculation data for a PLA composite: (1) PLA ingredient. 100
Table 14-9 Recirculation calculation data for a PLA composite: (2) inorganic ingredient. ...101
Table 14-10 Reporting template for a PLA composite suitable for chemical recycling. 102
Table 14-11 Incorrect recirculation calculation data for a PLA composite. 103
Table 14-12 Material composition of the component parts of a food container (per 100 kg mass basis). 104
Table 14-13 Recirculation calculation data for a wheat straw bowl. 107
Table 14-14 Recirculation calculation data for a recycled PET food container lid. 108
Table 14-15 Reporting template for a biodegradable food container...................................109
Table 14-16 Recirculation calculation data for a biodegradable food container (bowl and lid). 110

1 Summary

Application of standards, certification schemes and labels has positive long-term effects on the overall development of the European bio-based product market. Good product information that presents correct claims to industry and public procurers is vital for the usage of these new products. Ensuring the sustainable sourcing of raw materials and the effective measurement of bio-based content are important additional steps towards securing public confidence. A clear indication of the (comparative) functionality and optimal possible end-of-life options needs to underline the positive impact of bio-based products compared to regular products.

The Open-Bio project (www.open-bio.eu) aims at increasing the uptake speed of standards, labels and harmonized product information lists for bio-based products. It covers research into direct and indirect bio-based content methods, biodegradability, and ecotoxicity tests. Working with European standardisation committee CEN/TC 411 (http://www.biobasedeconomy.eu/standardisation/cen-tc411) the goal is to translate results from the Open-BIO project into European standards and product information lists. These will also form the basis for a database cataloguing bio-based products. A label will be developed in order to clearly distinguish bio-based products on the basis of the functionality to be described in standards. Public acceptance comes with clear and harmonized labels on products and packages.

Led by ECN (Stichting Energieonderzoek Centrum Nederland), work package 3 of the Open-Bio project addresses bio-based content and sustainability impacts. When a product is labelled ‘bio-based’, it does not necessarily guarantee that the product itself is sustainable or renewable. It is for this reason that one of the objectives of this research is to develop an indirect assessment of renewability considering both up-stream and down-stream (after use) movements of elements and molecules. With this in mind, criteria have been developed for bio-based products based on elemental recirculation, whereby the renewability of a bio-based product is then derived from its component elements. This new concept of recirculation will then be incorporated into the overall sustainability criteria being developed by Open-Bio partners.

To assist all Open-Bio partners in the task of addressing the sustainability of bio-based products and prior to developing the indirect methodology/assessment of renewability, suitable definitions for renewable molecules and renewable chemical elements have been created. Since there are several routes which the elements can take to be returned to use, these paths are clearly identified and differentiated. Conforming to these definitions would support a circular economy by discouraging feedstocks that are sourced and processed in such a way so they are not returned to use, in turn enhancing the reliability and market position of bio-based products. The preliminary work describing the definitions has been published at **Open-Bio deliverable report D3.4**.

This document describes an indirect method for the assessment of bio-based product recirculation. The test method described in this report has been developed to improve the design features of bio-based products so that they are made of the most appropriate renewable feedstocks, and are easily and effectively treated at end-of-life. This has the potential to lessen the environmental impact of plastics and other chemical products, building materials *etc*. Requirements are established as clauses, adapted from over 30 standards. These are complimented with original clauses that help establish the concept of recirculation in the design phase of a bio-based product. The test method is constructed in such a way to make it complimentary to standardisation ongoing in CEN/TC 411. Future standardisation committees in the area of ecodesign and resource efficiency may also find the results of this work helpful. Alternatively, the format of the design requirements lends itself to development into a certification scheme for bio-based products, or a series of recommendations that might form a reference document on Best Available Techniques (BAT) for material ecodesign.

2 Introduction

The aim of this task within the Open-Bio project has been achieved in two deliverables. This is the second. The first aimed to provide definitions for a 'renewable' molecule' and a 'renewable element' (as a component of a bio-based product), which was prepared and proposed to bio-based product stakeholders as part of a consortium led workshop. These definitions lead to the development of a new concept of recirculation (**Open-Bio deliverable report D3.4**).

The test method contained within is an indirect methodology by which to determine the renewability of component elements/molecules of bio-based products, building upon the results and methodologies developed in KBBPPS. It has been constructed with guidance from the Open-Bio consortium, relevant stakeholders, and CEN/TC 411. This report is divided into three sections. Part A (Chapter 3 to Chapter 8) is a proposal for a standard test method regarding the recirculation of bio-based products. The term 'recirculation' has been defined in **Open-Bio deliverable report D3.4** and replaces 'renewability' where it was used in the original project description of work. The draft test method focuses on product design concepts, thus remaining separate and distinct from practical end-of-life test methods and the analytical measurement or calculation of bio-based content, and is intended to be considered as a complimentary bridge between these topics. Part B contains recommendations on how to communicate recirculation (Chapter 9 and Chapter 14) and the feedback gathered on the topic is also reviewed (Chapter 10). Part C (Chapter 11 and Chapter 12) presents the background research gathered on European directives (Chapter 11), and a summary of **Open-Bio deliverable report D3.4** (Chapter 12).

Part A: Test Method Regarding Design for the Recirculation of Bio-Based Products

3 Scope of the test method

This draft test method may be applied to all products that have a measureable bio-based content according to a relevant standard, *e.g.* **prEN 16640** for bio-based carbon content or a calculated minimum bio-based content above 0%, *e.g.* **EN 16785-1** and **prEN 16785-2**. This is a pre-requisite for the application of this draft test method. In particular, bio-based lubricants, plastics, solvents and surfactants are representative products. Bio-based solvents and bio-based lubricants shall have at least 25% bio-based carbon content according to the respective standards (**CEN/TS 16766** and **prEN 16807**).

This methodology specifies requirements by which a bio-based product can be designed to be, and described as, recirculated in the context of a bio-based economy (and in anticipation of a circular economy). The precise description depends on the end-of-life options available, with bio-based products either reusable by remanufacture, recyclable, or the feedstock renewed through organic recycling (Figure 3-1).

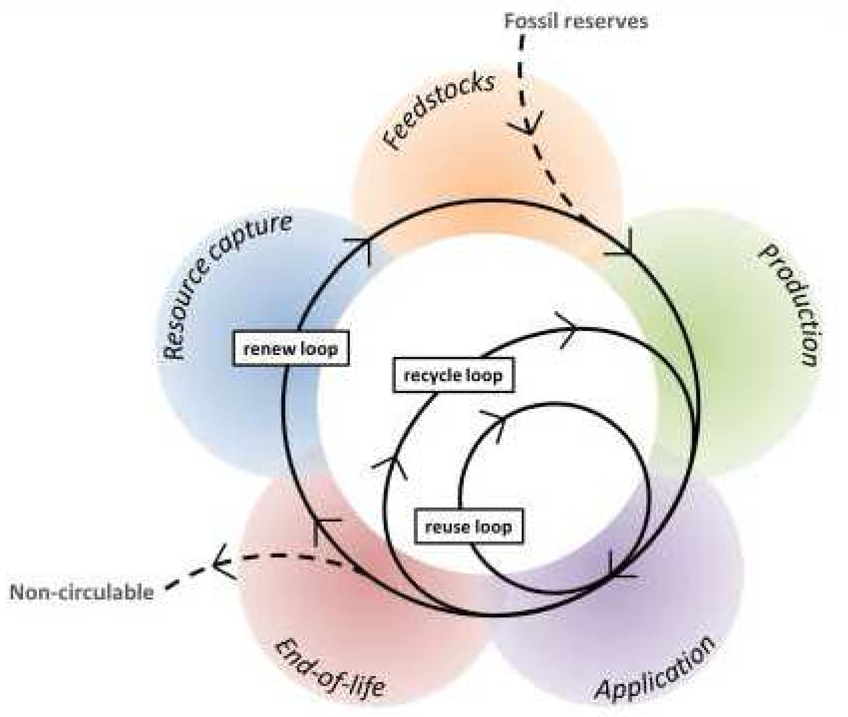

Figure 3-1 Product life cycle phases with recirculation loops indicated.

4 Principle

Increasing concerns over waste and pollution (as well as feedstock security) means manufacturers are under increasing accountability for their products post-application. The design of a product shall ideally maximise the possibility of realising the most efficient process of manufacturing (including the assembly of component parts) and the most appropriate waste management approach of the sort described in **BS 8887-1:2006**. This is the underlying principle behind this draft test method. The chosen manufacturing route should also reduce waste to a practical minimum. The product shall be designed to support the disassembly of any component parts in order to assist with end-of-life options. When a product consists of multiple parts with different end-of-life pathways, disassembly must be achievable with the primary purpose of separating the component parts so that they can enter the correct waste streams without cross-contamination. Single component products equally apply to this methodology but without the need for disassembly. The intended end-of-life pathway of a product or component, and its design for maximum functioning lifetime must not unnecessarily affect the performance of the entire article.

Herein a method is defined for first establishing, and then reporting the recirculation of a bio-based product. It is intended to be used by the manufacturers of bio-based products in order to demonstrate renewable feedstocks are being used efficiently without product redundancy and waste. The means to achieve the successful recirculation of bio-based products comes down to the design phase. The measures described by this draft test method specify design and manufacturing requirements for the purpose of facilitating end-of-life options. The material contained within a bio-based product is hence returned back to a usable state, without unnecessary waste. Three categories of end-of-life options (reuse, recycle, and renew) are defined. Adherence to at least one of these three categories shall indicate it is possible to recirculate the product (Figure 4-1). The final claim that can be made to describe the product is limited to recirculation, not specifically reusable, recyclable, renewable, or biodegradable, bio-based, *etc*. Other standards must be correctly applied independently of this draft test method in those instances.

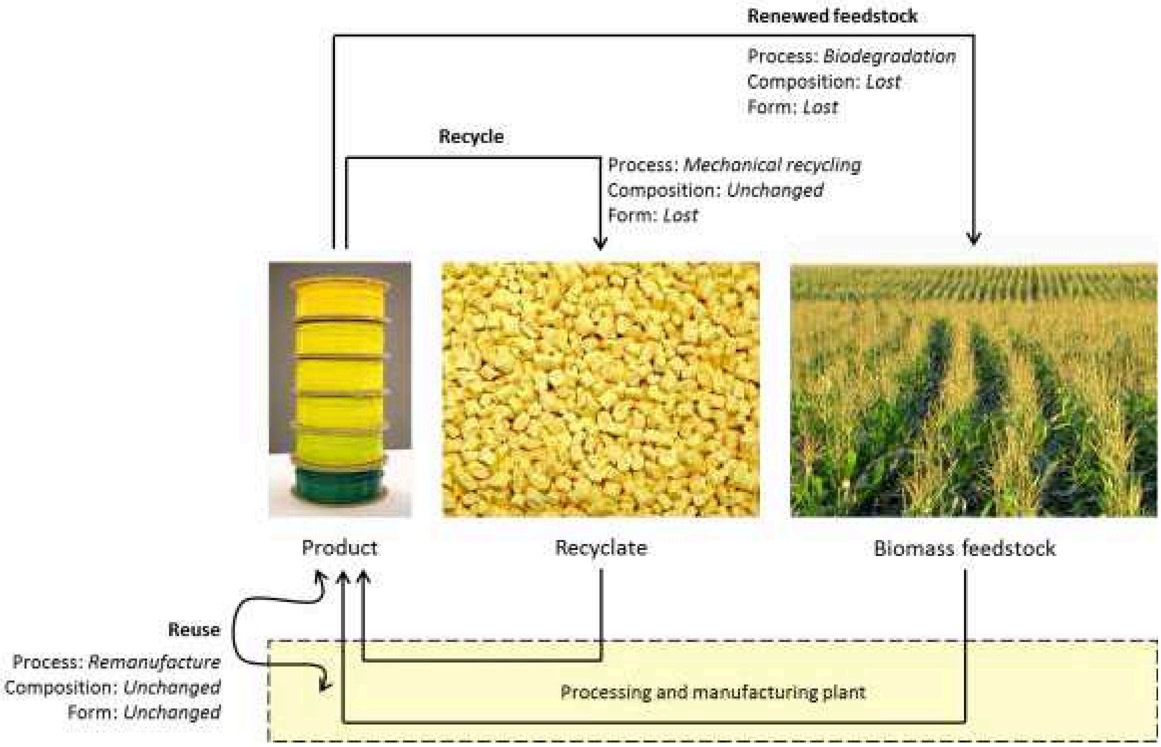

Figure 4-1 Product recirculation through examples of reuse, recycle, or feedstock renewal.

Different options for recirculating products are tabulated below (Table 4-1). Re-use has a number of different forms (see section 7.2). Remanufacture can be considered equivalent to closed loop recycling, but preferable because it is more direct and retains the form of the article or component part (Figure 4-1). Other forms of reuse (extended lifespan through repair, and reconditioning) are part of design for maximum resource efficiency but do not constitute recirculation alone. Biodegradation of fossil derived products or component parts is not considered as recirculation because there is no link between the feedstock and the material at end-of-life on a reasonable timescale. Also note that recyclable products (closed loop or open loop) containing recycled material can be considered as recirculated. This is because they do not cause a depletion of feedstocks for their manufacture and are designed to prevent waste. Products made from fossil derived feedstocks that are in turn recyclable (*e.g.* conventional PET) do not qualify as recirculated because of the net resource loss incurred. This methodology is only applied to products with a guaranteed bio-based content above 0%.

Table 4-1 Recirculation strategies.

	Made completely from biomass*	**Made from recycled material, or partially bio-based**	**Made from primary fossil feedstocks**
Reuse (extended product lifespan, repair, and reconditioning)	*This does not constitute recirculation on its own. It is required in this draft test method to demonstrate the maximum benefit of the material resource has been obtained, in addition to satisfactory end-of-life options as shown in the rows below.*		
Reuse (remanufacture)	Recirculated	Recirculated	*n/a (closed loop)*
Designed for closed loop recycling	Recirculated	Recirculated	*n/a (closed loop)*
Recyclable (open loop) because of materials chosen	Recirculated	Recirculated	No recirculation
Designed to biodegrade	Recirculated	No recirculation	No recirculation
Energy recovery	Recirculated**	No recirculation	No recirculation
No end-of-life considerations in design phase	No recirculation	No recirculation	No recirculation

*Including other directly renewed feedstocks (*e.g.* CO_2).
**Only acceptable if other end-of-life options are proven to be unworkable.

The product is considered as recirculated if the material balance (on a carbon and total mass basis as necessary), shows that there is not an unwarranted loss of resource and the value of that resource is retained to the extent that instead of waste, new products are created at end-of-life. The definition of resource is limited to the manufacturing feedstocks incorporated into the final product under the scope of this draft test method. If all the components of a product can be reused in remanufacturing, recycled, or successfully biodegraded in the case of any bio-based parts, it is fully recirculated. This is proposed in a way that is complementary to existing standards (Figure 4-2). Products without parts do not require disassembly, and can be treated in the same way that a single component of a more complex article would be.

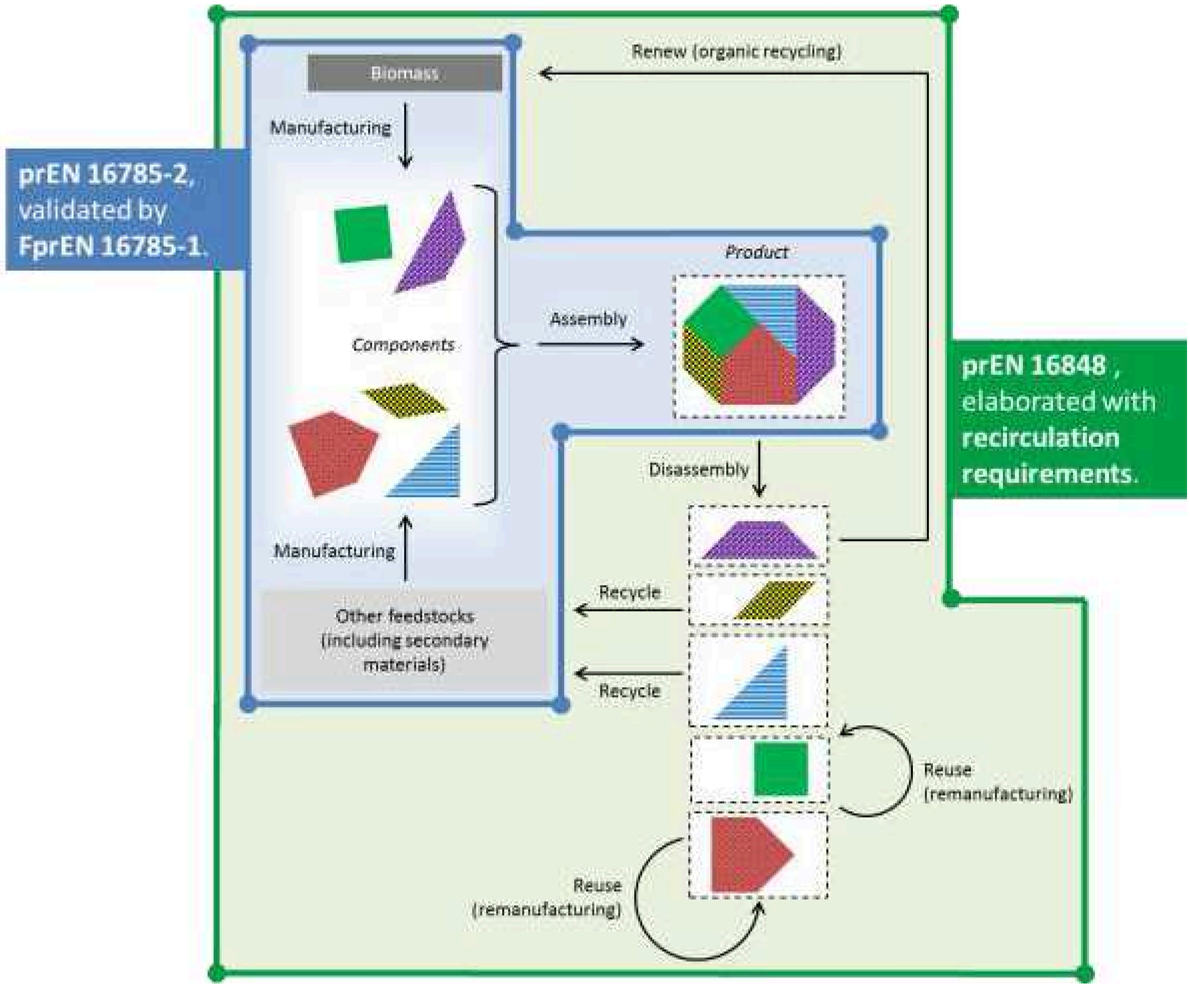

Figure 4-2 Schematic of a recirculated product's life cycle with different end-of-life treatments required for different components. The scope of different standards is also indicated.

