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Clark, James Hanley orcid.org/0000-0002-5860-2480, Farmer, Thomas James orcid.org/0000-0002-1039-7684, Moity, Laurianne et al. (1 more author) (2014) Definitions for renewable elements and renewable molecules. Research Report. Open-Bio

10.13140/2.1.1034.3042

Open-BIO

Opening bio-based markets via standards, labelling and procurement

Work package N° 3
Bio-based content and sustainability impacts

Deliverable N° 3.4:

Definitions for renewable elements and renewable molecules

Public

Version: 1
York (UK), June 2014

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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.

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Summary

Described in this report is an attempt produce definitions for renewable elements and molecules (as components of bio-based products). The purpose of these definitions is to assist the Open-BIO consortium when preparing sustainability criteria for the indirect assessments of bio-based products. Definitions were prepared and proposed to bio-based product stakeholders as part of a consortium led workshop (Cologne, Germany), as well as to members to the Green Chemistry Centre of Excellence (University of York, UK), Open-BIO project partners, and delegates at the 7th International Conference on Bio-Based Materials (Cologne, Germany). After these discussions it was decided to generate a family of definitions addressing specific aspects of the recirculation of elements and molecules as they are returned to use. A single overarching definition of renewability was not seen as appropriate for use horizontally across all bio-based products and chemical articles in general.

In order to track the constituent elements and molecules contained within an article before and after use, suitable definitions describing renewability, considering both up-stream and down-stream movements have been prepared. Several pathways have been identified and differentiated thusly: "*renewable*", "*reusable*", "*recyclable*" and "*recirculated*". These 4 definitions are stated as follows, and represented in the accompanying diagram (Figure 1).

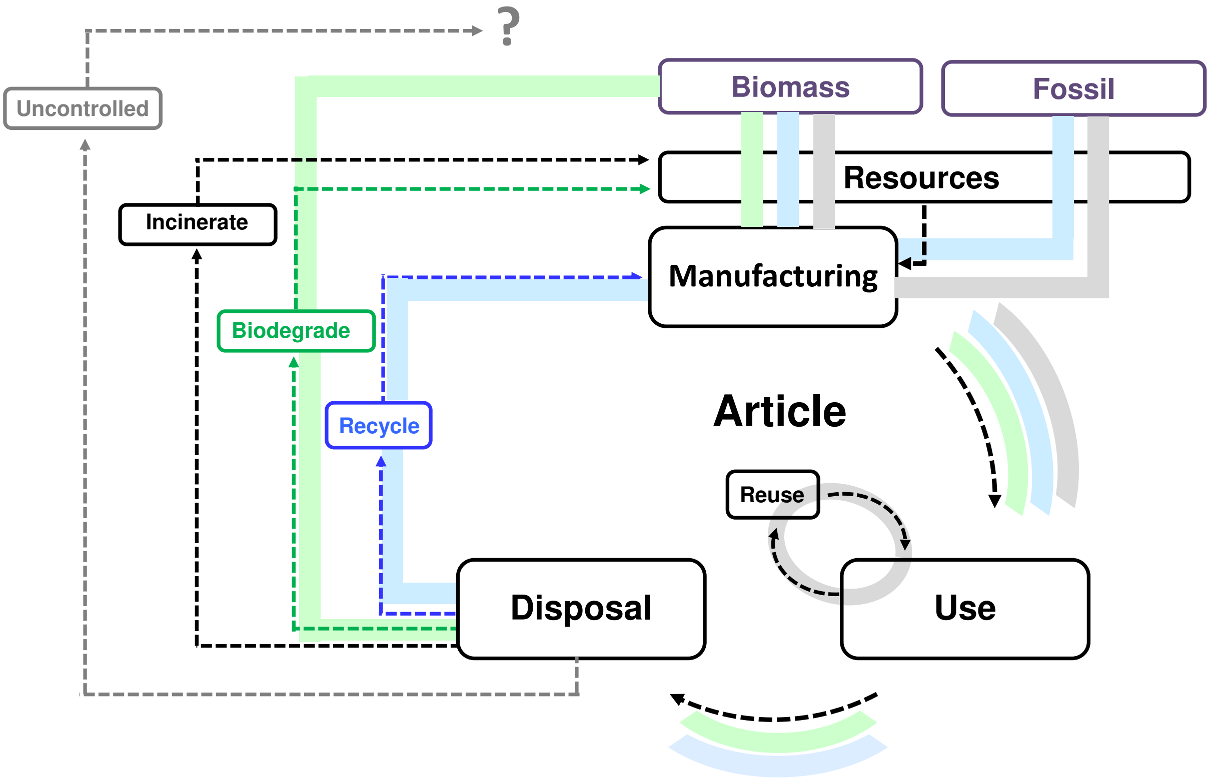

Figure 1: Coverage of the renewability definitions within the life cycle of bio-based products.

