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

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Annex: Indirect calculation of re-circulation

14Attempted calculation methodology

14.1 Explanation of the calculation methodology

The original intention for this work was to extend the indirect calculation methods for bio-based content explored in **KBBPPS deliverable report D4.6** to also consider end-of-life options. In this way the calculation of bio-based content is extended beyond its original cradle-to-gate scope into an assessment that covers a cradle-to-grave range of requirements. The calculation was attempted, as is documented here in Chapter 14. Unfortunately in certain scenarios a number of problems occur, and other times the calculation is redundant. For example, if a bio-based product is mechanically recycled, the bio-based content does not change. This means the calculation of recirculation, essentially how much of the bio-based content is successfully processed at end-of-life and hence made available again as a secondary feedstock material, is no different to the original bio-based content calculation. For biodegradation, this is only measured by carbon dioxide evolution (or indirectly by oxygen demand), and so only the carbon material balance can be completed. Furthermore, test methods for biodegradation may only require as little as 50% biodegradation to be recorded over the duration of the test. This is indicative of complete biodegradation of single substances, but it is not precisely quantified. Therefore there is no strong case for a quantitative calculation of recirculation, and it could even be considered as misleading or confusing. As such no calculation of recirculation features in the draft test method (Chapter 6 to Chapter 9). In order to demonstrate the failings of the calculation method, and fulfil our obligation to the Open-Bio project, the development of the calculations is provided as section 14.1, and some case studies follow in section 14.2. It is not expected or anticipated that this calculation method will be improved sufficient to warrant latter inclusion in the draft test method and should not be attempted as a demonstration of recirculation.

14.1.1 **Basis of calculation**

A mass balance calculation may confirm the percentage of the bio-based product (by mass) that has been designed (and proven) to enter appropriate end-of-life treatments for recirculation. As part of the calculation the amount of waste is also identified. The material balance technique is used in an analogous way to how the bio-based content of the product is calculated (**prEN 16785-2**). If required the total bio-based content material balance shall be verified according to **EN 16785-1**, as established in **KBBPPS deliverable report D4.6**. This concept is extended here to describe material flows leading to end-of-life processes to provide greater alignment with all life cycle categories. The extent of recirculation is calculated according to the following equations (on a mass basis) where the following terms apply. Each calculation term can be expressed as bio-based carbon mass, total carbon mass, total bio-based mass, and total mass as required (see Table 9-1).

End-of-life calculation terms (report on a mass basis, *e.g.* kilograms, for a given unit of product, *e.g.* 1 kilogram):

- **a.** Bio-based manufacturing input
- **b.** Secondary materials input including recycled materials and captured CO_2
- **c.** Other manufacturing input
- **d.** Total manufacturing input
- **e.** Product (typically a component or substance within an article)
- **f.** Manufacturing process waste
- **g.** Manufacturing material balance check
- **h.** Reusable components
- **i.** Waste or losses from remanufacturing including discarded components
- **j.** Recyclable material within the product
- **k.** Losses and non-recyclable materials rejected from recycling processes
- **l.** Biodegradable substances contained in the product
- **m.** Non-biodegradable mass entering compost or released into the environment
- **n.** Component parts with no end-of-life option for recirculation
- **o.** End-of-life processing rate

Manufacturing material balance equations:

$$\mathbf{d} = \mathbf{a} + \mathbf{b} + \mathbf{c} \qquad \text{(equation 1.)}$$

$$\mathbf{e} = \mathbf{d} - \mathbf{f} \qquad \text{(equation 2.)}$$

$$\mathbf{g} = \mathbf{e} + \mathbf{f} - \mathbf{d} = 0 \qquad \text{(equation 3.)}$$

Recirculation equations:

$$\mathbf{e} = \mathbf{h} + \mathbf{j} + \mathbf{l} + \mathbf{n} \qquad \text{(equation 4.)}$$

$$\mathbf{o} = (\mathbf{h} + \mathbf{j} + \mathbf{l} - \mathbf{i} - \mathbf{k} - \mathbf{m}) / \mathbf{e} \qquad \text{(equation 5.)}$$

Recirculation represents the end-of-life options that apply to the materials within the product that are not made from depleting, non-renewable resources. Bio-based carbon content and total bio-based content are calculated as shown below (described in reference to the cells of Table 9-1 where an **i** suffix (*e.g.* **a-i**) refers to bio-based carbon mass, **ii**; total carbon mass, **iii**; total bio-based mass, and **iv**; total mass as required). Any declaration of a calculated total bio-based content must adhere to the procedure established in **prEN 16785-2**, which shall be possible to validate using **EN 16785-1**. Recycled content in the product shall be declared according to **EN 15343** or equivalent. The proportion of carbon atoms within the product that come from recycled material should also be calculated, according to equation 8. To reiterate, equation 8 and equation 9 describe the amount of recycled material in a product/component, not what has the potential to be recycled. Recirculation is the calculation of bio-based and secondary manufacturing materials that also have satisfactory end-of-life options (equation 10), where *n* is the number of those components, substances, or portions of substances in the case of chemical recycling that comply, as identified in equations 1-5. Specific recirculation equations on a carbon (equation 11) and a total mass basis (equation 12) are also given.