More than one end-of-life treatment may be applicable, and the design of the product or component part will have a role in which option is preferable, as does the function and use of the product. The end-of-life practices that best retain the form and function of the product are prioritised as established in the following flow chart (Figure 4-3). Details are provided subsequently. Producers are expected to justify product design choices should they come to restrict the use of secondary materials and biomass feedstocks, or encourage less preferable end-of-life options. Materials in the product with different end-of-life options must be easily separated. Life cycle assessment (LCA) can be used as part of the justification, as can the functionality (*e.g*. food packaging limiting applications to a single use) in order to establish the most suitable end-of-life process. The end-of-life options are justified in a reporting template, as found in Chapter 9, in the same order as which they appear in Figure 4-3.

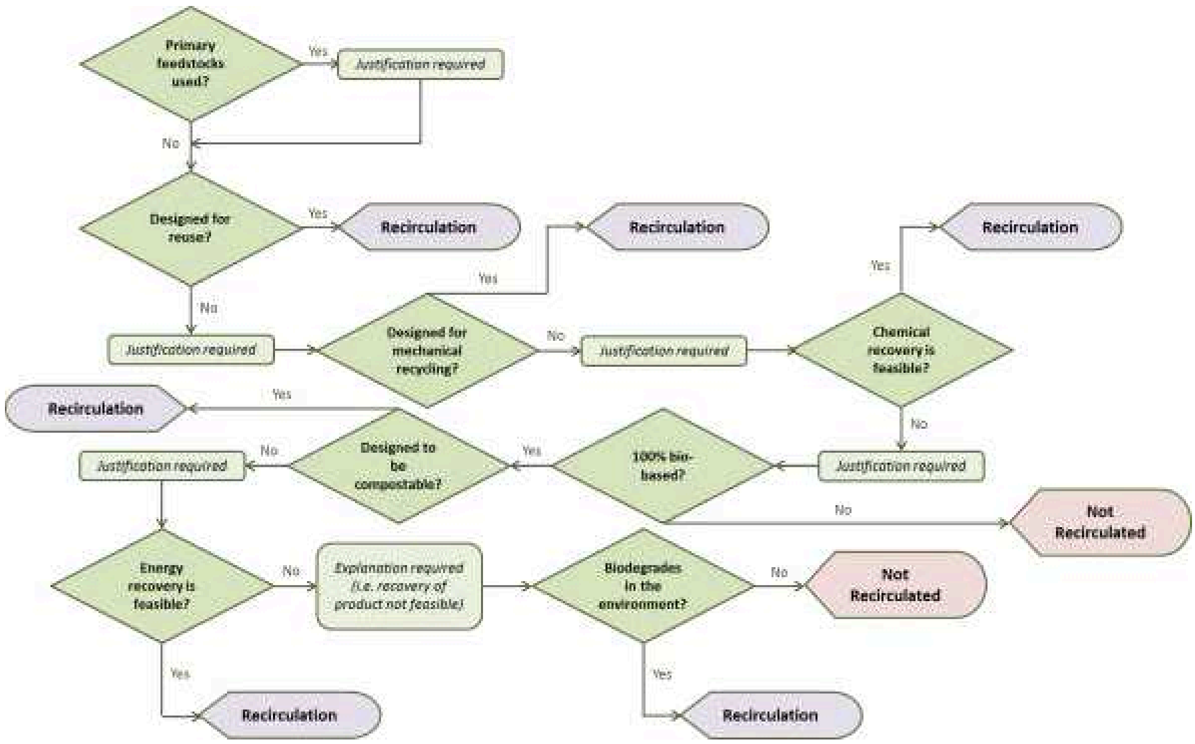

Figure 4-3 Decision flow chart for bio-based products designed to recirculate (for every disassembled part).

For example, a paper cup with an inner polyethylene film lining is made of two recyclable materials. However the article is not designed for reuse, recycling, or biodegradation because the different materials are not separable for their specific recycling processes. A polylactic acid film is compostable, as is the paper of the cup, and so the product has now been designed for recirculation. Even though perhaps the new end-of-life option (biodegradation) is less preferable than mechanical recycling that would preserve the chemical composition of the materials, it is now actually a workable solution. Biodegradable products must be 100% bio-based, or otherwise made from captured carbon dioxide in another way. If not a net increase in carbon emissions occurs, which also signifies a loss of resource.

This draft test method is not a replacement for a full LCA. Life cycle assessment measures the impact of emissions relating to a product or process. The purpose of this methodology is to assist the design and manufacturing of bio-based products only considering the material contained within them. The potential to maintain the value of material resources is maximised, as required by material ecodesign principles and circular economy initiatives. The concept of recirculation bridges the concepts of bio-based content and end-of-life options, two major areas of development in the current standardisation efforts of CEN/TC 411 (bio-based products). Both topics are being researched as part of the Open-Bio project independently of this work. Recirculation embraces related LCA (**EN 16760**) and sustainability criteria (**EN 16751**) standards to an extent but is only indirectly related to these topics. Integration with relevant terminology and recommendations for labelling and business-to-business (B2B) communications has also been sought (Figure 4-4). Recirculation is not to be used to replace claims and declarations of bio-based content or end-of-life options, but only as an additional conclusion to supplement these claims in reporting. It may even be the case that the common confusion over the use of the prefix 'bio-' can be helped in some way by using 'recirculation' instead as a different way to communicate the beneficial characteristics of certain bio-based products.

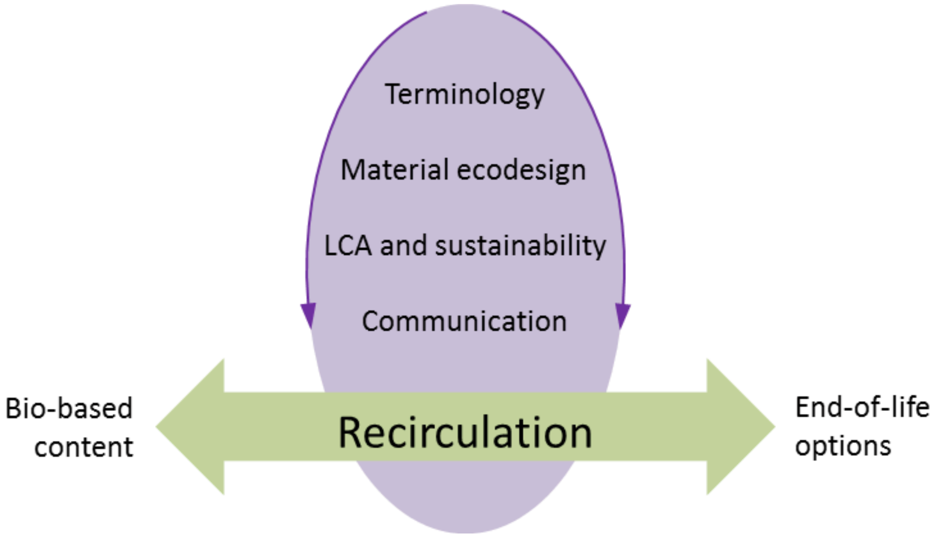

Figure 4-4 The relationship between this work and other topics covered in Open-Bio and CEN/TC 411.

As much as possible, definitions are used from existing standards or instead from the reports of the KBBPPS pre-normative European research project and the Open-Bio co-normative European research project. Furthermore, all practices and procedures referred to in this draft test method shall be conducted as specified in existing standards as noted. Claims of recycled content, biodegradability, and the European standards that define them, are independent of this test method.

5 Terms and definitions

The terms and definitions listed below originate from European (CEN) or British (BSI) standards, or alternatively other reports from the Open-Bio co-normative European research project as indicated. In some cases the definitions used here are more specialised or have a different focus. The only conflict is in the definition of 'renewable', which has previously been taken to refer to feedstocks. Here, this term is extended to consider the product.

Article. An object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition [EC 2008].

Assembly (BS 8887-2:2009). Collection of components fitted together in such a way as to be considered as a single unit for subsequent operations or use.

Bio-based (EN 16575:2014). Derived from biomass

Bio-based carbon (EN 16575:2014). Carbon derived from biomass

Bio-based carbon content (EN 16575:2014). Fraction of carbon derived from biomass in a product.

Bio-based content (EN 16575:2014). Fraction of a product that is derived from biomass.

Bio-based product (EN 16575:2014). Product wholly or partly derived from biomass.

Bio-degradation (EN 16575:2014). Degradation caused by biological activity, *e.g.* by enzymatic action, leading to a significant change in the chemical structure of a product.

Biomass (EN 16575:2014). Material of biological action excluding material embedded in geological formations and/or fossilized.

Component (BS 8887-2:2009). Part or small assembly of parts used as part of a larger assembly.

Disassembly (BS 8887-2:2009). Non-destructive taking apart of an assembled product into constituent materials and/or components.

End-of-life (BS 8887-2:2009). Point at which a product or component is taken out of use.

Energy recovery (BS 8887-2:2009). Production of useful energy from waste through direct and controlled combustion.

Feedstock recycling (EN 13437:2003). Recycling whereby typically organic materials are converted into low-molecular weight products which are reused for the production of other materials or in other chemical/production processes.

Mass balance (EN 16575:2014). Relationship between input and output of a specific substance within a system in which the output from the system cannot exceed the input of the system.

Part (BS 8887-2:2009). Individual piece of shaped material or set of pieces permanently connected together to be used in an assembly.

Recirculated (Open-Bio deliverable report D3.4). Returned to use within a certain timeframe by an anthropogenic process and/or a natural process. Recirculated includes the terms renewable, reusable and recyclable.

Recondition/refurbish (BS 8887-2:2009). Return a used product to a satisfactory working condition by rebuilding or repairing major components that are close to failure, even where there are no reported or apparent faults in those components.

Further note. According to **BS 8887-2:2009**, *reconditioning is intermediate of remanufacturing and repair, and performance can be expected to be satisfactory but inferior to the original performance.*

Reconditioning (EN 13437:2003). Necessary operations to bring a reusable packaging back into a functional state and having the same basic specification as the original packaging.

Further note. According to **EN 13437:2003**, *changes to its basic specification is covered under recycling, not reconditioning.*

Recyclable (Open-Bio deliverable report D3.4). Returned to use within a certain timeframe by an anthropogenic process.

Recycle (BS 8887-2:2009). Process waste materials for the original purpose or other purposes, excluding energy recovery.

Recycling (EN 13437:2003). Reprocessing in a production process of the waste materials for the original purpose or for other purposes including organic recycling but excluding energy recovery [Directive 94/62/EC].

Remanufacture (BS 8887-2:2009). Return a used product to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product.

Further note. According to **BS 8887-2:2009***, remanufacturing involves replacing components in order to restore the original performance.*

Renewable (Open-Bio deliverable report D3.4). Comes from renewable resources and is returned to use within a certain timeframe by a natural process.

[replaced definition, see *renewable*] **Renewable (BS 8887-2:2009).** Replenishable from natural sources, at a rate greater than consumption (applicable to materials and energy).

[replaced definition, see *renewable*] **Renewable material (EN 16575:2014).** Material that is composed of biomass and that can be continually replenished.

Repair (BS 8887-2:2009). Returning a faulty or broken product or component back to a usable state

Further note. According to **BS 8887-2:2009***, performance may be impaired after repair, which only serves the purpose of fixing a fault.*

Reusable (Open-Bio deliverable report D3.4). Returned to use within a certain timeframe without modification to the parent article or loss of performance.

[replaced definition, see *reusable*] **Reuse (BS 8887-2:2009).** Operation by which a product or its components are put back into use for the same purpose at end-of-life

Ultimate biodegradation (EN 14995:2006). Breakdown of an organic chemical compound by microorganisms in the presence of oxygen to carbon dioxide, water, and mineral salts or any other elements present (mineralization) and new biomass or in the absence of oxygen to carbon dioxide, methane, mineral salts and new biomass.

6 General manufacturing and feedstock considerations

6.1 Design and development

Requirements for the initial product design phase, leading to the feedstock choice and manufacturing process of recirculated bio-based products are addressed in this section. Relevant considerations for the latter life cycle stages of a product are listed subsequently. Adherence to the following requirements should be communicated in relevant documentation describing the article. Upon request, adherence to the following requirements shall be communicated, or an explanation given for why a requirement was not relevant, as part of B2B communications.

6.1.1 Incorporating environmental aspects into product design

a) Integrating environmental aspects into product design shall be managed and implemented according to **EN ISO 14001** and **EN ISO 14006** and **ISO/TR 14062**.
b) Design of the product shall allow for easy disassembly in accordance with relevant recirculation principles (**ISO/TR 14062**).
c) The repair of products issued with a warranty shall be made economically feasible with fast, uncomplicated and efficient disassembly. The warranty shall place the burden of correct end-of-life treatment with the supplier for any articles or component parts that are not routinely repairable. End-of-life treatments shall be consistent with a recirculation strategy defined in this draft test method. Products not issued with a warranty shall be designed for a suitable end-of-life treatment as defined in Chapter 8.
d) Disassembly of component parts with different end-of-life options shall be uncomplicated, and instruction given if not obvious by inspection.
e) When planning the conceptual design of the product, recirculation by reuse (*i.e.* remanufacture) should be prioritised above recycling in order to minimise energy use. Similarly closed loop recycling shall be prioritised above open loop recycling (downcycling) and biodegradation to preserve the inherent value of the product as much as possible. The final choice of end-of-life option shall be justified in a reporting template (see Chapter 9).
f) Periodic reviews of product performance should follow each of the product development phases of planning, conceptual design, detailed design, prototype testing, and product launch. This information can be fed back into the design process after each phase, and even after product launch to improve the effectiveness of recirculation. Based on an analysis of the environmental performance of the product, alternative approaches to the product design can be tested and possible improvements evaluated to enhance recirculation (**ISO/TR 14062**).
g) Design and production practices shall not compromise functionality aspects, especially those relating to safety and hygiene (**EN 13430**).
h) Some products are inevitably discharged into the environment as part of their function without the possibility for reuse or collection for recycling. This type of product shall

be designed to perform its intended function with as little material use as possible. These products shall also be bio-based, bio-degradable, and should be non-toxic to aquatic organisms as set out in any applicable regulations or standards. Examples include (but not limited to) hand dishwashing detergents and chainsaw lubricants, and other single use products typically issued without a warranty.

i) If a life cycle assessment (LCA) is being conducted, the procedure shall be according to **EN 16760**. Proof of recirculation is not equivalent to a LCA. The choice of feedstocks and viable end-of-life options a product is designed for should reflect the impact assesment of a LCA with unbiased cradle-to-cradle boundaries.

6.1.2 Components

a) The assembly and disassembly of components must be incorporated into the design (**BS 8887-1:2006**).
b) Minimise the parts in a product without impairing the function of the article, or the efficiency of end-of-life processing (**BS 8887-1:2006**).
c) Minimise the number of parts, the number of fixings, and join components in such a way as to facilitate easy separation (**BS 8887-1:2006**).
d) Avoid fastenings and adhesives that prevent separation (**BS 8887-1:2006**).
e) Avoid any combination of materials that will hinder mechanical recycling (*e.g.* metal inserts in plastic parts, adhesion of parts with different end-of-life pathways) (**BS 8887-1:2006**).
f) Avoid the combination of corrosive substances with aging materials (**BS 8887-1:2006**).
g) Component parts with no option to reuse, recycle (mechanically or chemically), or renew through organic recycling shall not be used unless no alternative exists. A justification is required under the requirements of Chapter 9 should this be the case.
h) A component part refers to all separable composites, materials or substances contributing to 1% or more of the total mass of the product. All such substances shall be demonstrated as possible to treat at end-of-life.

6.2 Raw material selection and bio-based content

The choice of raw materials determines the bio-based content. Determining the sustainability of products is a difficult process, and the approach presented in this draft test method is not a substitute for complete sustainability and life cycle assessments. It is instead an extension of existing bio-based content calculations (**KBBPPS deliverable report D4.6**, **prEN 16785-2**) intended to provide a link to the product design phase and end-of-life treatment. The use of biomass and recycled feedstocks is required of recirculated products. Biomass feedstocks shall be sustainable according to **EN 16751**. Note feedstock materials of fossil origin are not covered by **EN 16751**. Recycled materials are accepted only if compliant with traceability and recycled content standard **EN 15343** (or equivalent).

6.2.1 Feedstock choice and declaration

a) Minimise the impact of materials by using less material, or substituting for low environmental impact material including renewables and secondary materials (**ISO/TR 14062**).
b) Use of renewable materials shall be maximised, especially ubiquitous and abundant materials (**BS 8887-1:2006**).
c) The proportion of bio-based content in all products shall be declared according to a recognised standard (see section 6.2.2).
d) For any component parts where biomass is not a suitable feedstock, wherever possible use reclaimed or recycled materials and components that are routinely collected with a low embodied energy (**BS 8887-1:2006**).
e) If appropriate the proportion of recycled content should be reported according to **EN 15343**, **EN ISO 14021**, or equivalent.
f) The chemical structure of the feedstocks and intermediates will influence the optimal end-of-life option for the product. Substances that can be recirculated by chemical recycling (*e.g.* easily hydrolysed polyesters) should be considered.
g) Where possible, materials shall be selected so that each component within the product has a similar component lifespan, therefore avoiding the premature disposal of components in acceptable working condition (**BS 8887-1:2006**).
h) The choice of materials shall not negatively impact the end-of-life handling and treatment of products (*e.g.* recycling, **EN 13430**).
i) When using secondary (recycled) feedstocks, variation in composition shall not adversely affect product functionality or end-of-life handling and treatment (**EN 13430**).
j) Combinations of materials in component parts intended for mechanical recycling shall be compatible with recycling technologies (**EN 13430**).
k) Avoid pigmented plastics to help recycling of the product (**BS 8887-1:2006**).
l) Protect against soiling and corrosion to allow for effective recycling and a quality recyclate where relevant (**BS 8887-1:2006**).

6.2.2 Bio-based content

a) The declared bio-based content shall be reported as a guaranteed minimum value according to one or more of the following standards: **prEN 16640** (analytical bio-based carbon content), **EN 16785-1** (total bio-based content), **prEN 16785-2** (carbon and total bio-based content by calculation).
b) Where applicable, the bio-based content of the final product must meet or exceed the stipulated minimum values found in product specific standards (Table 6-1).
c) The measured or calculated bio-based carbon content and the total bio-based content shall be used in recirculation calculations and reported for business and consumer communications as appropriate (see Chapter 9).
d) Substances that will inevitably be released into the environment (*e.g.* chainsaw lubricants) shall be required to meet a stricter lower threshold of bio-based content and also be biodegradable to avoid waste and be considered as recirculated (see section

8.1). Hence the bio-based content requirements for recirculated products can be higher than for products defined as 'bio-based'.

Table 6-1 Standardised bio-based content requirements for different categories of products.

Category	Minimum bio-based content		Reference
	Carbon mass basis	*Total mass basis*	
Lubricant	25%	Not measured	**prEN 16807**
Plastic	No minimum	Not measured*	**ISO 16620-2**
Solvent	25%	Not measured	**CEN/TS 16766**
Surfactant	5%	Not measured	**FprCEN/TS 17035**
Other products	No minimum	No minimum	**prEN 16640** **EN 16785-1** **prEN 16785-2**

*Preparation of **ISO 16620-4** (determination of the bio-based mass content) is at the planning stage.

6.2.3 Feedstock sustainability

a) Biomass feedstocks shall be sourced sustainability, demonstrated according to sustainability criteria (*e.g.* **NTA 8080-1**, **EN 16751** or equivalent) and compliant with a recognised chain-of-custody system for traceability (*e.g.* **NTA 8080-2**, **EN 16760** or equivalent) where possible.
b) Depending on the implementation of this draft test method, alternatively appropriate certification is also permissible in order to meet the requirement of sustainable biomass. Certification schemes shall meet the greenhouse gas emission requirements of the Renewable Energy Directive (**2009/28/EC**), as well as sustainability criteria regarding the use of land with high carbon stock and areas of high biodiversity (see *ec.europa.eu/energy/node/73*).
c) The downstream sustainability of biomass once incorporated into the product should also be considered when integrating environmental aspects into product design. Relevant criteria can be found in **EN 16751**. Where possible sustainability criteria shall be applied to the product, and not just the feedstock, unless justified.
d) Reporting the sustainability of the biomass feedstock should be conducted according to Annex A of **EN 16751** and for B2B communications (in summary) according to Annex A of **FprEN 16848**.
e) The final product shall not be claimed to be sustainable as a result of applying this draft test method, or **EN 16751**. Any claims relating to sustainability should be made with reference to other relevant standards (*e.g.* **EN ISO 14020**).

6.3 Considerations for the manufacturing processes

Recirculation demands that the material a product comprises of is not wasted. The following requirements are provided to ensure no unnecessary waste is created outside of the material incorporated into the recirculated product. Any required packaging must conform to the legal requirements set out in the packaging waste directive **94/62/EC**, and as amended by subsequent directives originating from the European circular economy package.

Compliance can be achieved through the relevant standards for packaging (*e.g.* **EN 13427**). Sourcing of packaging material shall be guided by the following principles (section 6.3.3), but complete adherence to this draft test method is not required for any packaging used for the recirculated product. If the product itself is packaging then all the requirements of this draft test method shall apply.

6.3.1 Processes

The following aspects shall be included in design considerations unless marked with an asterisk (*):

a) Resource efficiency shall be a criteria in the planning of the process and product design, consistent with Europe 2020 strategy for economic growth and a resource efficient Europe (see *ec.europa.eu/resource-efficient-europe*).
b) *Manufacturing precision should be high to improve material economy (**BS 8887-1:2006**).
c) *Use net shape forming processes where possible (a technique of producing articles in the correct final form that minimises or eliminates the need for surface finishes, such as grinding) (**BS 8887-1:2006**).
d) *The individual parts should be easy to assemble (**BS 8887-1:2006**).
e) *Design for maximum application of cleaner production methods, avoiding hazardous chemicals and auxiliary materials and substances. Design decisions must be based on multiple relevant criteria and not based on a single narrow objective (**ISO/TR 14062**).
f) *End-of-pipe waste treatments should be replaced by the inherent elimination of pollution through considered process design (**ISO/TR 14062**).
g) A material balance approach shall be used to monitor all material input and output during the manufacturing process. Additionally biomass shall be traced according to the material balance approach in **prEN 16785-2** for subsequent use in recirculation calculations. The carbon material balance (total carbon and bio-based carbon) of the process shall be calculated for synthetic chemical processes.
h) *A carbon material balance is not equivalent or equatable to greenhouse gas (GHG) emissions. Accounting of GHG emissions shall be conducted in line with **EN 16760** and **EN 16751** and the requirements therein should it be required for reporting purposes.

**Clauses marked with an asterisk are not directly related to design for recirculation and are optional.*

6.3.2 Waste

The following aspects shall be included in design considerations unless marked with an asterisk (*):

a) *Maximise capture and reuse of materials arising as manufacturing waste (**BS 8887-1:2006**).

b) Material balance calculations of the sort described in **prEN 16785-2** should be used to identify the quantity of waste resulting from manufacturing and efforts made to reduce the quantity of waste through redesign of the product or process if appropriate.
c) *Avoid materials and chemicals that are hazardous, pre-treating any unavoidable hazardous waste (**BS 8887-1:2006**).
d) *Maximise energy efficiency and the capture and use of waste energy (**BS 8887-1:2006**).
e) *Minimise water use and where needed maximise the reuse of water (**BS 8887-1:2006**).
f) *Reduce land use, especially with respect to infrastructure and material production (**ISO/TR 14062**).

**Clauses marked with an asterisk are not directly related to design for recirculation and are optional.*

6.3.3 Packaging

a) The packaging should only contain the minimum amount of material necessary without impairing its function (**EN 13427**, citing **EN 13428**).
b) Dangerous substances (including lead, cadmium, chromium, and mercury) should be minimised (**EN 13427**, citing **EN 13428**).
c) Each component of packaging shall be reusable (**EN 13427**, citing **EN 13429**), recoverable by mechanical recycling (**EN 13427**, citing **EN 13429**), or organically renewable (**EN 13427**, citing **EN 13432**). Additionally, biodegradable packaging shall meet the bio-based content requirements of section 8.1.3. Compliance shall be ascertained through a declaration made by the supplier.
d) The packaging must be easily emptied of its contents and the different component parts of the packaging designed to be separated by the user prior to collection and end-of-life treatment. It is recommended that for materials that are not easily recognisable, a form of identification is used relevant to target user(s) (**EN 13430**).

7 Product use (and reuse) phase

7.1 Use

Functionality should not be impaired by end-of-life design considerations. An optimum balance between functionality, recirculation and product lifespan is required by design. Ecodesign considerations (from the perspective of energy, **EN ISO 14006**, and materials, see *www.eceee.org/ecodesign/Horizontal-matters/Resource_efficiency*) should be used to guide and improve functionality aspects of products so that they are fit-for-purpose, yet embrace environmental aspects to their design.

Because of the diversity of product functionality it is not possible to specifically address functionality aspects for every type of product within this draft test method. To communicate whether a product is fit for purpose, apply recognised environmental labelling and declaration standards (**EN ISO 14020**) and adhere to the product specific requirements of ecodesign (**EN ISO 14006**, European directive **2009/125/EC**) and EU Ecolabel (European regulation **66/2010**) where available. There are also additional performance requirements for bio-based solvents (**CEN/TS 16766**), and bio-based lubricants must be shown as 'fit for purpose' using general lubricant standards (**prEN 16807**). To find information helpful in assisting sustainable procurement refer to **BS 8903** or equivalent.

7.1.1 Ecodesign

The following aspects shall be included in design considerations unless marked with an asterisk (*):

a) *Maximise energy efficiency by firstly considering the total energy use throughout the product's life cycle and identifying where a reduction of energy use can be gained by use of low impact energy sources or from a greater energy efficiency of the product achieved through improved design (**ISO/TR 14062**).
b) Products also need to be designed to optimise longevity and usefulness, considering durability, and the ability to repair the product (**ISO/TR 14062**).
c) Maximise serviceability and the potential to upgrade the product where appropriate (**BS 8887-1:2006**).
d) *Minimise energy and water requirements of the product during its use (**BS 8887-1:2006**).
e) *Product designers shall review the latest ecodesign legislation if applicable regulation exists. Guidelines for incorporating ecodesign should follow the recommendations found in **EN ISO 14006**.

**Clauses marked with an asterisk are not directly related to design for recirculation.*

7.1.2 Fit for purpose

The following aspects shall be included in design considerations unless marked with an asterisk (*):

a) Products shall be designed to fulfil the intended function to an acceptable level of performance with the least possible material expended (resource efficiency). Proof of which shall be demonstrated according to any relevant performance standards if requested as part of B2B communications. All legal requirements regarding product safety and function shall be met.
b) Solvents shall additionally conform to the requirements **CEN/TS 16766**.
c) Lubricants shall additionally conform to the requirements of **prEN 16807**.
d) Surfactants shall additionally conform to the requirements of **FprCEN/TS 17035**.
e) *Additional, specific environmental claims shall be made in accordance with the requirements of **EN ISO 14020** or equivalent if desired.
f) *EU Ecolabel is a voluntary labelling scheme for products and services with a low environmental impact. Product designers are encouraged to follow EU ecolabel criteria if the corresponding product category exists (see *ec.europa.eu/environment/ecolabel/products-groups-and-criteria.html*).

**Clauses marked with an asterisk are not directly related to design for recirculation.*

7.1.3 Business model

Unconventional business models shall be considered as a means of providing bio-based products and associated services to consumers whilst conserving resources. Specifically, chemical leasing shall be considered for products designed for industrial treatments, painting, cleaning, performance (*e.g.* lubricants) and other applications. Other mechanisms where consumers pay for the service provided by the product rather than on the basis of the product itself are also encouraged, and shall be considered before placing the product on the market (*for examples see https://www.ellenmacarthurfoundation.org/case-studies*).

7.2 Reuse

Reuse of a product can be achieved by disassembling the article into its component parts. This allows for repair, but in terms of reuse also remanufacturing and reconditioning are then possible. Definitions of these terms can be found in Chapter 5. Repair alone does not constitute recirculation, but instead should be considered as part of maximising the working lifespan of the product. Refurbishing is taken to mean the same as reconditioning, an intermediate level of servicing between repair and full remanufacturing (Figure 7-1). Whereas remanufacturing requires the re-assembly of the product as if new components were used, reconditioning may only require cleaning of the product and basic quality control measures. Solvent recovery by distillation is an example of reconditioning. Reconditioning also cannot be considered as an end-of-life option because it is not guaranteed to deliver equal performance indefinitely. Repair and reconditioning as methods of improving product lifespan have been incorporated into the design requirements of recirculated products wherever relevant to improve material resource efficiency.

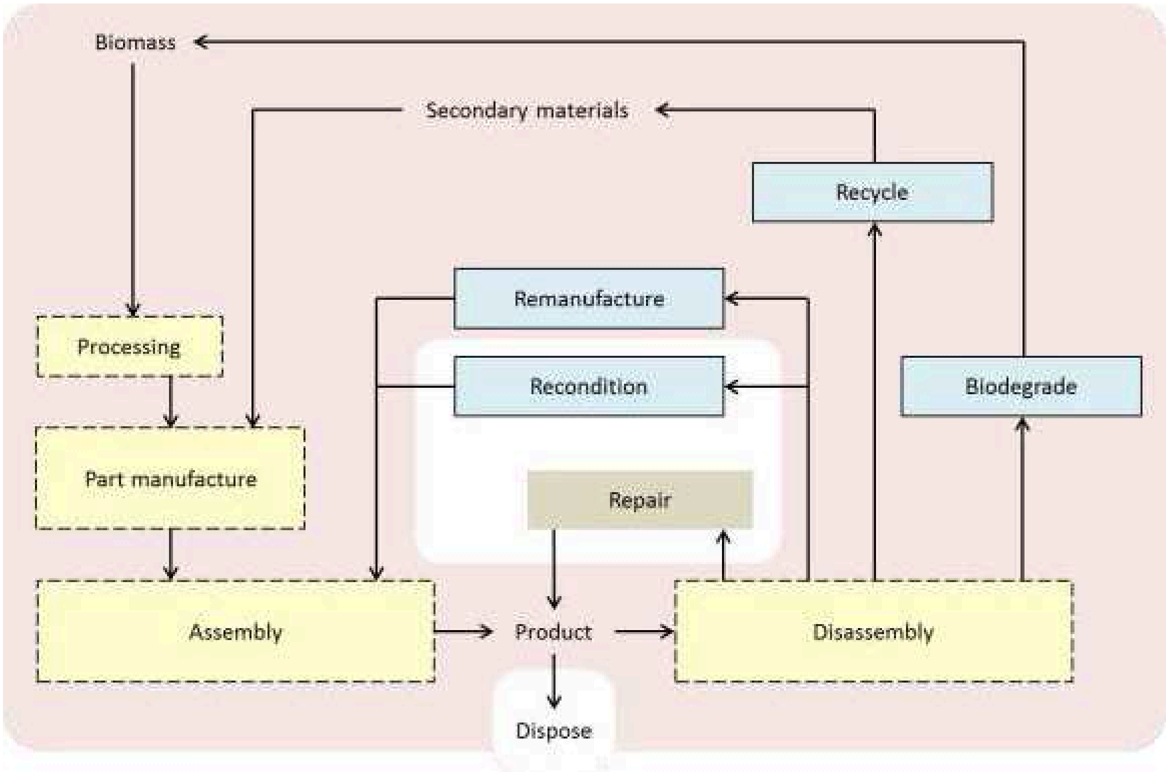

Figure 7-1 Reuse and recycling hierarchy (adapted from **BS 8887-2**). Assembly is not required for articles consisting of a single component. Recirculation routes fall within the shaded area.

Reuse options may be limited to a certain number of cycles. Eventually the component parts of the article may need to be recycled or composted to qualify as recirculated. To distinguish between remanufacturing as a recirculation strategy and other reuse options, the following rules apply: If it is expected that the user may need to buy a replacement part not made of remanufactured components to continue to operate and use the product and receive the same service, this indicates the product/component is not indefinitely reusable. Similarly, after normally predictable conditions of use if the manufacturer will not take back component parts for remanufacture then it is not reusable. In these instances, if the product or component part does not have an alternative end-of-life option, then it is not considered to be recirculated. Component parts that cannot be safely repaired, reconditioned or used in remanufacturing shall be recirculated according to another suitable end-of-life treatment (see Chapter 8). Proof of performance after remanufacture (therefore satisfying a requirement of recirculation) can be demonstrated if the operator issues the remanufactured product with an equivalent warranty to that of a new product (**BS 8887-2**).

7.2.1 **Optimal lifespan (including repair)**

a) The product shall have an operational lifespan appropriate to its function.
b) The product should enter repeated reuse cycles (in normally predictable conditions of use) and not limited in this respect by the design of the components or choice of materials (**EN 13429**).
c) The product can be reused without health or safety risks (**EN 13429**).

d) Single use products that cannot be reused or recycled because they are inevitably discharged into the environment as part of their function are excluded from the requirements of section 7.2.1. Nevertheless the product shall be designed to operate satisfactorily with the minimum possible quantity of substance used, and to be biodegradable according to section 8.1.3.
e) To demonstrate that a product is best designed for single use, a comparison to alternative reusable options shall be made. This exercise shall be conducted according to product design principles as listed in section 6.1. Multiple considerations should be assessed, and include (but not be limited to) energy requirements, material use, potential waste, and optimisation of end-of-life options.
f) The product shall perform the intended function without incurring damage through predictable conditions of use beyond what can be routinely repaired (**EN 13429**).
g) If the user can feasibly use the product repeatedly (*e.g.* cutlery), instructions on a hygienic cleaning procedure shall be provided if not obvious. Otherwise the user shall be informed that the product is for single use only by the use of clear labelling.
h) Redundant articles and components that cannot be repaired shall still adhere to the end-of-life requirements established in Chapter 8.
i) Where the product remains under the ownership of the supplier or another stakeholder, and in cases of extended producer responsibility, reuse shall be enabled and encouraged with information on the type and location of any return schemes.

7.2.2 **Disassembly**

a) The types of materials and their intended end-of-life treatment shall be made recognisable to the operators of appropriate waste treatment processes.
b) Component parts with different end-of-life options shall be easily and quickly separated from each other so disposal to landfill is not economically justified (**BS 8887-1:2006**).
c) All reusable or recyclable parts shall be identifiable. Coded components and audit trails are beneficial for this purpose (**BS 8887-1:2006**).
d) A quality assessment shall be made on any component parts prior to remanufacture so that health, safety and hygiene standards are adhered to (see section 7.2.3).
e) Biodegradable parts shall also be easily separable, and waste management instructions provided if not obvious.
f) The product should be designed so that any harmful materials are grouped into separate accessible modules (**BS 8887-1:2006**).
g) Potential releases into the environment originating from waste articles should be understood by the operator and appropriate measures implemented when designing the product to maximise safety (**EN 13430**). Appropriate documentation should be made available by the supplier.

7.2.3 **Remanufacture**

a) The product must be returned to use within a certain timeframe and ultimately without modification or depreciation to its form or function. The basic specification of the product therefore shall remain unchanged (**EN 13437**). Where it applies, a good indication of this is an equivalent warranty being issued once the product is returned to use (**BS 8887-2**).

b) Design for remanufacturing shall be considered at the design stage. Remanufacturing is applicable to medium and high value products consisting of multiple parts. It is not economical to collect and remanufacture commodity chemical products. Alternative recirculation strategies shall be considered for low value products, as should approaches for extended product lifespan.
c) A product shall qualify for remanufacturing if it has been used, or has exceeded its shelf life. The product shall be disassembled and the components inspected (**BS 8887-220**).
d) Components unsuitable for remanufacturing shall be designed to be separable and enter their own end-of-life treatments.
e) Functional remediation (cleaning, repainting, reskimming of surfaces *etc*.) of parts shall be performed and afterwards shown to function as new (**BS 8887-220**).
f) After re-assembly, the assembled product shall undergo comprehensive testing to ensure it performs equal to a new product according to the same specifications (**BS 8887-220**).
g) If remediation is not successful, component parts originally intended for remanufacture shall be replaced with alternatives, either new or remanufactured (**BS 8887-220**). Replacement components and parts shall also have been designed for recirculation.
h) If any components cannot be repaired or remanufactured, and no other recirculation mechanism is feasible (*e.g*. recycling, biodegradation), the part shall not be regarded as recirculated.