Bio-based content (χ_{bio}) calculations:

Bio-based carbon content (χ_{bio}^{C}) /% = **e-i** / **e-ii** (equation 6.)

Total bio-based content (χ_{bio}^{mass}) /% = **e-iii** / **e-iv** (equation 7.)

Recycled content (χ_{R}):

χ_{R}^{C} /% = {mass of recycled material · carbon content /%} / **e-ii** (equation 8.)

χ_{R}^{mass} /% = {mass of recycled material} / **e-vi** (equation 9.)

Recirculation (○):

$$○ /\% = \sum_{i=1}^{n}\left\{\mathbf{o}\cdot(\chi_{bio}+\chi_{R})\cdot\frac{M_i}{M}\right\} \quad \text{(equation 10.)}$$

$$○^{C} /\% = \sum_{i=1}^{n}\{\mathbf{o\text{-}ii}\cdot(\chi_{bio}^{C}+\chi_{R}^{C})\cdot\frac{M_i^{C}}{M^{C}}\} \quad \text{(equation 11.)}$$

$$○^{mass} /\% = \sum_{i=1}^{n}\left\{\mathbf{o\text{-}iv}\cdot(\chi_{bio}^{mass}+\chi_{R}^{mass})\cdot\frac{M_i^{mass}}{M^{mass}}\right\} \quad \text{(equation 12.)}$$

For further clarification of this calculation process, a schematic is provided as Figure 14-1 to demonstrate what circumstances can be considered as recirculation. For this theoretical article, four end-of-life scenarios have been described for its four different components. None of the components contain any recycled materials. If a component is a composite material containing a biodegradable but fossil derived substance, and a bio-based but non-biodegradable substance, no recirculation is demonstrated if the part enters a composting facility. Bio-based content and biodegradability are both required attributes for a recirculated substance.

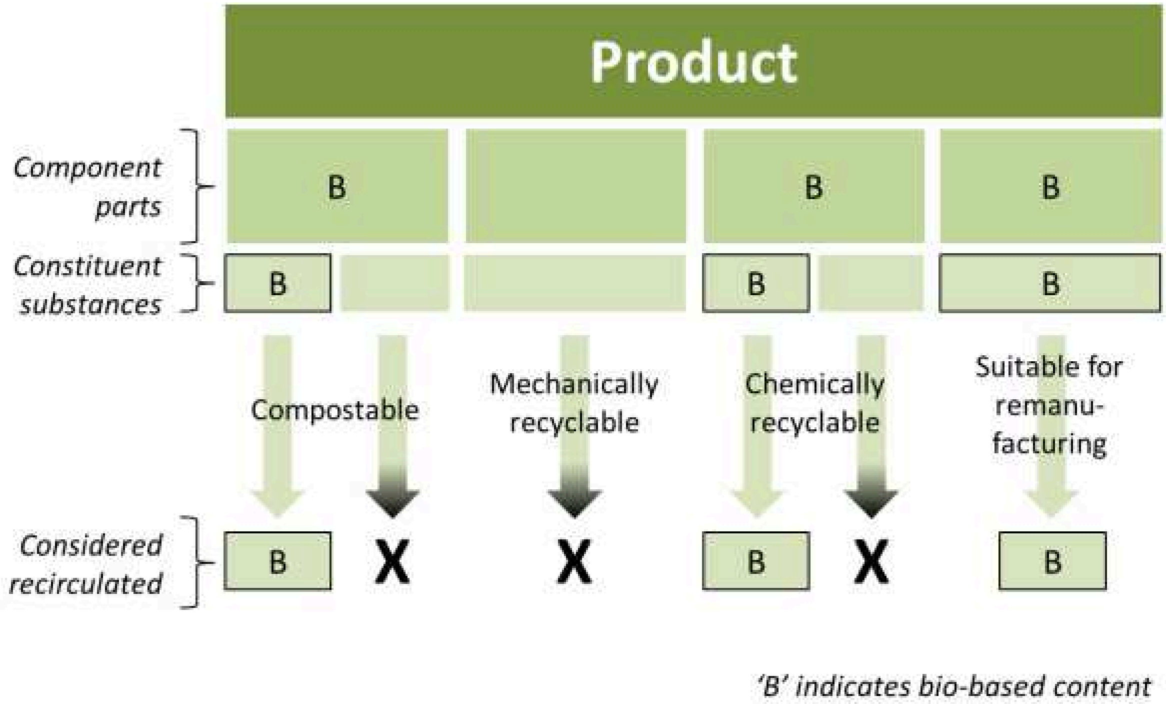

Figure 14-1 Recirculation requires substances to be treatable at end-of-life and either bio-based or alternatively made of other renewable feedstocks.

Any component parts that are mechanically recyclable must also be made of recycled material or biomass to be considered as recirculated (Figure 14-1). If it is possible to mechanically recycle a composite material made of a bio-based substance and a primary fossil feedstock derived substance, only the recycling of the bio-based product contributes to recirculation. Chemical recycling produces different substances not present in the original product, and so a distinction must be made at the molecular level regarding what is recirculated. In partially bio-based PET, only the bio-based ethylene glycol monomer can be reclaimed or transformed by chemical recycling as part of a recirculation strategy (Figure 14-2). The fossil derived terephthalate monomer does not qualify. (Refer to **Open-Bio deliverable report D6.10** for information on calculating recovery by chemical recycling.) The calculation of recirculated remanufactured parts shall be performed on the reused aspect of the component. Any fittings, protective covers, *etc*. that are removed and replaced with new parts count as losses.