7.2.4 **Reconditioning**

a) The product must be returned to use within a certain timeframe and ultimately without modification to its form or function. Some practices regarded as reconditioning described elsewhere can result in inferior product performance (**BS 8887-240**). This does not constitute recirculation. The product shall maintain its expected performance level in the intended application(s) (**EN 13429**).
b) The general practices of collection, inspection and remediation are the same as specified for remanufacturing (**BS 8887-240**).
c) Purification of used products by cleaning, extraction and other forms of separation are regarded as reconditioning, as is the recovery of volatile substances by distillation (*e.g*. solvents).
d) If any components cannot be repaired or reconditioned indefinitely, leading to a demand for material resources in order to replace the product, and no other recirculation mechanism is feasible (*e.g*. recycling, biodegradation), the product shall not be regarded as recirculated.

8 End-of-life requirements

8.1 Recycling

Recycling practices can be divided into biological, chemical, and physical processes. Mechanical (physical) recycling of plastics has one of the strongest associations to everyday recycling. After melting and extruding the plastic into pellets [Ignatyev 2014], the form of the article is lost but the chemical composition is preserved (Figure 4-1). The recyclate is then suitable as a secondary feedstock in manufacturing. The same principle applies to paper, aluminium, wood, steel, and glass on a large scale (**EN 13437**). Returning an article to its chemical precursor(s) indicates the product is recirculated, but in fact closed loop recycling is not always possible. For example PET drinks bottles are recyclable but not often made from recycled material. The PET that is recycled is used in other applications. Open loop recycling means the secondary product could be considered as recirculated because there is no primary resource depletion associated with its manufacture (but a suitable end-of-life option must exist). The original product is only recirculated if the feedstock is a renewable material, distinguishing bio-based PET bottles from the conventional petrochemical product for example.

Chemical recycling is the deconstruction of a substance into chemical intermediates. Closed loop chemical recycling will return the product to its precursor (*e.g.* polylactic acid can be hydrolysed back to lactic acid). Open loop chemical recycling (also known as feedstock recycling) produces different chemicals for use in the synthesis of other products. There is not a pre-existing standard test method describing chemical recycling. In the absence of established requirements, general protocols used for mechanical recycling should be adopted for quality control, batch identification *etc*. (**EN 15347**). Specific requirements for chemical recycling as found in **Open-Bio deliverable report 6.10** shall be adhered to. Chemical recycling should be considered especially for bio-based plastics without the option to recycle mechanically, *e.g*. poly(lactic acid).

Mechanical recycling preserves the molecular composition of the material, and while chemical recycling retains some of the chemical functionality, biodegradation oxidises the organic carbon completely to carbon dioxide. As such biological recycling retains the least material value of all the recirculation strategies at end-of-life. Accordingly is the least preferred option for recirculation because energy is again required for feedstock production and manufacturing. Organic recycling is nevertheless necessary for products that directly enter the environment, and for products with no formal waste collection procedure as a safeguard against pollution and waste. The requirements established by **EN 14995** or **EN 13432** (or equivalent) shall be used to evaluate compostability and biodegradation, applicable only to suitable components within a product that can be separated by hand. All other parts must have their own end-of-life option, which may involve a specialist separation process.

Minimum biodegradation requirements are established in other standards, and are (currently) product specific. The threshold values are indicative of complete biodegradation, even though for pure substances the values can be low within the constraints of the laboratory test duration. Compared to a reference material, 90% biodegradation is required of compostable plastics (**EN 14995**) and packaging (**EN 13432**), but only 50% (greases) or 60% (oils) for bio-based lubricants (**prEN 16807**).

Because carbon dioxide is liberated by biodegradation, biodegradable fossil derived substances contribute to a net increase in greenhouse gas emissions. This also corresponds to a loss of resource (the carbon associated with energy use during manufacturing and product use is not covered by this draft test method, nor is the waste created in the production chain). For complete recirculation, the bio-based carbon content of a product (expressed as a percentage of total carbon content) must equal 100% (to within the known test error of the analysis). Using current methods, a product composed of only carbon, hydrogen, nitrogen and oxygen with 100% bio-based carbon is also 100% bio-based (**EN 16785-1**). However, the minimum bio-based carbon content of a bio-lubricant or a bio-based solvent is 25% (**prEN 16807** and **CEN/TS 16766**). The requirements of a bio-based product can therefore be less than a recirculated product.

Characterisation of the relevant product properties for each end-of-life option shall follow the templates found in **CEN/TR 16957** should an inventory for the end-of-life phase in an LCA be required. This practice can be used to help identify issues with an end-of-life option and maybe re-evaluate the product design. Reuse, recycling (mechanical, chemical, composting, anaerobic digestion), incineration, waste water treatment, landfill and discharge into the environment are all covered in **CEN/TR 16957**.

8.1.1 Mechanical (physical) recycling criteria

a) Product design choices and selection of raw materials (including how they are joined during assembly) shall not have a negative impact on recycling (**EN 13430**).
b) The material composition of components must be compatible with the available sorting and recycling technologies given in **EN 13437** (**EN 13430**).
c) Suitability for mechanical recycling should be communicated with the statement sheet in Annex C of **EN 13430** or equivalent.
d) Mechanically recyclable materials should be used in a manner sympathetic to the current recycling infrastructure. Fulfilling specifications for recyclates (especially with respect to composition identification, including minor components) must be achievable and presented according to the statement template in **EN 15347** for plastics, and equivalent standards for specific polymers and other materials should they exist.
e) Materials with established recycling collection schemes (*e.g.* paper, PE, PET) in the region of use are considered fully recyclable if the product can be completely disassembled into the required material streams.

f) It shall also be demonstrable that no accumulation or leaching of additives or any other trace chemicals with potentially adverse side effects to humans or the environment occurs because of the recycling operation.
g) Any components of a product that are not suitable for mechanical recycling shall be identifiable, separable, and able to be removed before entering the recycling process. For example, biodegradable components shall be removed to avoid contamination of recyclates. Reusable components shall be removed so that they can be remanufactured without losing their form and therefore retain their value.
h) Reporting of recycling characteristics for B2B communications can be done using **FprEN 16848**.
i) Life cycle analysis (LCA) inputs for mechanical recycling shall follow the template in **CEN/TR 16957** if required. LCA can be used as the justification for certain end-of-life options.

8.1.2 Feedstock (chemical) recycling criteria

a) Product design shall encourage opportunities for chemical recycling.
b) Any components of a bio-based product that are not suitable for chemical recycling shall be identifiable, separable, and able to be removed before entering the recycling process.
c) Collection schemes shall be communicated where they exist. Extended producer responsibility shall be considered as part of the product design phase.
d) Processes suitable for the chemical recycling of bio-based products include (but are not limited to) esterification and transesterification, hydrolysis, reduction including hydrogenation, oxidation including dehydrogenation, pyrolysis and gasification by means of thermal, electrochemical, and ultraviolet or microwave irradiation treatments. The chemical composition of the product shall be complementary to these types of transformation for chemical recycling purposes.
e) The products of chemical recycling can be monomers for closed loop recycling, or different substances. All products must be characterised according to a relevant and informative specification depending on the chemical substance(s) formed, in line with the 'end-of-waste' criteria stated in European directive **2008/98/EC**.
f) The productivity of the chemical recycling process shall be comparable or superior to a technologically viable mechanical recycling process if available in order to justify this chosen end-of-life pathway.
g) In the absence of a comparative mechanical recycling process, the proportion of product precursor (*e.g.* monomer) that is reclaimed as part of closed loop chemical recycling shall always equate to, or exceed, 60% of the monomer units of the polymer entering the chemical recycling process (recovery factor, dry mass basis, as defined in **Open-Bio deliverable report D6.10**).
h) In cases where other chemical products are produced (*e.g.* open-loop chemical recycling) the proportion of chemically recycled materials shall equal or exceed 80% of the original product or component mass (recovery factor, dry mass basis, as defined in **Open-Bio deliverable report D6.10**). This requirement also applies to non-

polymeric articles and polymers without a clearly defined and understood chemical structure.

i) The primary products from chemical recycling shall not be for energy uses, although surplus heat generated during the chemical recycling process can be reclaimed as energy. Co-products of chemical recycling (*e.g.* hydrogen, partially degraded recyclate) can be used for energy uses (see section 8.2.1), but do not contribute to the chemical recycling recovery factor (as defined in **Open-Bio deliverable report D6.10**).

j) Materials within components that cannot be chemically recycled (*e.g.* mineral fillers in moulded plastic parts) should have another viable end-of-life option and reclaimed after the chemical recycling process.

k) Details of chemical recycling can be described for B2B communications as ‘additional information’ using the reporting template of **FprEN 16848**.

l) Life cycle analysis inputs for chemical recycling shall follow the template in **CEN/TR 16957** identical to mechanical recycling if required. LCA can be used as the justification for certain end-of-life options, including chemical recycling.

8.1.3 Organic (biological) recycling

a) The bio-based carbon content of the product shall be 100% (within the known accuracy of the analysis). The only exceptions are inorganic materials (*e.g.* calcium carbonate) that do not impact the biodegradation process as stipulated in subsequent clauses. If carbon containing inorganic substances are present, in this instance the bio-based carbon content will be lower. This should be explained in the justification of organic recycling as the preferred end-of-life option.

b) The product or components shall be designed to disintegrate under aerobic composting conditions if this is the intended end-of-life process (**EN 14995**). The distinction between home and industrial composting shall be made in instructions available to the user.

c) Specific compostability standards shall be used for relevant product types where available (*e.g.* **EN 13432** for packaging and **EN 14995** for plastics).

d) The organic carbon content, total dry solids and volatile solids (minimum of 50%) must be known for biodegradation and compost disintegration tests (**EN 13432**). The total organic carbon in the product must be consistent with a material balance describing its production.

e) Environmental risks should be ascertained with ecotoxicological tests, for example **OECD 208**, and no negative impact on the quality of compost shall be caused by the product (**EN 13432**).

f) If the product can be separated by hand into compostable and non-compostable parts, only the organic recycling of relevant components needs to be considered (**EN 13432**). Other components shall be recirculated by other means.

g) Separable components that are not suitable for organic recycling shall be identifiable, and able to be removed before entering the organic recycling process.

h) Chemically unmodified materials (*e.g.* cotton, paper pulp) can be considered as biodegradable without being demonstrated as such (**EN 13432**).
i) All organic substances present at above 1% of the total mass of the product must be biodegradable in order to contribute towards recirculation (**EN 13432**). No more than 5% of the product mass (or any separated component parts) undergoing composting shall be untested in this regard (**EN 14995**).
j) Reporting of organic recycling characteristics for B2B communications can be done using **FprEN 16848**.
k) Parameters relating to composting as part of LCA inputs shall follow the template in **CEN/TR 16957** if required.
l) Anaerobic digestion for energy production in the form of biogas shall be evaluated under the clauses given for energy recovery in section 8.2.1. Specialised operations generating biogas by anaerobic digestion exclusively for chemical production can be considered as equivalent to chemical recycling in this regard (refer to section 8.1.2).

8.2 Alternatives to recycling

If it can be justified that no remanufacturing or recycling processes will adequately recirculate the bio-based product, energy recovery from incineration can be offered as an end-of-life option. There is a high burden of proof required to permit energy recovery as an option for end-of-life processing (see Chapter 9) in order to encourage recycling as a means to eliminate waste. The product must be 100% bio-based in order to demonstrate the product does not release fossil carbon upon incineration. Additional requirements are stipulated in section 8.2.1.

As a consequence of their use, some products will be released into the environment. Where this is the case, and product design cannot overcome it, the lack of a formal collection and recycling strategy means the product shall be 100% bio-based and biodegradable. This short cycle carbon loop ensures, at least for the materials contained within the product, no net loss of resource is incurred as waste.

8.2.1 Energy recovery

a) If any of the component parts of a product do not have alternative end-of-life options as specified in section 7.2.3 (remanufacture), section 8.1.1 (mechanical recycling), section 8.1.2 (feedstock recycling), and section 8.1.3 (organic recycling), the product can be shown to be suitable for energy recovery. It shall be shown that the requirements for standards describing all the above recycling methods cannot be fulfilled. A detailed justification shall be provided as part of the reporting template found in Chapter 9.
b) Bio-based products for energy recovery must be 100% bio-based.
c) The net calorific value of the article shall be 5 MJ/kg or greater (**EN 13431**, **ISO 1928**).
d) Reporting of energy recovery characteristics for B2B communications shall follow the requirements of **FprEN 16848**.

e) Modelling of incineration impacts for a LCA shall follow the template in **CEN/TR 16957** if required.
f) It is also possible to convert bio-based products into solid, liquid, or gaseous fuels. Again, only if no other end-of-life option is shown to be viable, and revisions to the product design cannot avoid it, then the conversion of the product into a fuel can be accepted as a recirculation strategy. Typically the fuels will be either biogas, bio-ethanol and other fermentation products, bio-diesel, hydrocarbon fuels, or char.
g) Bio-based products that are converted into fuels must be 100% bio-based.
h) Anaerobic digestion for biogas production shall be modelled according to the template in **CEN/TR 16957** if it is the preferred end-of-life option. Particular attention should be paid to the methane production rate in order to demonstrate the process is satisfactory with respect to the conversion to methane, and that the process is not impaired by the introduction of the bio-based product.
i) For other fuel producing processes (fermentation, pyrolysis, *etc*.) the efficiency of the conversion from waste to fuel on a mass basis shall be determined, or otherwise calculated. This shall be performed and validated as was described for chemical recycling. Efforts to demonstrate no negative effect to the process is caused by the introduction the product shall also be made.

8.2.2 Total biodegradation in the environment

a) The bio-based carbon content of the product shall be 100% (within the known accuracy of the analysis). The only exceptions are inorganic materials (*e.g*. calcium carbonate) that do not impact the biodegradation process as stipulated in subsequent clauses. If carbon containing inorganic substances are present, in this instance the bio-based carbon content will be lower. This shall be explained in the justification of organic recycling as the preferred end-of-life option.
b) As defined in **CEN/TR 16957**, release of the product into the environment can be controlled or uncontrolled, and the product designed for biodegradation or not. Both controlled (*e.g*. mulching film) and uncontrolled (*e.g*. chainsaw lubricant) product release is covered by this draft test method. All products that are not designed to biodegrade in the environment shall have alternative end-of-life options with collection schemes available and in place.
c) The test of ultimate aerobic biodegradability must be equivalent to **ISO 14855** for plastics (or **ISO 14851** or **ISO 14852** where necessary), **EN ISO 9439** for lubricants, *etc*.
d) Environmental risks should be ascertained with ecotoxicological tests, for example **OECD 208**.
e) Chemically unmodified materials (*e.g*. cotton, paper pulp) can be considered as biodegradable without being demonstrated as such (**EN 13432**).
f) All substances present at above 1% of the total mass of the product must be inherently and ultimately biodegradable in order to contribute towards recirculation (**EN 13432**). No more than 5% of the product shall be untested in this regard (**EN 14995**).

▲

Part B: Reporting, Case Studies and Feedback

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9 Reporting of recirculation characteristics

9.1 Reporting

9.1.1 Claims

a) This draft test method is applicable to bio-based products, especially lubricants, plastics, solvents and surfactants. Materials and composites, packaging, and other multi-component articles are also examples of valid product types.
b) Only bio-based products are applicable to this draft test method. Products that are conventionally bio-based without a fossil derived equivalent (*e.g.* paper, cotton fabric) are not applicable to this draft test method. Any revision or subsequent publication of this draft test method shall specify the scope specifically. Composites containing the aforementioned substances and any other bio-based components are appropriate.
c) The template in section 9.1.3 shall be used for B2B communication purposes (Table 9-2), in addition to the reporting template found in **FprEN 16848**.
d) Adherence to this draft test method permits a claim that a product is either "*recirculated*", or "*designed for recirculation*". The precise use of these claims shall follow the guidance in section 9.1.3 (Table 9-4).
e) Where a statement regarding recirculation is made, the minimum bio-based content shall also be communicated and made visible on the product's labelling (B2C) or datasheet (B2B). The two claims shall not be confused by adding any misleading terminology or combined into one single claim.
f) This draft test method does not permit claims of reuse, recycling, or biodegradability, or any equivalent terms and their variants. Furthermore, claims that a product is renewable or sustainable are also not permitted. Other standards determining the use of these claims can be applied and used in alongside this draft test method. For example, clarification of suitable end-of-life options can be achieved separately with the B2C claims permitted by **prEN 16935**.
g) General material and/or energy ecodesign claims are not permitted. These must follow product specific schemes.
h) Communication of bio-based content (carbon mass and total mass) and the end-of-life options for bio-based products should follow standard data sheets. For B2B communications, **FprEN 16848** shall be used, or alternatively **CEN/TS 16398**. For B2C communications, **prEN 16935** (and the nine communication principles therein) shall be used.
i) If appropriate the proportion of recycled content may also be reported according to **EN 15343**, **EN ISO 14021**, or equivalent.
j) Application of this draft test method does not replace or supersede standards and claims of bio-based content, recycled content, or end-of-life options. Characteristics described using **FprEN 16848** and **EN 15343** for example shall be provided in con-

junction with the reporting templates of this draft test method if necessary as evidence to support recirculation statements (Table 9-2).

k) Where possible the primary materials of each constituent component part should be identified in the reporting template found as Table 9-2. Hazardous substances shall be communicated in accordance with chemical regulation using a safety datasheet (refer to Annex II of REACH, **EC regulation 1907/2006**). Any chemicals likely to hinder end-of-life processing should also be identified and a definitive explanation offered as to why they are contained within the product. This justification must identify socio-economic arguments that on balance vindicate the inclusion of such substances, and measures described to limit accidental exposure.

9.1.2 Self-assessment

The process of providing relevant information to explain the recirculation of a product follows the chain of events explained below (Figure 9-1). Firstly the manufacturer or supplier assesses the recirculation of the product, beginning at the product design phase and finally reviewed in a self-assessment. Other standards are additionally required to describe the bio-based content of the product and the preferred end-of-life option(s). That concludes the internal evaluation. The B2B template found as Annex A of **FprEN 16848** is used to summarise these characteristics for external communications (alternatively **CEN/TS 16398** could be used if more appropriate for plastics). Recirculation claims can be added in the 'additional information' section of the B2B template in **FprEN 16848**. The detail can be limited to a short claim as allowed in section 9.1.1. A supplementary reporting template specifically for describing recirculation is used to clarify the claim, and the choice of end-of-life option(s) justified separately.