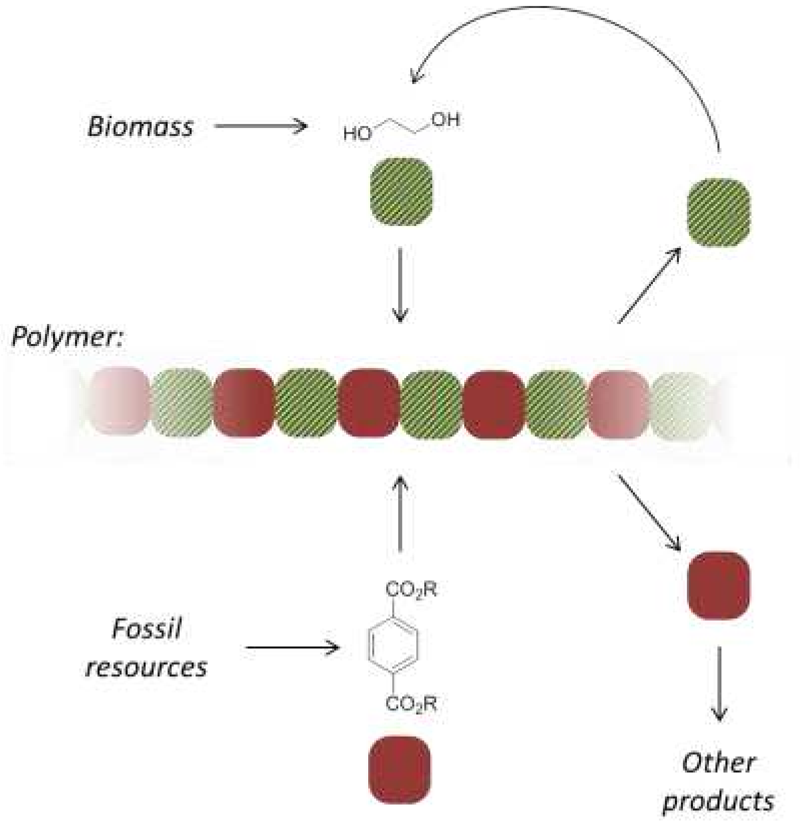

Figure 14-2 Chemical recycling recirculation scheme of bio-based ethylene glycol in PET.

14.1.2 Calculation and assessment

a) The self-assessment template in section 9.1.2 (Table 9-1) should be used for internal checks by the product design team and manufacturer. Separate components are treated individually on the basis of what is being processed at end-of-life. Components that consist of composites have to be assessed on the basis of each substance if the end-of-life option is different for each. Chemical recycling of specific monomers within a polymer requires that each type of monomer is treated separately.
b) Reporting in B2B communications shall follow the requirements in section 9.1, using Table 9-2.
c) Equations 1-3 are required to check the manufacturing material balance (**prEN 16785-2**).
d) Equation 4 is used to ensure all component parts of the product (present in quantities equal or greater than 1%) are accounted for.
e) The equations can be calculated on the basis of total mass, total bio-based mass, total carbon mass, and bio-based carbon mass, including end-of-life processing efficiency (equation 5).
f) For chemical and mechanical recycling, the total mass of all useful, marketable products is used towards calculation term **j**. Products that are subsequently incinerated for energy recovery as part of the recycling operation are subtracted in calculation term **k** (equation 5).

g) *Upon biodegradation, the maximum allocation of bio-based carbon is used to calculate recirculation. For example, if a product with 40% bio-based carbon content has a reported biodegradation of 50% (CO_2 evolution basis), all the bio-based carbon content is calculated as being recirculated. If the extent of biodegradation is 30%, then one quarter of the bio-based content remains outside the recirculation loop.
h) Recirculation shall be calculated using equation 10. Specifically if the bio-based content of the article is reported in terms of carbon mass, equation 11 shall be used. If the bio-based content is preferentially reported on a total mass basis, equation 12 shall be used.
i) Biodegradation is not calculated on the basis of total mass, only carbon mass. Therefore recirculation by biodegradation shall be calculated on the basis of carbon mass (equation 11).
j) Additionally, reporting recirculation on the basis of the total mass of the product only is permitted if the determined biodegradability is complete within the accepted error margin of the test method (*e.g.* equal biodegradation at test plateau relative to an acceptable reference substance ± test error margin).

**The recirculation calculations can produce values representing low recirculation of material that is not permissible by the requirements of the draft test method (Chapter 6 to Chapter 9). No thresholds are in place because this calculation methodology described in Chapter 14 is not accepted within the draft test method.*

14.2 Examples of the recirculation calculation

Some representative product examples are given to demonstrate how recirculation can be calculated, which highlights how the design of the product is crucial.

14.2.1 **Bio-based PET film**

Polyethylene terephthalate (PET) films are used in packaging, insulation, recording tapes *etc*. The availability of bio-based ethylene glycol means PET can be produced partially from biomass (Table 9-7). The resulting plastic is 20% bio-based according to carbon content and 31% bio-based on a total mass basis. The manufacturing process is considered to be the reaction between ethylene glycol and dimethyl terephthalate, meaning the original feedstocks are bio-ethanol, water, oxygen, methanol and *p*-xylene (for a detailed description refer to **KBBPPS deliverable report D4.5**).