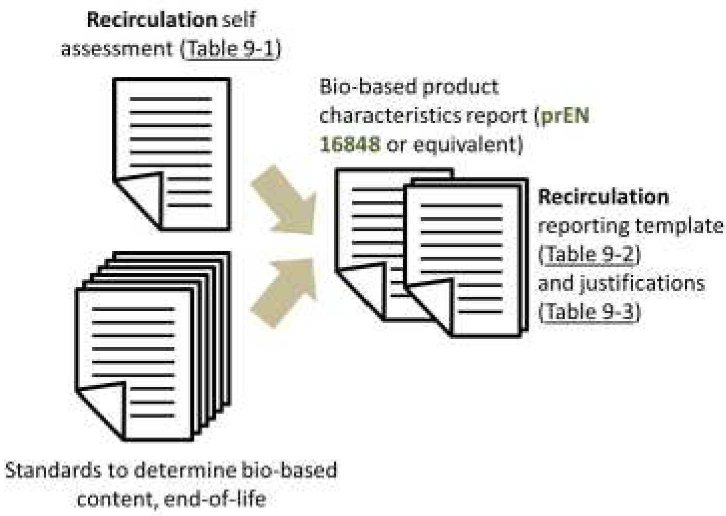


Figure 9-1 Use of standards, test methods and communication templates to supply information on product recirculation.

The template provided as Table 9-1 is for guidance in a self-assessment of the recirculation of a bio-based product. Entries are made on a mass basis. It is easier to calculate recirculation for individual components in separate templates, and the data can be combined to describe the entire article at a later stage if desirable. Table 9-1 is not to be used for B2B or B2C communication, but only in a self-assessment. The production of the bio-based component or product is included to help fulfil the material balance requirements of section 6.3.1. Here it is possible to identify wastestreams that could be minimised, and calculate bio-based carbon content and total bio-based content in accordance with **prEN 16785-2**. Additional guidance on how to fill in Table 9-1 is found in the examples of section 9.2. A slightly different version of the self-assessment form (with an additional final row) is found in Chapter 14 that was used for the calculation of recirculation on a percentage basis (now redundant).

Table 9-1 Blank data table for self-assessment of recirculation calculations.

		(i) Bio-based carbon mass /kg	(ii) Total carbon mass /kg	(iii) Total bio-based mass /kg	(iv) Total mass /kg
Manufacturing					
a	Bio-based input				
b	Recycled input				
c	Other input				
d	Total input				
e	Product				
		Bio-based carbon content /%		Total bio-based content /%	
		Recycled carbon content /%		Recycled content /%	
f	Process waste				
g	Material balance				
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material				
k	Waste/losses				
l	Biodegradable				
m	Waste/losses				
n	No options				
o	Processing rate /%				

In the second section of Table 9-1 the end-of-life processing is also considered. Each available end-of-life process may incur waste. This can arise because of the presence of inappropriate materials that cannot be separated from the other component parts, or the low efficiency of the process itself. In terms of the latter, this should only apply to either chemical recycling (if just some of the material is recycled), or parts that must be discarded or replaced during remanufacturing operations. Substances adhering to the compostability or biodegradation requirements presented in section 8.1.3 are regarded as completely processed with no waste occurring. The percentage biodegradation (*e.g*. measured CO_2 evolution) is not used to define the proportion of material recirculated. Materials with widely recognised mechanical recycling processes, *i.e*. polymers with resin identification code 1-6 (**ASTM D7611**) or specialised mechanical recycling operations that the product may enter at end-of-life because of a relationship based on extended producer responsibility (or equivalent), are all considered completely processed. However if the assembly of the product makes the separation of individual materials difficult and therefore prevents mechanical recycling the design of the product shall be subject to revision under the terms of this draft test method stipulated in section 6.1.1. Component parts that are chemically recycled require the calculation of a recovery factor (refer to **Open-Bio deliverable report D6.10**) to indicate the mass of recirculated material (see section 8.1.2). Energy products and energy recovery, and ultimate biodegradation in the environment after uncontrolled release are not included in Table 9-1 because these are last resort options that must be justified according to how the product is used and where. How the most appropriate end-of-life option is chosen shall follow the flow chart provided as Figure 4-3. The ultimate justification for the end-of-life option proposed shall be defended with robust statements and made available as part of B2B communication.

The precise (indirect) calculation of recirculation was attempted and the corresponding methodology can be found in Chapter 14. However this was deemed unfeasible and has been replaced with qualitative judgements, which can be communicated externally with the reporting templates discussed in section 9.1.3. The problems with the calculation approach are documented in in Chapter 14.

9.1.3 **Communication**

Business-to-business (B2B) communication of bio-based content and end-of-life options are presented in the form of the reporting template in **FprEN 16848**. The categories of the "*data sheet for Business to Business declaration for bio-based products according to* **FprEN 16848**" are as follows (correct as of February 2016). Certain declarations must cite an appropriate standard where indicated in **FprEN 16848**.

- Product name
- Supplier name and contact for further information
- Intended use
- Biomass type(s)
- Biomass origin(s)
- Minimum verifiable bio-based carbon in relation to the total carbon (%)
- Minimum verifiable biomass in relation to the total mass of the product (%)
- Information on aspects of biomass sustainability
- Material recycling
- Organic recycling
- Energy recovery
- Biodegradability characteristics for products used in nature

- Managed disposal
- Additional information

Within the reporting template of **FprEN 16848**, the sections on '*material recycling*', '*organic recycling*' and '*biodegradability characteristics for products used in nature*' could be used to clarify what component parts of the product each option applies to, as well as to provide any disassembly instructions. However the description in **FprEN 16848** is intended to reflect the product as a whole. Sometimes a product will need to be disassembled, for different materials may require separate end-of-life treatments. Therefore evidence justifying the ability to recirculate the product, including additional information relating to the design of the product, and especially the disassembly and end-of-life options for the different components individually, should be provided separately using the following reporting template (Table 9-2).

Table 9-2 Reporting template for B2B communication of recirculation characteristics.

This product has been designed for recirculation according to [*test method reference*].

Component number	1	2	3	4
Characterisation				
Component name				
Mass /%				
Main substance				
Bio-based carbon content /%				
Total bio-based content /%				
Recycled content (carbon) /%				
Recycled content (total) /%				
End-of-life				
Treatment				
Justification supplied (Y/N)?				
Efficiency (material basis)				
Procedural guidance				

Additional information

Design features	
Instructions on proper use	
Collection schemes	
Disassembly instructions	
Further information	

Reporting template Table 9-2 is arranged by component. Each component is described in terms of its relative mass within the complete product, the bio-based (carbon) content and recycled (carbon) content. Equations for the calculation of these attributes are provided in Chapter 14. Characteristics of the complete article can only be communicated using **FprEN 16848**. Where the end-of-life option is different for separate components, Table 9-2 provides a more comprehensive description of the recirculation strategy than what is possible using **FprEN 16848** alone. Information on design features for recirculation and collection schemes can also be added. The specifics of chemical recycling can be reported under '*Further information*' within Table 9-2, citing the test method provided in **Open-Bio deliverable report D6.10**, including instructions to relevant organisations in the supply chain. Examples of how to use Table 9-1 for self-assessment purposes and Table 9-2 for B2B reporting are given in section 9.2.

The justification for each suggested end-of-life treatment must be rigorous. This is only briefly referred to in Table 9-2 by the '*Justification supplied (Y/N)?*' cell. The following table is used to demonstrate the ideal end-of-life process is achievable, and that a less beneficial option is not applied because of artificial limitations imposed by the design of the product (Table 9-3). Each component, as listed in Table 9-2, is treated separately. Following the hierarchy of end-of-life treatments, if an option is not appropriate a justification must be given, based on either (1) how the product is used, (2) the safe use of the product, (3) hygiene reasons, (4) legal requirements, (5) limitations to the manufacturing processes presently available to the producer. For examples of appropriate claims, see section 9.2. For the end-of-life option the component is designed for, evidence in the form of a test method shall be given (refer to Chapter 8 and the examples in section 9.2). Relevant test methods that could be used in reporting the end-of-life option the product is designed for include **BS 8887-220** (remanufacturing) and **EN 13430** (mechanical recycling of packaging). This list is not exhaustive, and newer standards should also be considered when they become available.

Failure to meet the specification of a relevant test method (*e.g.* recyclate quality assurance, as in **EN 15348**) is the preferred evidence to justify using a less preferable end-of-life option. Third party validation as part of a certification scheme would also be helpful in this respect. Then the optimum balance between resource efficiency and end-of-life processing becomes more formal and would benefit the execution of this draft test method. However note that this draft test method has been produced autonomously, and was not commissioned by a standards organisation, or a certification agency. This means there is no formal recognition of this test method as of yet.

Table 9-3 End-of-life process selection justifications for each component.

End-of-life process selection for component number: [*insert component number*]

Option	**Justification**	**Test method**
Remanufacture		
Mechanical recycling		
Chemical recycling		
Organic recycling		
Energy recovery		
Biodegrades when released in the environment		

The terminology relating to recirculation has not been introduced to consumers, which means labelling is not sensible at this present time. In the future B2C claims may become appropriate. "*Recirculated*" or "*designed for recirculation*" are suggested as phrases to describe recirculated products (section 9.1.1), the proper use of which is set out in Table 9-4. The latter claim of "*designed for recirculation*" is not applicable to products entering energy recovery or that are released into the environment and biodegrade.

Table 9-4 The use of claims in a B2C context.

Circumstance		**Claim**	
Bio-based content	End-of-life option	*Recirculated*	*Designed for recirculation*
>0 %*	Remanufacture	✓	✓
>0 %*	Mechanical recycling	✓	✓
>0 %*	Chemical recycling	✓	✓
100% bio-based	Organic recycling	✓	✓
100% bio-based	Energy recovery	✓	
100% bio-based	Biodegradation in the environment	✓	

*Minimum bio-based content thresholds may apply to specific product types.

9.2 Case studies

The following case studies are presented in 2 formats. Some of the examples are descriptive, explaining practices that demonstrate products are designed for recirculation. Those case studies for which sufficient detail of the different components was available have been complemented with the completed templates for self-assessment and B2B communication (see section 9.1).

9.2.1 Remanufactured casings

Computer casing is sometimes recycled in closed loop processes, operated by the product manufacturer (see *www.dell.com/learn/us/en/uscorp1/corp-comm/closed-loop-recycled-content*). This end-of-life operation would be defined as mechanical recycling, but it is also possible to remanufacture computers (**BS 8887-211**). Additionally it is also now possible to incorporate bio-based plastic into heat resistant plastics for building electrical equipment, including photocopiers (see *www.mynewsdesk.com/uk/pressreleases/bioplastics-the-future-of-photocopiers-447573*). The remanufacturing of bio-based products is the ideal recirculation strategy as proposed in the draft test method presented in this work.

Xerox operates a remanufacturing plant for photocopiers in the UK (see *cfsd.org.uk/Remanufacturing%20and%20Product%20Design.pdf*). After sorting and cleaning up to 80% of the parts are directly introduced back into the manufacturing line. The remainder are recycled. This 'back-up' option to recycle components that fail to meet the remanufacturing quality controls fulfils the requirements of section 7.2.3. If the product were to contain bio-based parts, then they would be applicable under the terms of the recirculation draft test method.

9.2.2 Mechanically recyclable PET packaging

Poly(ethylene terephthalate), PET, is a ubiquitous packaging material and commonly used for carbonated beverage bottles. For food and drink applications recycled PET is less common because of the additional hygiene and safety requirements when using secondary materials [Regulation (EC) No. 282/2008]. To move away from non-renewable primary petrochemical feedstocks, bio-based PET is produced from bio-based ethylene glycol. In the future 100% bio-based PET will be available, but this example only concerns partially bio-based PET where the terephthalate component of the polymer is fossil derived (Figure 9-2).

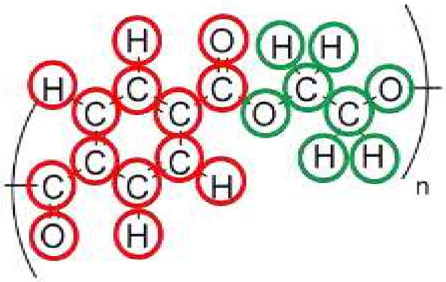


Figure 9-2 The chemical structure of PET, with bio-based atoms circled in green, and fossil derived atoms emphasised with red circles.

The mechanical recycling of PET is well established, especially for single use PET packaging. Of course the type of product and its design features will have an impact on how it can be recycled. This example will concern mechanically recyclable, partially bio-based PET packaging. Representative information about the PET life cycle that will be known to PET packaging producers and PET recyclers is provided in Table 9-5 for context.

Table 9-5 Information regarding the life cycle of PET.

Stage	Description
Resource	Sugar cane is used in bio-ethanol production, and that is converted into ethylene glycol as a drop-in replacement. The terephthalate monomer is still petrochemical in origin, although recent advances suggest an economical source of bio-based terephthalic acid will soon be available.
Production	Terephthalic acid or its methyl ester is reacted with ethylene glycol through the intermediate diethylene glycol terephthalate [Webb 2013]. Atmospheric CO_2 emissions from PET production, are approximately 2.4 kg per kilogram of PET (from cradle to gate). This could be improved by using bio-based terephthalic acid [Webb 2013]. Bio-based PET has 20% bio-based carbon content and 31% total bio-based content.

Stage	Description
Application	Extrusion, injection moulding or blow moulding shapes the PET resin into products (packaging, polyester fibres, films, *etc.*) [Webb 2013].
End-of-life	Aromatic polyesters do not biodegrade well. However the diethylene glycol terephthalate monomer is biodegradable [Zhang 2004], and actually it is the crystallinity of PET that is the problem [Webb 2013]. The chemical recycling of PET has been comprehensively studied, allowing the monomers to be reclaimed for the synthesis of new PET [Karayannidis 2007]. Mechanical recycling produces flakes of PET, which can then be melt extruded into pellets or spun into fibres. In 2014, the European collection rate of PET bottles and containers for mechanical recycling was 57% (see *www.petcore.org/news/over-66-billion-pet-bottles-recycled-europe-2014*). In total 1.7 million tons of PET were recycled in Europe in 2014, of which 39% was turned into fibres, and 25% into packaging (see *www.petcore.org/recycled-products*).

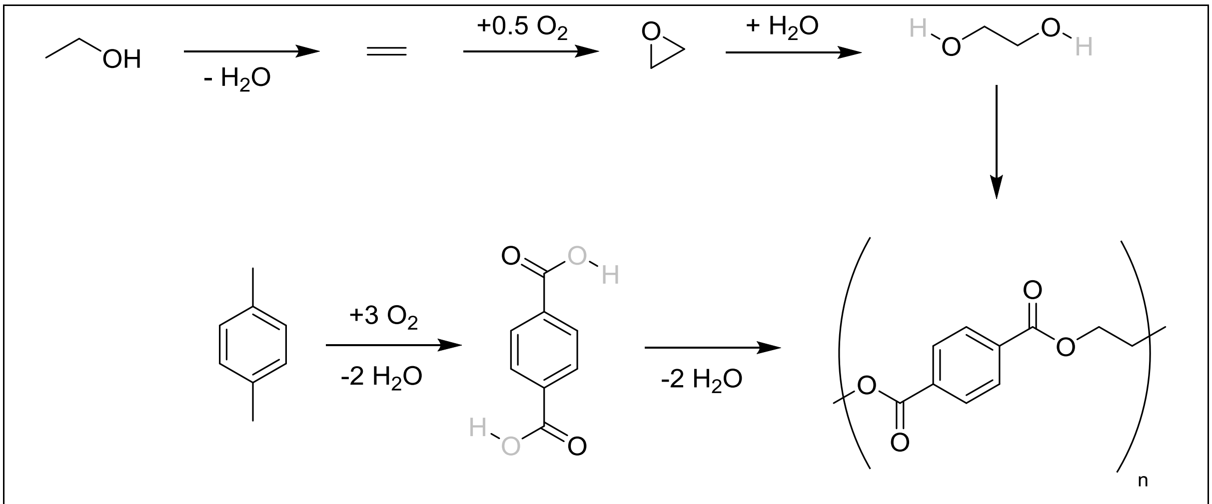
Clearly mechanical recycling is the most common end-of-life option for PET packaging. In terms of the end-of-life hierarchy (Figure 4-3), only remanufacturing is prioritised over mechanical recycling. To prove recirculation an adequate explanation as to why remanufacturing is not suitable for the packaging item must be given. Alternative materials that could be remanufactured should have been considered when designing the product. The self-assessment template has been completed to confirm the successful (at least in principle) recirculation of a bio-based PET packaging item, 30 g in mass (

Table 9-6). To complete the self-assessment a material balance was produced assuming stoichiometric conversion from reactants to the PET based product (Table 9-7). Because of the reaction pathway, some oxygen is considered bio-based (*i.e*. the portion reacting with the bio-ethylene) and the remainder is considered fossil derived (*i.e*. the portion reacting with the *p*-xylene) in accordance with **prEN 16785-2**.

Table 9-6 Self-assessment of a mechanically recyclable item of PET packaging

		(i) Bio-based carbon mass (g)	(ii) Total carbon mass (g)	(iii) Total bio-based mass (g)	(iv) Total mass (g)
Manufacturing					
a	Bio-based input	3.8	3.8	12.5	12.5
b	Recycled input				
c	Other input		15.0		31.6
d	Total input		18.8		44.1
e	Product	3.8	18.8	9.4	30.0
		Bio-based carbon content /%	20%	Total bio-based content /%	31%
		Recycled carbon content /%	0%	Recycled content /%	0%
f	Process waste	0	0	3.1	14.1
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material	3.8	18.8	9.4	30.0
k	Waste/losses	0	0	0	0
l	Biodegradable				
m	Waste/losses				
n	No options				
o	Processing rate /%	100%	100%	100%	100%

Table 9-7 Material balance data describing PET production (grey atoms are not present in the final product.



Reactant	Origin	Mass /g	Mass in product /g	Waste /g
Ethanol	Biomass	7.2	4.4	2.8
Oxygen	Biomass	2.5	2.5	0.0
Oxygen	Fossil	15.0	5.0	10.0
Water	Biomass	2.8	2.5	0.3
p-Xylene	Fossil	16.6	15.6	1.0

In B2B communication, we imagine here for this case study that the PET packaging is in the form of a 500 mL drinks bottle, and supplied empty to a beverage producer. Hence a B2B reporting template is necessary. For simplicity the cap for the bottle is not considered in this case study (a more complete example of a bottle with a cap and label can be found in 14.2.2). The final users are consumers, and the responsibility for disposal is ultimately with them. As a single use product (for hygiene reasons) that is compatible with widely available domestic waste collection services extended producer responsibility is not necessary. Table 9-8 summarises the conclusions of the internal self-assessment (

Table 9-6) for the B2B communication. All the cells have been filled in but this is not always needed depending on what information is considered relevant.

Table 9-8 Reporting template completed for PET packaging.

This product has been designed for recirculation according to [*test method reference*].

Component number	1

Characterisation

Component name	Packaging.
Mass /%	30 g (approx.), 100% of article.
Main substance	PET
Bio-based carbon content /%	20%
Total bio-based content /%	31%
Recycled content (carbon) /%	0%
Recycled content (total) /%	0%

End-of-life

Treatment	Mechanical recycling.
Justification supplied (Y/N)?	Y (refer to end-of-life process selection form).
Efficiency (material basis)	Completely recyclable.
Procedural guidance	Suitable for domestic and commercial plastic collection and recycling schemes.

Additional information

Design features	Made from lightweight, recyclable, bio-based material.
Instructions on proper use	Single use only.
Collection schemes	Widely available.
Disassembly instructions	Not applicable.
Further information	Not applicable.

Mechanical recycling can only be accepted as the end-of-life procedure if remanufacturing is unsuitable and a justification is given in Table 9-9. Again all the cells have been filled in, but it is only necessary to complete the end-of-life process selection form until the preferred end-of-life option has been reached. Annex C of **EN 13430** is used to declare the availability of the packaging for recycling, and as **EN 13430** was referred to in Table 9-9, the supplier would have to comply with that standard. The form found in Annex C of **EN 13430** has 13 cells to complete, but materials accepted for recycling (based on standards, *e.g.* **EN 15348** for PET) require just basic information: a description of each component, the mass of each component, the intended recycling stream (*e.g.* plastics), and the percentage of the material that is recycled (100% by default for recognised recyclates).

Table 9-9 End-of-life process selection for the example of PET packaging.

End-of-life process selection for PET (packaging)

Option	Justification	Test method

Remanufacture	Remanufacturing processes not conducted by the supplier. PET has been chosen over other materials to reduce manufacturing and transportation costs. PET cannot be steam sterilised without degrading the polymer. Alternative disinfection methods not EFSA approved. Recommended for single use only.	**BS 8887-220** not applicable
Mechanical recycling	Made from mechanically recyclable material (PET, resin identification code 1, as marked on the product). Handlers of the PET recyclate are advised to follow **EN 15348**. Information characterising the product and a recycling compliance statement has been made in accordance with **EN 13430**.	**EN 13430**
Chemical recycling	Not designed to be chemically recycled.	
Organic recycling	Not suitable for organic recycling. Collect for mechanical recycling instead.	
Energy recovery	Can be incinerated for energy recovery.	**EN 13431**
Biodegrades when released in the environment	Not designed to biodegrade. Collect for mechanical recycling instead.	

9.2.3 **Compostable PLA composite**

Single use coffee cups and food wrappers are widespread, convenient and hygienic. Food wrappers often consist of a paper bag with a transparent plastic film for display purposes. Paper cups have plastic linings to contain the beverage. Whereas the food wrappers can be separated into paper and plastic for recycling, for the plastic lined paper cups this is not generally feasible. New technology does permit the paper to be separated and recycled (see *www.recyclenow.com/what-to-do-with/paper-coffee-cups*), but capacity is limited and the fate of the plastic film is not certain. Alternatively cups can be designed so that the two materials are easily separated, and this would be a welcome step towards recirculation (see *www.theguardian.com/environment/2014/jun/27/recyclable-coffee-cup-uk-landfill-breakthrough*). Another option is to design the plastic lining to enter the same end-of-life process as the paper, alleviating the need for separation. Biodegradable bio-based plastics are suitable for this purpose, and PLA lined cups for example are now available.

If a producer of typical wax or polyethylene lined paper cups were to re-evaluate their product design, they might consider PLA as an alternative material. As the producer of a composite product the material balance of the process might only require paper and PLA inputs with minimal waste. For this reason the material balance will not be explained here in this case study. An example of a self-assessment is provided below (

Table 9-10). It is assumed that PLA makes up 5 wt% of the product mass. Bio-based carbon analysis according to **prEN 16640** takes into account all carbon in the sample, and so small amounts of mineral filler could have an impact. In reality this is not greater than the accuracy of the bio-based carbon content analysis and so the bio-based carbon content has been assumed to be 100%. The inorganic content in the paper is still considered in the calculation, which is reflected in

Table 9-10 and the total bio-based content of 96%.

The self-assessment reveals the mineral binder in the paper is not biodegradable. It is not organic and so there is no conflict with biodegradation standards (*e.g.* **EN 13432**) as long as no negative impact on the quality of compost occurs as a result. It is not addressed separately under the terms of the recirculation draft test method because is it part of a component (paper), not a component in its own right. No threshold to define the minimum processing rate has been set in this work, but could be applied as part of a certification scheme. The calculation of recirculation was rejected as an approach to quantify recirculation. At 96% (total mass basis) the achievable recirculation rate for this product is not a cause for concern. Lower efficiencies would require the manufacturer to reconsider the design of the product and the materials chosen as feedstocks, as is the purpose of this self-assessment.

Table 9-10 Self-assessment of the recirculation of a PLA lined paper cup (mass scaled to represent a 1 kilogram batch).

		(i) Bio-based carbon mass (kg)	(ii) Total carbon mass (kg)	(iii) Total bio-based mass (kg)	(iv) Total mass (kg)
Manufacturing					
a	Bio-based input	0.43	0.43	0.96	0.96
b	Recycled input		0		0
c	Other input		0		0.04
d	Total input		0.43		1.00
e	Product	0.43	0.43	0.96	1.00
		Bio-based carbon content /%	100%	Total bio-based content /%	96%
		Recycled carbon content /%	0%	Recycled content /%	0%
f	Process waste				
g	Material balance				
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material				
k	Waste/losses				
l	Biodegradable	0.43	0.43	0.96	0.96
m	Waste/losses	0	0	0	0.04
n	No options				
o	Processing rate /%	100%	100%	100%	96%

The B2B reporting template has been completed (The justification for biodegradation as the preferred end-of-life option requires remanufacturing, mechanical recycling and chemical recycling to be ruled out. As a single use coffee cup, remanufacturing is not suitable for much the same reasons that were given for the previous example of PET packaging. The plastic lining is problematic for mechanical recycling of the paper. PLA is not an ideal plastic for mechanical recycling anyway. Chemical recycling is more promising but facilities are not operational at the present time. The justification for organic recycling is given in Table 9-12. A reference to the test method is provided (suggested here as **EN 13432**, which has its own conformity assessments which must be followed).

Table 9-11). The information from the self-assessment has been repeated. It is not necessary to add additional information, although specifying whether the product is suitable for home composting or just industrial composting would be helpful. The exact information supplied can be negotiated between supplier and customer.

The justification for biodegradation as the preferred end-of-life option requires remanufacturing, mechanical recycling and chemical recycling to be ruled out. As a single use coffee cup, remanufacturing is not suitable for much the same reasons that were given for the previous example of PET packaging. The plastic lining is problematic for mechanical recycling of the paper. PLA is not an ideal plastic for mechanical recycling anyway. Chemical recycling is more promising but facilities are not operational at the present time. The justification for organic recycling is given in Table 9-12. A reference to the test method is provided (suggested here as **EN 13432**, which has its own conformity assessments which must be followed).

Table 9-11 Reporting template for B2B communication of the recirculation characteristics of a PLA lined paper cup.

This product has been designed for recirculation according to [*test method reference*].

Component number	1

Characterisation

Component name	PLA lined cup
Mass /%	100%
Main substance	Paper
Bio-based carbon content /%	100%
Total bio-based content /%	96%
Recycled content (carbon) /%	-
Recycled content (total) /%	-

End-of-life

Treatment	Composting
Justification supplied (Y/N)?	Y
Efficiency (material basis)	Completely biodegradable
Procedural guidance	-

Additional information

Design features	-
Instructions on proper use	-
Collection schemes	-
Disassembly instructions	-
Further information	-

Table 9-12 End-of-life process selection justifications for a PLA lined paper cup.

End-of-life process selection for component number: 1

Option	Justification	Test method

Remanufacture	Damage, including staining, makes reuse impossible.	
Mechanical recycling	Facilities are not widespread. Specialised collection impractical.	
Chemical recycling	Facilities not available.	
Organic recycling		**EN 13432**
Energy recovery		
Biodegrades when released in the environment		

9.2.4 Surfactant based domestic cleaning product

Cardanol from cashew nut-shell liquid can be modified with a polyether to give a bio-based surfactant [Tyman 2004]. On average 13 ethylene glycol groups are present per molecule (Figure 9-3), and the biodegradability of the surfactant is comparable to glucose. Surfactants using in cleaning formulations are typically discharged with the waste water, and require treatment in a biological effluent plant to purify the water. The inherent waste caused by surfactant use is not ideal but there is no obvious way in which surfactants can be feasibly recovered in a reusable state. For this reason design for total biodegradation in the environment is acceptable to fulfil the recirculation requirements proposed in this work.

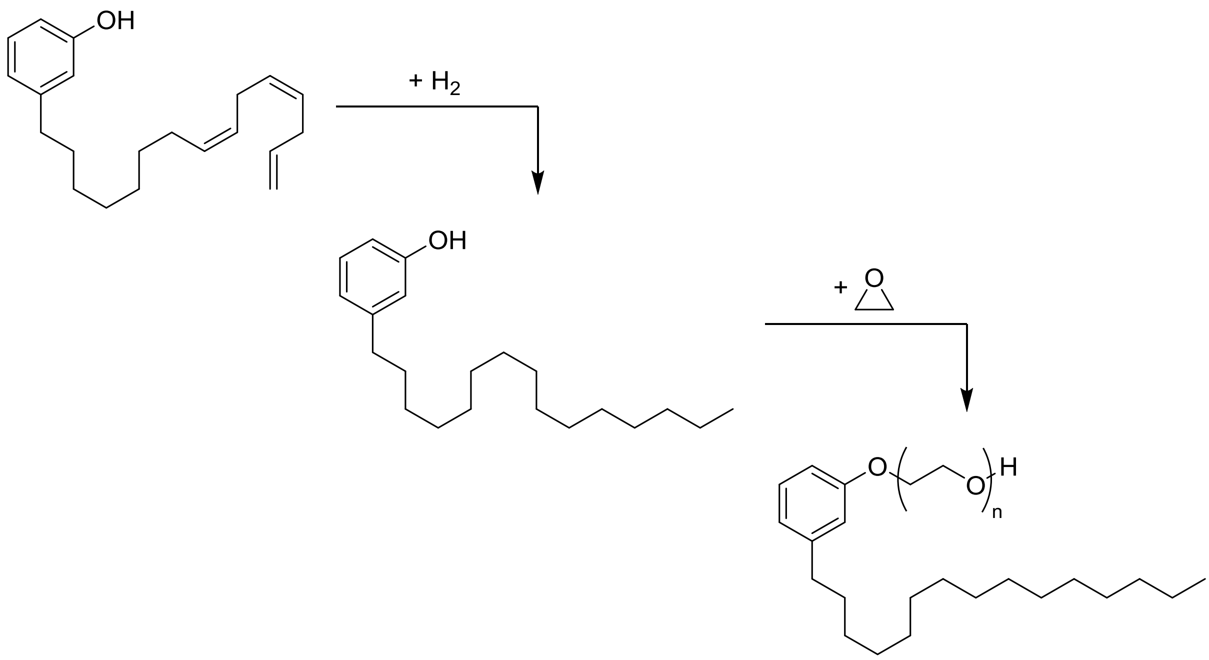


Figure 9-3 The hydrogenation of cardanol and subsequent polyethoxylation to give a surfactant (n = 13).

It will be assumed for the purpose of this case study that the recirculation is being calculated by the manufacturer of the surfactant, in order to supply the substance to a formulator of cleaning products. If the ethylene oxide used to produce the polyether hydrophilic portion of the surfactant does not come from renewable feedstocks, biodegradation will not be a suitable end-of-life option for the product. In The producer will have to re-evaluate the choice of feedstock, for at present the surfactant cannot be sold with documentation regarding its recirculation characteristics as is proposed by this draft test method. Ethylene oxide can be produced from bio-ethanol, and so it is not impossible using currently available processes and resources to make the surfactant 100% bio-based. Although the self-assessment form is not necessary to make the producer aware of this, in more complex instances where multi-component products have parts with different end-of-life options (see section 9.2.7), the use of unsuitable feedstocks is quantified and made clearer as a result. The form also highlights the amount of waste generated in the manufacturing process which is useful when identifying possible improvements. A satisfactory self-assessment and the resulting B2B reporting template are not completed for this example. Please refer to section 9.2.5 for a case study of a bio-based product designed to biodegrade in the environment.

Table 9-13 an initial attempt at self-assessment proves the product is not designed to be recirculated. The low bio-based content means biodegradation liberates long cycle carbon dioxide as waste.

The producer will have to re-evaluate the choice of feedstock, for at present the surfactant cannot be sold with documentation regarding its recirculation characteristics as is proposed by this draft test method. Ethylene oxide can be produced from bio-ethanol, and so it is not impossible using currently available processes and resources to make the surfactant 100% bio-based. Although the self-assessment form is not necessary to make the producer aware of this, in more complex instances where multi-component products have parts with different end-of-life options (see section 9.2.7), the use of unsuitable feedstocks is quantified and made clearer as a result. The form also highlights the amount of waste generated in the manufacturing process which is useful when identifying possible improvements. A satisfactory self-assessment and the resulting B2B reporting template are not completed for this example. Please refer to section 9.2.5 for a case study of a bio-based product designed to biodegrade in the environment.

Table 9-13 A self-assessment failing to demonstrate the recirculation of a partially bio-based surfactant made from fossil derived reactants.

		(i) Bio-based carbon mass (kg)	(ii) Total carbon mass (kg)	(iii) Total bio-based mass (kg)	(iv) Total mass (kg)
Manufacturing					
a	Bio-based input	0.288	0.288	0.349	0.349
b	Recycled input				
c	Other input		0.353		0.656
d	Total input		0.641		1.005
e	Product	0.286	0.639	0.345	1.000
		Bio-based	45%	Total	

	carbon content /%	(too low for the end-of-life)	bio-based content /%	35%
	Recycled carbon content /%		Recycled content /%	
f Process waste	0.02	0.02	0.04	0.05
g Material balance	0.000	0.000	0.000	0.000
End-of-life				
h Reusable parts				
i Waste/losses				
j Recyclable material				
k Waste/losses				
l Biodegradable	0.268	0.639	0.345	1.000
m Waste/losses	0.000	0.000	0.000	0.000
n No options				
o Processing rate /%	100%	100% (not enough bio-based content)	100%	100%

9.2.5 Chainsaw lubricant

A chain lubricant is formulated for use in chainsaws, and the intended use is in the forestry sector. The lubricant will inevitably be lost to the environment during application due to the design of the chainsaw, not the lubricant, and therefore it cannot be reclaimed for recycling. The only reasonable end-of-life option is total biodegradation in the environment. Bio-based lubricants shall be 25% bio-based (carbon mass basis) and 60% biodegradable (for oils) according to **prEN 16807** and the cited standards within. However this is not acceptable to demonstrate the material the lubricant is made of is also recirculated. The product must have 100% bio-based carbon content and be considered as recirculated. The 60% biodegradation threshold (according to the procedure in **EN ISO 14593**, **EN ISO 9439**, **ISO 16221**, or **EN ISO 9408**) is indicative of complete biodegradation. Table 9-14 presents the self-assessment of a lubricant formulation consisting of an estolide ester base oil formulated with performance additives.

Table 9-14 Self-assessment of lubricant recirculation.

	(i) Bio-based carbon mass (kg)	**(ii) Total carbon mass** (kg)	**(iii) Total bio-based mass** (kg)	**(iv) Total mass** (kg)
Manufacturing				
a Bio-based input	0.66	0.66	0.91	0.91
b Recycled input		n/a		n/a

c	Other input		0.02		0.09
d	Total input		0.68		1.00
e	Product	0.66	0.68	0.91	1.00
		Bio-based carbon content /%	97%	Total bio-based content /%	91%
		Recycled carbon content /%	n/a	Recycled content /%	n/a
f	Process waste	0.00	0.00	0.00	0.00
g	Material balance	0.00	0.00	0.00	0.00
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material				
k	Waste/losses				
l	Biodegradable	0.69	0.68	0.91	0.91
m	Waste/losses	0.00	0.02	0.00	0.09
n	No options				
o	Processing rate /%	100%	97%	100%	91%

The bio-based carbon content of 97% is explained in the B2B reporting template. The presence of inorganic, carbon containing, additives is acceptable, which is assumed to be the case here in this example. If the additives were organic molecules, the product shall be redesigned to consist of only bio-based organic ingredients, or a means of recycling the product found instead. The B2B reporting template has been filled in for the different ingredients of the formulation (Table 9-15). This is not always necessary but can be appropriate in certain business relationships. Completing the form in this way makes the bio-based carbon content of the entire product unclear because the total carbon content of each component is not given. Here the bio-based carbon content is provided as additional information. The end-of-life justification has also been completed (Table 9-16).

Table 9-15 Reporting template for B2B communication of the recirculation characteristics of a lubricant.

This product has been designed for recirculation according to [*test method reference*].

Component number	1	2	3	4

Characterisation

Component name	Base oil	Additive ‘A’	Additive ‘B’	Additive ‘C’
Mass /%	91%	5%	2%	2%
Main substance	Estolide ester	*undisclosed*	*undisclosed*	*undisclosed*

Bio-based carbon content /%	100%	0%	0%	0%
Total bio-based content /%	100%	0%	0%	0%
Recycled content (carbon) /%				
Recycled content (total) /%				

End-of-life

Treatment	Bio-degradable			
Justification supplied (Y/N)?	Y	N	N	N
Efficiency (material basis)	Completely			
Procedural guidance				

Additional information

Design features	
Instructions on proper use	
Collection schemes	
Disassembly instructions	
Further information	Bio-based carbon content = 97%

Table 9-16 End-of-life process selection for a lubricant.

End-of-life process selection for component number: 1

Option	Justification	Test method
Remanufacture	Not recoverable.	
Mechanical recycling	Not recoverable.	
Chemical recycling	Not recoverable.	
Organic recycling	Not recoverable.	
Energy recovery	Not recoverable.	
Biodegrades when released in the environment	Bio-lubricant designed to be biodegradable. All organic ingredients are biodegradable.	**EN ISO 14593** (**prEN 16807**)

9.2.6 **Bio-based solvents**

Solvents are most prevalent in paints and coatings, but evaporate upon application, generally into the atmosphere. Other major applications are found in a variety of industrial processes. Here the solvent will generally be distilled and purified before being used again. This is considered as reconditioning and does not satisfy the recirculation requirements set out in this document. Remanufacturing and mechanical recycling are not applicable for liquid substances, and while chemical recycling is possible, to date there are no demonstrations of this on solvent products. Many solvents are biodegradable and this would meet the end-of-life requirement of a recirculated product. The bio-based content of the solvent would have to be at least 25% (carbon mass basis) to meet the requirements of **CEN/TS 16766**, but 100% bio-based carbon content is needed to be considered as recirculated by organic recycling. It is also worthwhile to note that most solvents will evaporate readily, and so biodegradation testing must meet the requirements of relevant standards to show they do indeed biodegrade. If all forms of recycling are shown to be unfeasible, then energy recovery is possible, and this is a regular practice for batches of spent solvent.