The self-assessment template has been completed for a PET film (Table 14-1). Using the synthesis of PET to describe the manufacturing mass input and waste streams, the bio-based content has been calculated. The product is commonly collected and processed for mechanical recycling. Polyethylene terephthalate is not biodegradable. In this simple example the PET film is assumed not to contain any other substances above 1% and is considered as a single component product. The recirculation characteristics of the PET film are reported for B2B purposes in Table 14-2. This template is modified from that in Chapter 9 (Table 9-2) to include the mathematical basis of reporting. Through mechanical recycling the PET is recirculated, but restricted by the low bio-based content of the product. A 100% bio-based PET plastic under the same circumstances would be 100% recirculated. An equivalent product containing recycled materials (*i.e.* rPET) and no biomass would not apply to this draft test method because it is not bio-based. Only if a rPET film is a component of a bio-based product does it qualify for assessment. The bio-based content calculation shall always be consistent with the approach established in **prEN 16785-2**. For this example of a product with a dedicated biomass feedstock, ideally the bio-based carbon content would be analytically determined using **prEN 16640** and total bio-based content validated using **EN 16785-1** to support the claims in Table 14-1. Table 14-1 and Table 14-2 show that end-of-life management is not an issue for this product. Its limitation is the low bio-based content.

Table 14-1 Recirculation calculation data for a PET product.

		(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	13	13	42	42
b	Recycled input				
c	Other input		63		139
d	Total input		75		180
e	Product	13	63	31	100
		Bio-based carbon content /%	20%	Total bio-based content /%	31%
		Recycled carbon content /%	0%	Recycled content /%	0%
f	Process waste	0	13	9	80
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material	13	63	31	100
k	Waste/losses	0	0	0	0
l	Biodegradable				
m	Waste/losses				
n	No options				
o	Processing rate /%	100%	100%	100%	100%
		Carbon recirculation /%	20%	Total mass recirculation /%	31%

Table 14-2 Reporting template for a PET film.

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

Component number	1			

Characterisation

Component name	Film			
Mass /%	100%			
Main substance	PET			
Bio-based carbon content /%	20%			
Total bio-based content /%	31%			
Recycled content /%	0%			

End-of-life

Treatment	Mechanical recycling			
Efficiency (material basis) /%	100%			
End-of-life problems	-			

Recirculation /%	20% (carbon basis) 31% (total mass)

Additional information

Design features	-
Instructions on proper use	-
Collection schemes	Widely collected (resin identification code 1).
Disassembly instructions	Not required.
Further information	-

14.2.2 **PET bottle with PP cap and label**

The declaration form in **EN 13430** (a standard for the recycling of packaging) contains an example of a polyethylene terephthalate (PET) bottle, which has been adapted for use here. The bottle cap is made from polypropylene (PP) and in this example a full wrap shrink label made from orientated polystyrene (PS) is applied to the product (Figure 14-3). The material composition of the whole article (38 g per unit) is 82% PET bottle, 8% PP cap, and 10% PS label (Table 14-3). The product is assembled from chemically synthesised polymers, and so a carbon mass balance is possible. Although it is not shown, the recirculation calculations depend on this. The manufacture of the individual components is not dealt with here. The PET is assumed to be partially bio-based, produced using ethylene glycol derived from bio-ethanol as in the previous example.

Figure 14-3 Plastic bottles with full wrap shrink labels.

Table 14-3 Component parts of a plastic bottle by mass.

Component	PET	PP	PS
Bottle (82%)	31.16 g total mass 9.74 g bio-based mass 19.48 g carbon 3.90 g bio-carbon		
Cap (8%)		3.04 g total mass 2.60 g carbon	
Label (10%)			3.8 g total mass 3.51 g carbon

Despite being made from recyclable materials, the design of the product means that the potential for recirculation through mechanical recycling cannot be realised. The use of a full-wrap shrink label means the PET bottle itself, as well as its label, cannot be effectively recycled (see *www.napcor.com/pdf/NAPCORfullwrap.pdf* and *www.plasticsrecycling.org/images/pdf/market_development/web_seminars/APR_Sleeve_Label_Web_Seminar_08_2013.pdf*). This is because PET recyclates are separated from conventional roll-on labels using floatation and elutriation techniques, which is not possible with shrink labels. These labels can then interfere with the near-infra red sorting of plastics and so PET bottles with full wrap shrink labels are often rejected from recycling operations. Therefore the initial self-assessment shows poor recirculation, with only the PP cap free to be separated and recycled (Table 14-4). If the product was redesigned to have separable parts the recirculation could reach 34%, also assuming the PP cap is now made of recycled material but that the label is still not recyclable (

Table 14-5). The mass of each component and its material composition has been kept the same for comparison. The low bio-based content of the major PET component still limits the achievable recirculation, as reported in Table 14-6. The recirculation of 34% equals the sum of the total bio-based content and the recycled content of the whole product because both the bio-based PET and the recycled PP are assumed to be completely recycled with maximum efficiency (as permitted by the clauses of section 8.1.1 where mechanical recycling is concerned).

Table 14-4 Recirculation calculation data for an inadequately designed PET bottle product.

		(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	0.0039	0.0039	0.0097	0.0097
b	Recycled input				
c	Other input		0.0217		0.0283
d	Total input		0.0256		0.0380
e	Product	0.0039	0.0256	0.0097	0.0380
		Bio-based carbon content /%	15%	Total bio-based content /%	26%
		Recycled carbon content /%	0%	Recycled content /%	0%
f	Process waste	0	0	0	0
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material	0.00390	0.0256	0.0097	0.0380
k	Waste/losses	0.00390	0.0230	0.0097	0.0350
l	Biodegradable				
m	Waste/losses				
n	No options				
o	Processing rate /%	0%	10%	0%	8%
		Carbon recirculation /%	0%	Total mass recirculation /%	0%

Table 14-5 Recirculation calculation data for an improved PET bottle design.

		(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	0.0039	0.0039	0.0097	0.0097
b	Recycled input				
c	Other input		0.0217		0.0283
d	Total input		0.0256		0.0380
e	Product	0.0039	0.0256	0.0097	0.0380
		Bio-based carbon content /%	15%	Total bio-based content /%	26%
		Recycled carbon content /%	10%	Recycled content /%	8%
f	Process waste	0	0	0	0
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material	0.00390	0.0256	0.0097	0.0380
k	Waste/losses	0	0.0035	0	0.0038
l	Biodegradable				
m	Waste/losses				
n	No options				
o	Processing rate /%	100%	86%	100%	90%
		Carbon recirculation /%	25%	Total mass recirculation /%	34%

Table 14-6 Communication of a PET bottle recirculation characteristics (with improved design).

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

Component number	1	2	3	4

Characterisation

Component name	Bottle	Cap	Label	-
Mass /%	82%	8%	10%	-
Main substance	PET	PP	PS	-
Bio-based carbon content /%	20%	0%	0%	-
Total bio-based content /%	31%	0%	0%	-
Recycled content (carbon) /%	0%	100%	0%	-
Recycled content (total) /%	0%	100%	0%	-

End-of-life

Treatment	Mechanical recycling	Mechanical recycling	Mechanical recycling	-
Efficiency (material basis) /%	100%	100%	0%	-
End-of-life problems	-	-	Separation	-

Recirculation /%	25% (carbon basis) 34% (total mass)

Additional information

Design features	New easy to remove label (see product disposal instructions on packaging)
Instructions on proper use	Single use only
Collection schemes	Municipal collection
Disassembly instructions	Remove label before recycling
Further information	-

14.2.3 **Chemical recycling of PLA cutlery**

A 71% bio-based polylactic acid (PLA) cutlery product could be used for production of ethyl lactate as a secondary product by chemical recycling. The remainder of the product mass is an inorganic filler containing no carbon (*e.g.* calcium sulphate) (Table 14-7). The end-of-life option produces a new product, and so the process is open-loop. The efficiency of the chemical transesterification of PLA to ethyl lactate is assumed to deliver 85% of the maximum theoretical conversion. The production of the original cutlery product is taken to be the blending of the two ingredients, and the manufacturing losses recycled internally within the plant.

Table 14-7 Composition of the PLA composite material (per 100 kg).

Component	PLA	Binder
Composite	71.0 kg total mass 71.0 kg bio-based mass 35.5 kg carbon 35.5 kg bio-carbon	29.0 kg total mass

Table 14-8 and Table 14-9 present the recirculation data.

Table 14-8 Recirculation calculation data for a PLA composite: (1) PLA ingredient.

		(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	35.5	35.5	71.0	71.0
b	Recycled input				
c	Other input		0		0
d	Total input		35.5		71.0
e	Product	35.5	35.5	71.0	71.0
		Bio-based carbon content /%	100%	Total bio-based content /%	100%
		Recycled carbon content /%	0%	Recycled content /%	0%
f	Process waste	0	0	0	0
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material	35.5	35.5	71.0	71.0
k	Waste/losses	5.3 (15%)	5.3 (15%)	10.7 (15%)	10.7 (15%)
l	Biodegradable				
m	Waste/losses				
n	No options	0	0	0	0
o	Processing rate /%	85%	85%	85%	85%
		Carbon recirculation /%	85%	Total mass recirculation /%	85%

When calculating the end-of-life options for recirculation, the two materials need to be considered separately, for the chemical recycling only applies to one material (PLA). Otherwise the calculation is not correct. The B2B reporting template is still completed as a description of one component to preserve the confidentially of the product's composition (Table 14-10). Recirculation is calculated at 60% (total mass basis). This is a result of the 85% efficiency of the chemical recycling of PLA (71% of the product mass). Equation 12 is applied as indicated below:

$\circlearrowleft^{mass}$ /% = $\sum_{i=1}^{n}\left\{\mathbf{o\text{-}iv}\cdot(\chi_{bio}^{mass}+\chi_{R}^{mass})\cdot\frac{M_i^{mass}}{M^{mass}}\right\}$

$\circlearrowleft^{mass}$ /% = $\left\{\mathbf{85}\%\cdot(100\%+0\%)\cdot\frac{71}{100}\right\}+\left\{\mathbf{0}\%\cdot(0+0)\cdot\frac{29}{100}\right\}$ = 60%

The carbon recirculation is 85%, corresponding to the efficiency of chemical recycling, because the recycled ingredient (PLA) contains all the carbon in the product and is itself completely bio-based.