A summary of different bio-based solvents is given in the following table (Table 9-17). All are considered biodegradable under the right conditions. If an appropriate biodegradation treatment cannot be implemented, then energy recovery is the next best option. However dimethyl isosorbide and solketal are not completely bio-based (Figure 9-4), and therefore cannot be recirculated unless they are chemically recycled. Unfortunately no specific process allows this, and although gasification would be possible, the products may not then be used for energy purposes. To design these solvents to be recirculated through biodegradation, all the feedstocks would have to be renewable. This would mean utilising bio-based methanol for the synthesis of dimethyl isosorbide, and bio-acetone in the synthesis of solketal (Table 9-17).

Table 9-17 Bio-based solvent characteristics relevant to recirculation

Solvent	Bio-based carbon content	End-of-life option for recirculation
Acetone	100%	Biodegradation
Dimethyl isosorbide	75%	(not recirculated)
Ethanol	100%	Biodegradation
Ethyl lactate	100%	Biodegradation
Glycerol	100%	Biodegradation
Limonene	100%	Biodegradation
2-Methyl tetrahydrofuran	100%	Biodegradation
Solketal	50%	(not recirculated)

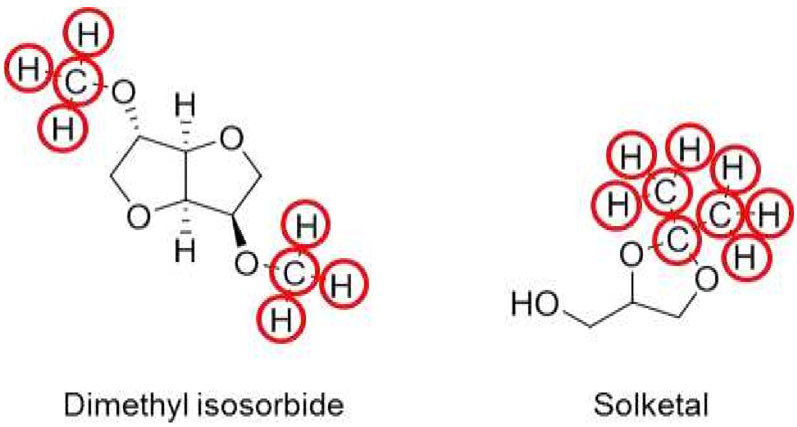


Figure 9-4 Dimethyl isosorbide (left) and the ketal of acetone with glycerol, solketal (right), with fossil derived atoms in red.

9.2.7 Multi-component product: carpet tiles

Carpet tiles are typically composed of a layered bitumen-plastic composite backing and a fabric consisting of fibres (*e.g.* nylon) which is bound to the backing with an adhesive. For a carpet to be durable the binding of the layers must be strong. However this leads to difficulties in separating the component parts after use, and as a result millions of tonnes of carpet waste are disposed of each year [Wang 2007].

The binder between the carpet fibres and the backing can be is made from acetylated starch [Shuttleworth 2010]. The adhesive can now be controllably deactivated with a mild alkali solution or steam, allowing the carpet tile components to be separated. The carpet fibres can then be recycled [Mihut 2001, Realff 1999], and the backing remanufactured into more carpet tiles. Extended producer responsibility schemes are in operation to assist with the material recirculation (see *interface.com/CA/en-CA/about/modular-carpet-tile/ReEntry-20-en_CA*). The presence of the starch based adhesive also eliminated the need for brominated flame retardants [Shuttleworth 2010]. Removing the need for these hazardous components contributes towards compliance with the safety requirements of section 8.1.1.

In summary, the nylon carpet fabric is recyclable, and the product can be made of 100% recycled nylon (see *interface.com/CA/en-CA/about/modular-carpet-tile/ReEntry-20-en_CA*). The bitumen backing can be melted down and reformed for new carpet tiles, but the acetylated starch adhesive is washed out and cannot be reclaimed. However, the acetylated starch, and its hydrolysis products (starch, sugars, acetic acid) are all biodegradable. For this to be an acceptable end-of-life process, the acetylation of the starch must use bio-based acetic acid or an equivalent acetylation reagent (*e.g.* acetic anhydride). Acetic acid is a fermentation product, and so this is possible.

The following self-assessment of recirculation is calculated on the basis of a single carpet tile weighing 125 g (Table 9-18). The nylon is recycled, as is the bitumen backing, and the adhesive is 100% bio-based. The low bio-based content is acceptable in the absence of a specific requirement, and crucially the only the bio-based part of the product is being biodegraded.

Table 9-18 Carpet tile self-assessment of recirculation.

		(i) Bio-based carbon mass (kg)	**(ii) Total carbon mass** (kg)	**(iii) Total bio-based mass** (kg)	**(iv) Total mass** (kg)
Manufacturing					
a	Bio-based input	0.005	0.005	0.010	0.010
b	Recycled input		0.025		0.040
c	Other input		0.065		0.075
d	Total input		0.095		0.125
e	Product	0.005	0.095	0.100	0.125
		Bio-based carbon content /%	5%	Total bio-based content /%	8%
		Recycled		Recycled	

		carbon content /%	26%	content /%	32%
f	Process waste	*(cuttings recirculated)*	*(cuttings recirculated)*	*(cuttings recirculated)*	*(cuttings recirculated)*
g	Material balance	0.000	0.000	0.000	0.000
End-of-life					
h	Reusable parts	*n/a*	*n/a*	*n/a*	*n/a*
i	Waste/losses	*n/a*	*n/a*	*n/a*	*n/a*
j	Recyclable material	*n/a*	0.090	*n/a*	0.105
k	Waste/losses	*n/a*	0.000	*n/a*	0.000
l	Biodegradable	0.005	0.005	0.010	0.010
m	Waste/losses	0.000	0.000	0.000	0.000
n	No options	0.000	0.000	0.000	0.000
o	Processing rate /%	100%	100%	100%	100%

The B2B reporting template demonstrates its full value in this case study (

Table 9-19). The information required for a recirculated multi-component product is much greater than what is needed for the simpler examples that preceded this one. Instructions for how the extended producer responsibility is implemented can be provided, as well as basic details on the bio-based content and recycled content.

Table 9-19 Reporting template for the B2B communication of the recirculation characteristics of a carpet tile.

This product has been designed for recirculation according to [*test method reference*].

Component number	1	2	3	4

Characterisation

Component name	Backing	Fabric	Glue	
Mass /%	60%	32%	8%	
Main substance	Bitumen	Polyester	Starch	
Bio-based carbon content /%			100%	
Total bio-based content /%			100%	
Recycled content (carbon) /%		100%		
Recycled content (total) /%		100%		

End-of-life

Treatment	Recycle	Recycle	Biodegrade	
Justification supplied (Y/N)?	Y	Y	Y	
Efficiency (material basis)	100% recyclable	100% recyclable	Fully bio-degradable	
Procedural guidance	Take back scheme	Take back scheme	Take back scheme	

Additional information

Design features	Separable carpet fibres and backing sheet for easy and complete recycling. Free from brominated flame retardants.
Instructions on proper use	Only to be fitted by trained personnel.
Collection schemes	On arrangement.
Disassembly instructions	Take back scheme operated by supplier. Do not attempt disassembly yourself.
Further information	Contact supplier on [*tel.*]

The end-of-life process selection has to be justified for the separate components of the carpet tile. A separate form must be filled in for each component. In **Error! Not a valid bookmark self-reference.** the reuse of the bitumen backing has been treated as remanufacture, which would be acceptable. The key point is communicated, whether it is considered as remanufacturing or recycling does not affect the outcome of the assessment, but the documentation must be accepted by the business customer. Table 9-21 documents the design of the carpet fabric for mechanical recycling. Finally the test method demonstrating the recirculation of the bio-based adhesive is provided in

Table 9-22.

Table 9-20 End-of-life process selection justifications for the bitumen backing component of a carpet tile.

End-of-life process selection for component number: 1

Option	Justification	Test method
Remanufacture	Backing is reformed by melting (in-house producer owned technology). Arrange collection of carpet tiles when they need to be replaced.	
Mechanical recycling		
Chemical recycling		
Organic recycling		
Energy recovery		
Biodegrades when released in the environment		

Table 9-21 End-of-life process selection for carpet fibres.

End-of-life process selection for component number: 2

Option	Justification	Test method
Remanufacture	Wear to the polyester fabric means it must be reformed through recycling.	
Mechanical recycling	In-house process (**EN 13437**). Waste polyester characterised using **EN 15347**.	**EN 13437**
Chemical recycling		
Organic recycling		
Energy recovery		
Biodegrades when released in the environment		

Table 9-22 End-of-life process selection for a carpet tile adhesive.

End-of-life process selection for component number: 3

Option	Justification	Test method
Remanufacture	Adhesive is design to allow the recycling of the other components. The process degrades the adhesive.	
Mechanical recycling	No process exists.	
Chemical recycling	Component not reclaimed.	
Organic recycling	Component not reclaimed.	
Energy recovery	Component not reclaimed.	
Biodegrades when released in the environment	Designed to be biodegradable. Deactivated adhesive is washed into waste water.	**EN ISO 14855-1**

10Feedback and recommendations

10.1 Open-Bio consortium feedback

At the 5th project meeting of the Open-Bio consortium an earlier version of the re-circulation draft test method was scrutinised in detail. Many comments were made and the vast majority have been incorporated into this document, regarding both the organisation of the draft test method and its content. For example, diagrams for clarification have been added. Recycled material is now quantified in reporting templates. The relationship to LCA is now clarified. The calculation methodology in Chapter 14 was rejected at this meeting, primarily because of its failure to interpret biodegradation correctly (*e.g*. the value of humus and the fact that indicators of complete biodegradation can be as low as 50% of the maximum possible CO_2 evolution). It was recommended to place the calculation methodology in an Annex to demonstrate the Open-Bio description of work was fulfilled, but kept distinct from the main draft test method.

The question of energy products and energy recovery (by incineration) was raised. In some sense biodegradation and energy recovery have similar objectives. Whereas before energy recovery was ruled out of the recirculation draft test method it is now included with strict conditions dictating when it is appropriate. Biogas production is included within energy recovery. Essentially the value of resources as materials is ranked ahead of energy uses, and reuse and recycling shall be prioritised as shown in Figure 4-3. As for biodegradation, energy recovery is only applicable to 100% bio-based products within the methodology put forward in this report.

The general consensus within the consortium was that the draft test method provides sufficient guidance but lacked a means to demonstrate how recirculation is achieved. Table 9-3 was introduced to document how design measures have been implemented to maximise recirculation. The clarification of the end-of-life hierarchy through Figure 4-3 assists the decision making process.

Some thought was given to the role of this draft test method. Labelling is not appropriate because the concept of recirculation is not commonly understood. Furthermore labels with end-of-life guidance are created on a country specific basis and so centralised European normalisation is not appropriate. This might affect how labels communicating recirculation could be designed and might limit their effectiveness. With the possibility of formal standardisation low (at least within a short time span at the European level, *i.e*. development in CEN/TC 411), alternative publication routes have been considered. These will continue to be pursued.

10.2 Advisory partners and stakeholder feedback

Consultations were conducted to assist the development of the definitions presented in **Open-Bio deliverable report D3.4**. The outcomes are presented in the aforementioned report.

After publication of **Open-Bio deliverable report D3.4** an Open-Bio advisory workshop was held in Brussels on 26th May 2015. At this meeting the concept of recirculation was presented and feedback gathered prior to the final development of the draft test method. The representative from the European Commission's Directorate General (DG) Growth requested a stronger and more complete emphasis on life cycle assessment (LCA). It was also suggested that alignment with energy and climate targets could be more obvious. For example a carbon containing product is for a time sequestering that carbon, and some end-of-life options will liberate carbon dioxide to the atmosphere. The DG Growth representative also said that in order to contribute to a circular economy Open-Bio was not adventurous enough. In response, the draft test method provided in this document emphasises closed loop carbon use, with no long cycle carbon releases permitted (within the scope of bio-based products; energy and auxiliary materials are not considered). Circular economy considerations are now at the forefront of the recirculation test method, which was made possible after the European Commission's circular economy package was announced in December 2015. This is achieved through the design ethic that is presented. The recirculation test method is not an interpretation of end-of-life waste management practices, but demands products are inherently designed to avoid becoming waste. The recommendation to create this work as a guideline for LCA was rejected. Recirculation is an extension to the definition of a bio-based product, but without the complexity of a LCA. Increasing the demands of the draft test method so that they become a barrier is not conducive towards the aims of a bio-based economy. A standard for LCA of bio-based products is available (**EN 16760**), and this work does not contradict the requirements of that standard. Hopefully the design principles required for recirculated products will be reflected by improved LCA impacts.

Also at this advisory workshop a representative of a certification agency offered some input. The definition of renewable as presented in **Open-Bio deliverable report D3.4** requires a different emphasis to contemporary usage of the term, which was not received well. Here in this final version of the draft test method, 'recirculation' based claims are allowed but claims of 'reusable', 'recyclable' or 'renewable' are not permitted. References to renewable products have been modified to suggest the material resource is renewed or captured (or other equivalent terms) instead.

10.3 CEN/TC 411 feedback

Open-Bio was represented at the 10th plenary meeting of CEN/TC 411 (bio-based products). The case for standardising 'recirculation' according to the test method provided in this work was made. Generally the response was complementary, but the work on recirculation attributed to a circular economy and not the bio-based economy. Sadly there was little support for extending the scope of CEN/TC 411 to circular economy initiatives within the committee.

As had been found previously, some confusion still exists over how the definitions created for in **Open-Bio deliverable report D3.4** are applied, and the potential to mislabel bio-based products as renewable. The draft test method found in this work is not reliant on the individual ‘reusable’, ‘recyclable’ or ‘renewable’ terms and so to an extent this problem has been purposely avoided. However this reiterates that unfamiliarity with the concept of recirculation is a massive hurdle preventing the acceptance and standardisation of the responsible design clauses presented in this report.

10.4 Ambitions towards the sustainability of bio-based products

Open-Bio deliverable report D3.6 documents sustainability schemes for sustainable biomass and bio-based products. The conclusions of that report are accepted and complimentary to the work described here. In relation to **Open-Bio deliverable report D3.6**, this work contributes to the goal of using the cascading of biomass to retain value and minimise greenhouse gas emissions. A clear recommendation of **Open-Bio deliverable report D3.6**, and a consequence of this report, is that LCA should be used to verify sustainability claims and ensure environmental impacts are not negative. Furthermore the scope of sustainability schemes should be extended to routinely incorporate end-of-life questions. All biomass should be recognised as being sustainability produced, but it is increasingly important to evaluate downstream sustainability also.

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Part C: Discussion of Broader Concepts

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11Relevant initiatives and legislation

11.1 European initiatives

Regulation determines the use and import of chemicals in Europe and limits emissions. Complementary standards and initiatives support markets (*e.g.* the bio-based product market). Here is a brief consideration of legislation and practices that the concept of recirculation can assist with regarding the promotion of a bio-based economy.

11.1.1 **Registration, Evaluation, Authorisation & restriction of Chemicals (REACH)**

Registration, Evaluation, Authorisation & restriction of Chemicals (REACH) is European regulation that requires a comprehensive characterisation of chemical substances, and can result in the use of toxic and environmentally damaging products being restricted. Some requirements for the registration of substances are listed in Table 11-1, along with the annual manufacturing or import tonnage at which the criteria become active. Of particular interest is that at 100 tonnes or more, the biodegradation products of a substance must be appreciated.

Table 11-1 REACH substance data requirements.

Characteristic	Annual Tonnage
Physicochemical properties	
Melting point	1+
Boiling point	1+
Density	1+
Vapour pressure	1+
Surface tension	1+
Water solubility	1+
Partition coefficient (octanol/water)	1+
Flash point	1+
Flammability	1+
Explosive properties	1+
Autoignition temperature	1+
Oxidising properties	1+
Granulometry	1+
Stability	100+
Dissociation constant	100+
Viscosity	100+
Toxicological information	
Skin irritation	1+
Eye irritation	1+
Skin sensitisation	1+
Mutagenicity	1+

Characteristic	Annual Tonnage
Acute toxicity	1+
Repeated dose toxicity	10+
Reproductive toxicity	10+
Toxicokinetics	10+
Carcinogenicity	1000+
Ecotoxicological information	
Aquatic toxicity	1+
Degradation	1+
Environmental fate	10+
Terrestrial organism effects	100+

Increased recycling driven by circular economy targets for reduced landfill may have negative impacts because of the chemicals contained in products (see *www.chemtrust.org.uk/reach-helps-the-circular-economy-clean-up-facilitating-sustainable-recycling*). For recirculated products, the presence of hazardous chemicals have a greater potential for harm because they are in use for longer, and secondary feedstocks may have unpredictable and fluctuating levels of problematic chemicals within them. The REACH regulation helps to minimise the presence of hazardous chemicals, making recirculation more feasible. It will become difficult for manufacturers to incorporate toxic and environmentally damaging substances into products because of REACH restrictions. By applying the clauses that define recirculation in this work, especially those relating to the presence of hazardous substances (see section 6.3.1 and section 8.1.1 in particular), product design practices that are harmonious with REACH are promoted. Both REACH and the concept of recirculation can be viewed (alongside other initiatives) as a stimulus for innovative technologies and products that avoid the use of undesirable chemical substances, which at present is a cause of concern for recyclers as a key stakeholder in a circular economy (see *www.axionpolymers.com/uncategorized/does-the-need-for-a-toxic-free-europe-override-the-need-for-a-circular-economy-package*). It would be sensible that future authorisation granted to toxic or environmentally damaging chemicals takes into consideration circular economy issues of material use and reuse.

11.1.2 **Critical raw materials**

The European Commission has developed a methodology to identify critical raw materials, meaning economically important materials with a significant supply risk (see *ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical/index_en.htm*). Some material feedstocks are at risk because of resource scarcity, or access is vulnerable due to poor geographical distribution and the trade policies of the exporting nations. Europe is deficient of many precious metals for example. This could be incorporated into the design requirements of recirculated products, but the status of many new technologies means critical raw materials are still necessary at present. The recycling of these metals is especially crucial, and design strategies for recirculation could help promote the extended use and reuse of critical raw materials in the future.

11.1.3 The bio-based product market

The purpose of the Open-Bio project is to increase the uptake of standards for bio-based products. It does this by providing a scientific rationale for the requirements contained within these standards, as well as providing guidance on labels and harmonised product information lists. The introduction of standards, as well as certification schemes and labels, has positive long-term effects on the European bio-based product market. This was recognised by the 'Lead Market Task Force' for Bio-Based products, established by the European Commission to recommend how to coordinate policies in this area (see *www.errma.com/wp-content/uploads/2014/02/Annex-5-prep_bio.pdf*). In response a mandate was issued to initiate the development of standards for bio-based products [EN mandate M/492 2011]. Thus the standardisation committee CEN/TC 411 was established and has now produced a number of standards (Table 11-2). Bio-based solvents are the only product group specifically addressed. A number of horizontal standards describing vocabulary, communication, bio-based content, sustainability criteria and life cycle analysis have been published or plan to be published. These standards have been vital in the construction of this work, and feedback on the concept of recirculation proposed here has been gathered from CEN/TC 411 directly.

Table 11-2 Bio-based product standards produced by CEN/TC 411 (as of September 2016).

Reference	Year	Title
CEN/TR 16721	2014	Bio-based products - Overview of methods to determine the bio-based content
CEN/TS 16640	2014	Bio-based products - Determination of the bio based carbon content of products using the radiocarbon method
CEN/TS 16766	2015	Bio-based solvents - Requirements and test methods
EN 16575	2014	Bio-based products - Vocabulary
EN 16751	2016	Bio-based products - Sustainability criteria
EN 16760	2015	Bio-based products - Life cycle assessment
EN 16785-1	2015	Bio-based products - Bio-based content - Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis

The role of a bio-based economy is important in an age of fluctuating fossil fuel prices, rapid climate change and resource scarcity, as a model of more stable and sustainable economic growth. The proposal of a European circular economy has similar aims, and it is important that bio-based products are not neglected in favour of only recycling and the use of secondary materials. This is because in order to allow markets to grow without increasing our dependency on unsustainable fossil derived resources, biomass must be used as a feedstock. A circular economy and a bio-based economy can work in tandem to provide an adequate supply of resource efficient materials, and recirculation is complementary to both and does not form a distinction between secondary materials and biomass feedstocks. The concept of recirculation also help to promote bio-based products, lest they diminish in importance as a circular economy rises to prominence.

It is also important to recognise that the design of bio-based products can limit their end-of-life value, and bio-based products are not necessarily biodegradable. The standards produced by CEN/TC 411 are concerned with characterising products, especially the bio-based content, but not improving their design. Recirculation provides greater emphasis on end-of-life and product design than what is currently provided by existing standards and test methods.

11.1.4 **Waste framework directive**

The European directive **2008/98/EC** on waste establishes a hierarchy of end-of-life options in order to reduce waste and increase resource efficiency (see *ec.europa.eu/environment/waste/framework/index.htm*). Extended producer responsibility is introduced as well as the 'polluter pays principle'. The recirculation categories explained in this report are based on end-of-life options. The hierarchy used here in this work (Figure 4-3) is largely consistent with the waste hierarchy found in **2008/98/EC**.

The concept of 'end-of-waste' is introduced in European directive **2008/98/EC**. Waste is considered to be "*any substance or object which the holder discards or intends or is required to discard*". Recovery (recycling and the like) elevates the material from waste into a product, if the following conditions are met: The substance is commonly used and a market exists for it; a technical specification is fulfilled; and the product does not cause harm to humans or the environment. This process is governed by legislation and standards that dictate the technical specification. Recirculation incorporates this ethic of returning 'waste' to use as products. Future revisions to the waste framework directive and ecodesign directive in the context of a circular economy are bridged through the common ground established by the draft test method for recirculation as presented in this report.

11.1.5 **Ecodesign**

European directive **2009/125/EC** concerns the framework for ecodesign (limited to energy related products). Energy related products as a definition extends to insulation materials and water taps, with the function and performance of these products linked to energy consumption. Generally an 'energy-related-product' is taken to mean "*any good that has an impact on energy consumption during use which is placed on the market and/or put into service, and includes parts intended to be incorporated into energy-related products covered by this Directive which are placed on the market and/or put into service as individual parts for end-users and of which the environmental performance can be assessed independently*". Energy efficiency can be improved to the benefit of consumers and enhance the sustainability of the product. It is the responsibility of importers and producers to only place energy related products bearing the 'CE' conformity marking on the market.

Directive **2009/125/EC** is clear when it states the important phase of a products' life cycle (when it comes to determining the energy efficiency of that article) is the design phase. It is in the design of a product where the maximum efficiency is determined, and the knock-on effects of the design of a product impact economic and environmental factors. Environmental performance should be achieved in a cost effective way to support industrial competitiveness. Elaborating this concept of 'ecodesign' into a formal definition, **2009/125/EC** states "*ecodesign means the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle*".

A comprehensive optimisation of environmental performance is ideal. However a priority of greenhouse gas mitigation sits within the broader environmental challenges. The link between greenhouse gas emissions (most significantly carbon dioxide) and energy consumption is clear and so the measure of greenhouse gas mitigation is a reasonable indicator of energy efficiency as well as a key measure of environmental impact. Compliance to **2009/125/EC** is implemented through product-specific regulations, for example **Commission regulation (EU) No 813/2013** with regard to ecodesign requirements for space heaters and combination heaters. The applicable product groups are identified through working plans that are updated every three years.

The established ecodesign concept for energy related products is limited to design for maximised energy efficiency. Recent developments in the ecodesign concept (see *ec.europa.eu/DocsRoom/documents/105/attachments/1/translations/en/renditions/pdf*), and a draft standardisation request (see *ec.europa.eu/DocsRoom/documents/11465/attachments/1/translations/en/renditions/native*), are leading towards new ecodesign requirements for material efficiency to support **2009/125/EC**. The anticipated standards that will answer this request should cover the following product design aspects:

- Extending product lifetime.
- Ability to re-use components or recycle materials from products at end-of-life.
- Ability to recover energy from products at end-of-life.
- Use of re-used components and/or recycled materials in products.
- Ability to extract key components for reuse, repair, recycling and treatment.
- Methods to identify components by their mean-time to failure or environmental impact.
- Reporting formats for reusability, recyclability, and recoverability and calculation of recycled and re-used content in products.

The aims of ecodesign are complimentary to the objectives of recirculation, especially ecodesign for material efficiency. Recirculation is based on a horizontal methodology, and so could be used to cover lower value products that do not have dedicated ecodesign requirements described in legislation. This approach would avoid direct conflict, although both concepts basically have the same objectives and broadly speaking employ the same means of product design principles to achieve it. The recirculation test method could be adapted to meet new ecodesign for material efficiency principles once they are published.

11.1.6 The circular economy

The circular economy is an economic system where materials are valued for the service they provide, and maximising and extending that service through improved resource efficiency and less waste is more profitable and more sustainable. A product itself is not valuable, it is the function of that object that is valued. If a product's end-of-life means the material can only be discarded, it is not an efficient use of the resource and its potential to deliver a service.

The plan for the European legislative aspect of a circular economy was announced in December 2015, and focuses on waste reduction (see *ec.europa.eu/environment/circular-economy/index_en.htm*). This will require amendments to existing policies, such as the waste framework directive and the ecodesign directive that were previously discussed. Prior to that a report from the UK government highlighted the advantages of a bio-based economy with strong links to a circular economic model (see *www.gov.uk/government/uploads/system/uploads/attachment_data/file/408940/BIS-15-146_Bioeconomy_report_-_opportunities_from_waste.pdf*).

The ambitions set out for a circular economy can only be realised by improving waste collection attitudes and practices while also specifically designing products to be recirculated. It is the rethinking of products and how they are designed that can be addressed by the proposed test method describing recirculation. At a more basic level, just the way of thinking in terms of recirculation is helpful to adjust to a circular economy, and this is covered in Chapter 12. As the EC proposal for a circular economy begins to be realised, the value in the concept of recirculation should become evident.

12 The language of bio-based product recirculation

12.1 Current usage of the term renewable

'Renewable resources', 'renewable feedstocks' and 'renewable energy' are familiar terms applied to biomass and fuels made from biomass. A 'renewable resource' has been defined as a "*resource with the ability to be continually replenished by natural processes*" [BSI 2013]. 'Renewable material' has been defined as "*material that is composed of biomass and that can be continually replenished*" (**EN 16575**). The term 'resource' can generally be substituted with 'feedstock' when applicable to the input of bio-based product manufacturing. The same is true of definitions for the term 'renewable chemical' (although less prevalent), meaning "*a monomer, polymer, plastic, formulated product, or chemical substance produced from renewable biomass*" [US 2013]. Renewable energy is considered to come from a source that is not depleted when used directly or converted into energy, and so defers back to the definition of a renewable resource.

A bio-based product can be produced from a renewable feedstock but that does not guarantee that the article contributes to the replenishment of the renewable resources. The end-of-life of a bio-based product is not part of its definition. 'Recirculation' was proposed as a term to describe bio-based products with end-of-life options that facilitate the continued availability of the material the product is made from. **Open-Bio deliverable report D3.4** presents the definitions of recirculation and related terms. Key points are now summarised, in section 12.2.

12.2 Open-Bio definitions of renewability and related terms

The following passages are an adapted and much abbreviated version of **Open-Bio deliverable report D3.4**, in which the terminology of recirculated bio-based products is described. It is summarised in this update only to provide background to readers who need more context before applying the recirculation test method. The report attempted to place the description of a reusable, recyclable, or renewable substance on the product itself rather than its precursor resources. When the elements that constitute a molecule are considered renewable for example, the molecule itself is then renewable. In turn, a bio-based product consisting of renewable molecules is considered to be renewable also (Figure 12-1). Accordingly an article can be thought of in terms of the sum of its constituent molecules or atoms. This approach can be helpful when considering the life cycle of a bio-based product, because the complete article will not remain whole as its constituent parts are recirculated. Biodegradation is one example of this.

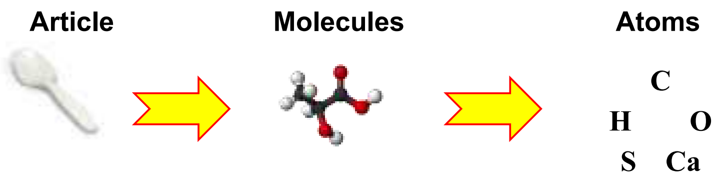

Figure 12-1. The composition of articles.

Every chemical product is produced from some form of feedstock. In terms of organic feedstocks these resources can be biomass or fossil derived intermediates. Broadly speaking elements are also incorporated into articles from three other sources: mineral reserves (the source of all metallic elements), water (by means of hydrolysis and hydration), and direct synthesis with atmospheric gases (*e.g.* oxidation chemistry). Wastes including higher value recycled articles are also considered as resources and may incorporate elements and molecules originally from any of the five resources identified.

The following definitions of recirculation were generated to treat articles as the sum of their constituent elements. The definitions for '*recyclable*', '*renewable*', and '*reusable*' are subsets of the over-arching recirculation definition (Figure 12-2), as all three involve the constituent elements of an article being returned to use.

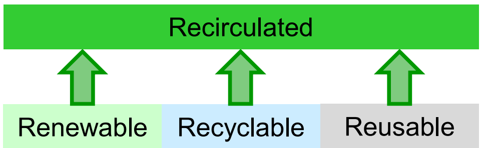

Figure 12-2. Hierarchy of renewability definitions.

Recirculated. *Returned to use within a certain timeframe by an anthropogenic process and/or a natural process. Any element that is not returned to use is considered in an* ***'****uncontrolled****'*** *framework. Recirculated includes the terms renewable, reusable and recyclable.*

Renewable. *Comes from renewable resources and is returned to use within a certain timeframe by a natural process.*

Recyclable. *Returned to use within a certain timeframe by an anthropogenic process.*

Reusable. *Returned to use within a certain timeframe without modification to the parent article or loss of performance.*

Some concessions have been made regarding the definitions to accommodate existing definitions that encompass the concept of renewability. For example '*renewable*' is specific to the recirculation of 100% bio-based products. This leaves biodegradable fossil derived articles unclassified with respect to the three subset definitions for '*recyclable*', '*renewable*', and '*reusable*'. Validation of successful design for recirculation (*i.e.* with the draft test method provided in this report) must be obtained to apply the term '*recirculated*' as defined above.

The use of inflectional suffixes is applicable to the subset definitions when appropriate: '*recycled*', '*renewed*', and '*reused*'. To consider these terms as valid, recirculation must be actually proved. Then the overarching term '*recirculated*' also acts as a more general term. With its derivational suffix, '*recirculatable*' is not part of the terminology developed here because the broadness of this definition undermines any potential usefulness. Note that the draft test method in this report does not cover use of the three subset definitions. Only claims of "*recirculated*" or "*designed for recirculation*" are permitted. This is for a number of reasons. Firstly, existing standards describing biodegradation, recycling, and reuse are not to be contradicted or superseded. Claims that a product is able to be recycled, or that it is made from recycled (secondary) materials, shall be made using appropriate standards. It is unnecessary to add additional claims. Additionally, the use of these terms for other purposes (especially 'renewable') has meant it is difficult for some business sectors to accept a new usage. Recirculation on the other hand is not used in any other context that might overlap with bio-based products, and so the potential for confusion is low.

13 Conclusion

This report fulfils an obligation of the Open-Bio project to investigate the renewability of bio-based products, and provide an indirect method to describe it. Over the course of the project, the terminology has evolved to a point where 'recirculation' is now used to describe the use of non-depleting feedstocks to create products made of reusable and recyclable materials, or renewable materials. Renewability is treated as one aspect of recirculation, depending on the end-of-life option for the product.

The recirculation methodology specifies requirements by which a bio-based product can be designed to be, and described as, recirculated. The purpose is to increase the value of bio-based products by extending product lifetime, reducing waste and environmental impact, while maximising the service provided by a (renewable) material. The context for this work is provided by the desire to accelerate the growth of the European bio-based economy. Meanwhile the anticipation of a circular economy creates added importance to the recirculation concept. The draft test method is based on product design requirements, with a focus on efficient end-of-life processing in order to return materials to use and avoid waste.

The decision to focus on a methodology different to a life cycle analysis (LCA) or a sustainability assessment is justified with reference to clause 5.5 in **EN ISO 14021**: "*The concepts involved in sustainability are highly complex and still under study. At this time there are no definitive methods for measuring sustainability or confirming its accomplishment. Therefore, no claim of achieving sustainability shall be made*". With the existence of standards for LCA (**EN 16760**) and sustainability criteria (**EN 16751**) for bio-based products, but without thresholds to indicate absolute sustainability, it was decided instead to provide guidance on product design. Thus an approach to improve LCA indicators and meet sustainability criteria is offered by the draft test method in this report.

The recirculation approach has been developed through open discussions in project meetings and the meetings documented in Chapter 10, as well as the feedback that contributed to **Open-Bio deliverable report D3.4**. Liaison with the work on labelling in Open-Bio work package 7, end-of-life in Open-Bio work package 6, and the other tasks in Open-Bio work package 3 regarding bio-based content has also shaped the finished draft test method.

The draft test method for the recirculation of bio-based products is akin to a certification scheme in many ways. Rather than act as a standalone standard, it would actually benefit from third party verification, especially when it comes to proving the most suitable end-of-life option. How the recirculation methodology can be best applied is not decided at this time, but for now it is offered as a tool to help product design in the context of promoting the use of biomass for making products, increasing material efficiency and reducing waste. New circular economy initiatives should find this work to be of use.

In order for the draft test method to successfully describe the recirculation of bio-based products, some definitions are required that will be unfamiliar to operators. In particular, the definition found in **Open-Bio deliverable report D3.4** for a 'renewable' bio-based product has concerned some parties because of the shift from talking about feedstocks to products, with an emphasis on end-of-life that dictates the application of the definition. This can be viewed as introducing a contradiction with existing definitions of renewable materials (**EN 16575**) but in fact only adds to it by stating the material is not renewable unless it can be returned into a feedstock. Two further conflicts exist. The first (and less significant) is created by requiring that reconditioning returns an article to the same working condition. Inferior performance is permitted in the terminology of **BS 8887-240**. Reconditioning is considered here to only extend product/component lifespan, and so actually is not covered by the description of recirculation. A final and more difficult inconsistency arises because recirculation sometimes requires a product to be completely (100%) bio-based. This is true of biodegradable products for example because the carbon is released into the atmosphere to be reclaimed (in a mass balance sense) as new biomass. This closed loop operates without a net loss of (carbon) resource. However a bio-based product can have quite low bio-based content, meaning biodegradable, bio-based products are not necessarily recirculated as permitted by this draft test method. It is not a contradiction as such, as bio-based products are not by default biodegradable. Nevertheless the bio-based product terms and requirements generated in Open-Bio could be viewed as not aligned with the published work of CEN/TC 411. In response, the concept of recirculation cannot permit fossil carbon to be a part of biodegradable products. This requirement cannot be relaxed, otherwise the whole concept is compromised. Instead, this conclusion should be considered to be insightful with respect to the design of biodegradability standards for bio-based products.

Biodegradability tends to be defined for types of product without differentiating between bio-based and fossil articles, but for bio-lubricants requirements for both bio-based content and biodegradability are present in the same standard (**prEN 16807**). Here the low threshold of bio-based content is inconsistent with the requirements needed to demonstrate a lubricant is recirculated (section 8.1.3). The conclusions of this work would endorse a review of standards that specify a minimum bio-based content for products that are designed to biodegrade. It may not be suitable or advantageous for 100% bio-based (carbon) content requirements to be implemented, but a distinction between renewable (in the context of recirculation), bio-based, and biodegradable needs to become more widely recognised and ultimately accepted.

Ultimately the purpose of this draft test method is not to consolidate the terminology that describes bio-based products, but to enhance the design of bio-based products and demonstrate biomass is used appropriately. This has meant pushing the boundaries of our understanding of renewability when associated to products, with the purpose to achieve a healthy bio-based economy prominent within the new framework of a European circular economy. It may be that the terminology is not appropriate for consumers, but at least material suppliers and producers should be more aware of their responsibility for sustainable product design as realised by demonstrating the recirculation of articles.

The publication of this report in its current format serves the purpose of creating awareness, but is not formally recognised as a test method. Beyond publication as a European standard, there are other formats that this work could potentially be published as. Anyone is welcome to apply the recirculation test method and principles as it currently stands as an internal tool (unless this report is superseded by the publication of a standard). If you wish to adapt this work for publication in a different format, please contact the authors using the contact details on the front page.