Table 14-9 Recirculation calculation data for a PLA composite: (2) inorganic ingredient.

		(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	0	0	0
b	Recycled input	0	0	0	0
c	Other input	0	0	0	29
d	Total input	0	0	0	29
e	Product	0	0	0	29
		Bio-based carbon content /%	0%	Total bio-based content /%	0%
		Recycled carbon content /%	0%	Recycled content /%	0%
f	Process waste	0	0	0	0
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material				
k	Waste/losses				
l	Biodegradable				
m	Waste/losses				
n	No options	29	29	29	29
o	Processing rate /%	0%	0%	0%	0%
		Carbon recirculation /%	0%	Total mass recirculation /%	0%

Table 14-10 Reporting template for a PLA composite suitable for chemical recycling.

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

Component number	1			

Characterisation

Component name	Cutlery			
Mass /%	100%			
Main substance	PLA			
Bio-based carbon content /%	100%			
Total bio-based content /%	71%			
Recycled content /%	0%			

End-of-life

Treatment	Chemical recycling			
Efficiency (material basis) /%	85% (assumed)			
End-of-life problems	-			

Recirculation /%	85% (carbon basis) 60% (total mass)

Additional information

Design features	-
Instructions on proper use	-
Collection schemes	Return to supplier for chemical recycling.
Disassembly instructions	-
Further information	Also compostable.

The additional information section in Table 14-10 can also be used to indicate alternative end-of-life options. Any claim will need to be justified to the same level as the primary end-of-life approach. Reporting of all feasible end-of-life options is possible with **FprEN 16848**.

If the recirculation calculation is performed on the PLA composite as a whole, where only the PLA portion is suitable for chemical recycling, the result is erroneous on a total mass basis. In the recirculation equation (equation 12), the 85% chemical recycling rate must be calculated against the 100% bio-based PLA material that is actually recycled, and not multiplied by the 71% total bio-based content of the product. The result is valid on a carbon-only basis because there is no carbon in the filler material to skew the result. The recirculation calculations (equations 10-12) shall only be applied as a description of substances that intentionally enter end-of-life processes. In the case of composite materials, different substances need to be treated separately. Sometimes chemical recycling is only applied to specific monomers of plastics and these need to be distinguished from the remainder of the polymer.

Table 14-11 Incorrect recirculation calculation data for a PLA composite.

		(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	35.5	35.5	71.0	71.0
b	Recycled input				
c	Other input		0		29.0
d	Total input		35.5		100
e	Product	35.5	35.5	71.0	100
		Bio-based carbon content /%	100%	Total bio-based content /%	71%
		Recycled carbon content /%	0%	Recycled content /%	0%
f	Process waste	0	0	0	0
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material	35.5	35.5	71.0	71.0
k	Waste/losses	5.3 (15%)	5.3 (15%)	10.7 (15%)	10.7 (15%)
l	Biodegradable				
m	Waste/losses				
n	No options	0	0	0	29
o	Processing rate /%	85%	85%	85%	60%
		Carbon recirculation /%	85%	Total mass recirculation /%	43% (should be 60%)

14.2.4 **Biodegradable food container**

Compostable bagasse or wheat straw food containers (*e.g.* bowls) with a lid made of recycled poly(ethylene terephthalate) (rPET) are commercially available bio-based products (for example: *worldcentric.org/biocompostables/bowls/plantfiber* and *www.biopac.co.uk/c/146/natural-pac-bowls-trays*). Test result certificates for compostability and bio-based content are available online for some of these products (see *worldcentric.org/sustainability/reports*). Here the example is of a wheat straw derived bowl and a rPET lid (Table 14-12).

Table 14-12 Material composition of the component parts of a food container (per 100 kg mass basis).

Component	Wheat straw	Recycled PET	Binder (succinic anhydride)
Bowl (60%)	94% (56.25 kg)		6% (3.75 kg)
Lid (40%)		100% (40 kg)	

Biodegradation of the bowl component (93% bio-based carbon content, 94% total bio-based content) is reported to be 95%. This means all of the bio-based carbon can be allocated as CO_2 generated by biodegradation (Figure 14-4). The carbon recirculation calculation (equation 11) produces a result of 88%, but this can be overruled for biodegradation processes to permit the maximum recirculation for the amount of bio-based carbon content present (see section 14.1.2):

$\circlearrowleft^C$ /% = $\sum_{i=1}^{n}\{\textbf{o-ii}\cdot(\chi_{bio}^{C}+\chi_{R}^{C})\cdot\frac{M_i^C}{M^C}\}$ (original form of equation 11)

$\circlearrowleft^C$ /% = $\{95\%\cdot(93\%+0\%)\cdot\frac{M_i^C}{M^C}\} = 88\%\cdot\frac{M_i^C}{M^C}$ (without allocation)

$\circlearrowleft^C$ /% = $\sum_{i=1}^{n}\{\textbf{o-i}\cdot(\chi_{bio}^{C}+\chi_{R}^{C})\cdot\frac{M_i^C}{M^C}\}$ (adapted form of equation 11)

$\circlearrowleft^C$ /% = $\{100\%\cdot(93\%+0\%)\cdot\frac{M_i^C}{M^C}\} = 93\%\cdot\frac{M_i^C}{M^C}$ (with allocation)

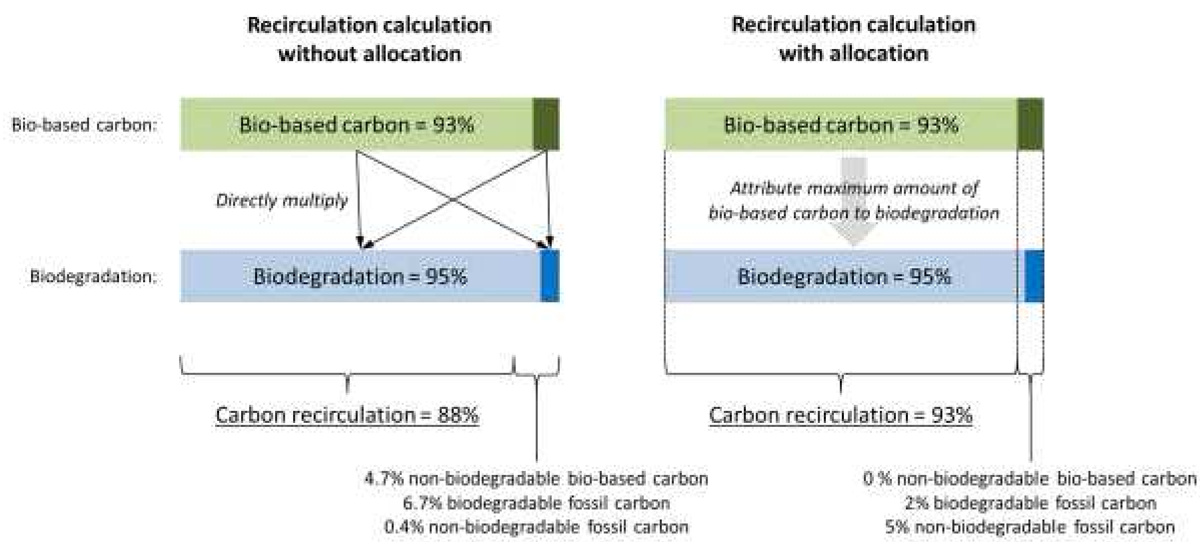

Figure 14-4 A schematic of the allocation process for allocating the maximum recirculation in biodegradation processes.

Without complete biodegradation reporting of recirculation on the basis of total mass of the article is not permitted (Table 14-13). The lid component is fully recyclable (

Table 14-14), bringing the total carbon recirculation to 96% (

Table 14-15). The lid component is not bio-based, but as part of a bio-based product qualifies for assessment.

Table 14-13 Recirculation calculation data for a wheat straw bowl.

		(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	23.9	23.9	56.3	56.3
b	Recycled input		0		0
c	Other input		1.8		3.7
d	Total input		25.7		60.0
e	Product	23.9	25.7	56.3	60.0
		Bio-based carbon content /%	93%	Total bio-based content /%	94%
		Recycled carbon content /%	0%	Recycled content /%	0%
f	Process waste	0	0	0	0
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material				
k	Waste/losses				
l	Biodegradable	23.9	25.7	56.3	60.0
m	Waste/losses	0 (allocated)	1.3 (5% test error)	-	-
n	No options				
o	Processing rate /%	100% (allocated)	95%		
		Carbon recirculation /%	93% (allocated)	Total mass recirculation /%	-

Table 14-14 Recirculation calculation data for a recycled PET food container lid.

		(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	0	0	0
b	Recycled input		25.0		40.0
c	Other input		0		0
d	Total input		25.0		40.0
e	Product	0	25.0	0	40.0
		Bio-based carbon content /%	0%	Total bio-based content /%	0%
		Recycled carbon content /%	100%	Recycled content /%	100%
f	Process waste	0	0	0	0
g	Material balance	0	0	0	0
End-of-life					
h	Reusable parts				
i	Waste/losses				
j	Recyclable material	0	25.0	0	40.0
k	Waste/losses	0	0	0	0
l	Biodegradable				
m	Waste/losses				
n	No options				
o	Processing rate /%		100%		100%
		Carbon recirculation /%	100%	Total mass recirculation /%	100%

Table 14-15 Reporting template for a biodegradable food container.

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

Component number	1	2		

Characterisation

Component name	Bowl	Lid		
Mass /%	60%	40%		
Main substance	Wheat straw	rPET		
Bio-based carbon content /%	93%	-		
Total bio-based content /%	94%	-		
Recycled content /%	-	100%		

End-of-life

Treatment	Composting	Recycling		
Efficiency (material basis) /%	95%	100%		
End-of-life problems	-	-		

Recirculation /%	96% (carbon basis)

Additional information

Design features	-
Instructions on proper use	-
Collection schemes	-
Disassembly instructions	Components separable by hand
Further information	-

For completeness, the self-assessment for the entire product (bowl plus lid) is presented as Table 14-16). The bio-based carbon content of the entire product is 47% (recycled carbon content is 49%).

Table 14-16 Recirculation calculation data for a biodegradable food container (bowl and lid).

		(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	23.9	23.9	56.3	56.3
b	Recycled input		25.0		40.0
c	Other input		1.8		3.7
d	Total input		50.7		100
e	Product	23.9	50.7	56.3	100
		Bio-based carbon content /%	47%	Total bio-based content /%	56%
		Recycled carbon content /%	49%	Recycled content /%	40%
f	Process waste	0	0	0	0
g	Material balance	0	0	0	0
End-of-life: component 1 (bowl)					
l	Biodegradable	23.9	25.7	56.3	60.0
m	Waste/losses	0 (allocated)	1.3 (5% test error)		
n	No options				
o	Processing rate /%	100% (allocated)	95%		
End-of-life: component 2 (lid)					
j	Recyclable material	0	25	0	40
k	Waste/losses	0	0	0	0
n	No options				
o	Processing rate /%		100%		100%
		Carbon recirculation /%	96%	Total mass recirculation /%	-

15 List of standards

BS 8887-1	Design for manufacture, assembly, disassembly and end-of-life processing (MADE). Part 1. General concepts, process and requirements (2006).
BS 8887-2	Design for manufacture, assembly, disassembly and end-of-life processing (MADE). Part 2. Terms and definitions (2009).
BS 8887-220	Design for manufacture, assembly, disassembly and end-of-life processing (MADE). Part 220. The process of remanufacture. Specification (2010).
BS 8887-240	Design for manufacture, assembly, disassembly and end-of-life processing (MADE). Part 240. Reconditioning (2011).
BS 8903	Principles and framework for procuring sustainably. Guide (2010).
CEN/TR 16721	Bio-based products. Overview of methods to determine the bio-based content (2014).
CEN/TR 16957	Bio-based products. Guidelines for life cycle inventory (LCI) for the end-of-life phase (2016).
CEN/TS 16398	Plastics. Template for reporting and communication of bio-based carbon content and recovery options of biopolymers and bioplastics. Data sheet (2012).
CEN/TS 16766	Bio-based solvents. Requirements and test methods (2015).
EN 13427	Packaging. Requirements for the use of European Standards in the field of packaging and packaging waste (2004).
EN 13428	Packaging. Requirements specific to manufacturing and composition. Prevention by source reduction (2004).
EN 13429	Packaging. Reuse (2004).
EN 13430	Packaging. Requirements for packaging recoverable by material recycling (2004).
EN 13431	Packaging. Requirements for packaging recoverable in the form of energy recovery, including specification of minimum inferior calorific value (2004).
EN 13432	Packaging. Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging (2000).
EN 13437	Packaging and material recycling. Criteria for recycling methods. Description of recycling processes and flow chart (2003).

EN 14995	Plastics. Evaluation of compostability. Test scheme and specifications (2006).
EN 15343	Plastics. Recycled plastics. Plastics recycling traceability and assessment of conformity and recycled content (2007).
EN 15347	Plastics. Recycled Plastics. Characterization of plastics waste (2007).
EN 15348	Plastics. Recycled plastics. Characterization of poly(ethylene terephthalate) (PET) recyclates (2014).
EN 16751	Bio-based products. Sustainability criteria (2016).
EN 16575	Bio-based products. Vocabulary (2014).
EN 16760	Bio-based products. Life cycle assessment (2015).
EN 16785-1	Bio-based products. Bio-based content. Determination of the bio-based content using the radiocarbon analysis and elemental analysis (2015).
EN ISO 14001	Environmental management systems. Requirements with guidance for use (2004).
EN ISO 14006	Environmental management systems. Guidelines for incorporating ecodesign (2011).
EN ISO 14020	Environmental labels and declarations. General principles (2001).
EN ISO 14021	Environmental labels and declarations. Self-declared environmental claims (type II environmental labelling) (1999).
EN ISO 14855-1	Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions. Method by analysis of evolved carbon dioxide. Part 1: General method (2012).
FprEN 16848	Bio-based products. Template for B2B reporting and communication of characteristics. Data sheet (2015, draft).
FprCEN/TS 17035	Surface Active Agents - Bio-based surfactants - Requirements and test methods (2016, draft).
ISO/TR 14062	Environmental management. Integrating environmental aspects into product design and development (2002).
ISO 16620-2	Plastics. Bio-based content. Part 2: Determination of bio-based carbon content (2015).
ISO 1928	Solid mineral fuels. Determination of gross calorific value by the bomb calorimetric method and calculation of net calorific value (2009).

NTA 8080-1	Sustainably produced biomass for bioenergy and biobased products. Part 1: Sustainability requirements (2014, draft).
NTA 8080-2	Sustainably produced biomass for bioenergy and biobased products. Part 2: Chain-of-custody requirements (2014, draft).
prEN 16640	Bio-based products. Bio-based carbon content. Determination of the bio-based carbon content using the radiocarbon method (2015, draft).
prEN 16785-2	Bio-based products. Bio-based content. Part 2: Determination of the bio-based content using the material balance method (2015, draft).
prEN 16807	Liquid petroleum products. Bio-lubricants. Criteria and requirements of bio-lubricants and bio-based lubricants (2014, draft).
prEN 16935	Bio-based products. B2C reporting and communication. Requirements for claims (2015, draft).

16 References

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