An ‘*article*’ means 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]. An article is the end product of a manufacturing process, that consumers and procurers purchase and apply in the intended application (*e.g*. packaging, clothing, cleaning products, *etc*.). Articles consist of a composite or formulated combination of molecules, in turn constructed from atoms of various elements. Accordingly an article can be thought of in terms of the sum of its constituent molecules or atoms. This approach is helpful when considering the life cycle of an article, because the complete article will not necessarily remain whole as its constituent parts are recirculated. Biodegradation is an example of this.

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 (*Figure 2*).*

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.*

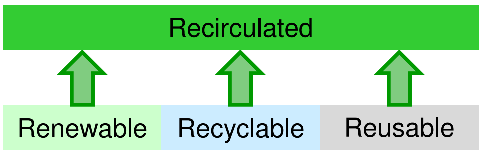

Figure 2: The hierarchy of the renewability definitions.

Subsequently these definitions will be used by Open-BIO partners to generate sustainability criteria (in terms of components and used elements/molecules) for bio-based products. General use of these definitions is also encouraged when describing the renewability of bio-based products, including bio-plastics, bio-lubricants, bio-based solvents and bio-based surfactants.

Acknowledgements

It is here that the authors of this report would like to thank all persons that participated in the questionnaire that helped refine the definitions. A consultation with members of the Green Chemistry Centre of Excellence (University of York, UK) was held on 2nd April 2014. Open-BIO project partners and advisory partners from industry and standardisation and regulatory organisations were consulted at the KBBPPS and Open-BIO (Bio-based products' standardization and market implementation research) combined advisory workshop on 7th April 2014 (Cologne, Germany). Lastly, delegates at the 7th International Conference on Bio-Based Materials (Cologne, Germany) were helpful in filling in questionnaires on 8th April 2014.

The Nova Institute is acknowledged for organising the definition discussions during the combined advisory workshop on 7th April 2014 (Cologne, Germany). Bruno De Wilde and Nike Mortier (OWS, Belgium), as well as Francesco Degli Innocenti (Novamont, Italy) are acknowledged for their inputs about definitions and end-of-life options (biodegradation, composting).

1 Project Introduction

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 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 number 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, sustainability criteria are being developed for bio-based products based on elemental renewability, whereby the required renewability of a bio-based product is based on its component elements. The proposed sustainability criteria for elemental/molecular renewability 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 must be created that are sympathetic to concerns about the length of time required for a certain proportion of an element to be returned to use again. The goal is to ‘track’ the constituent elements contained within an article before and after use. Since there are several routes which the elements can take to be returned to use, these paths must be clearly identified and differentiated. With this in mind, it appeared wise not only to consider “*renewable*” criteria but also other criteria such as “*reusable*”, “*recyclable*” and “*recirculated*”. Conforming to these definitions would support a circular economy by discouraging elements that are sourced and processed in such a way so they are not returned to use, enhancing the market position of bio-based products.

2 Renewability definitions

2.1 The life cycle of elements and molecules with respect to an article

An ‘*article*’ means 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]. An article is the end product of a manufacturing process, that consumers and procurers purchase and apply in the intended application (*e.g*. packaging, clothing, cleaning products, *etc*.). Articles consist of a composite or formulated combination of molecules, in turn constructed from atoms of various elements (Figure 3). Accordingly an article can be thought of in terms of the sum of its constituent molecules or atoms. This approach is helpful when considering the life cycle of an article, because the complete article will not necessarily remain whole as its constituent parts are recirculated. Biodegradation is an example of this.

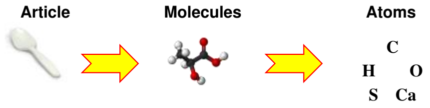

Figure 3: Article, molecules and atoms (e.g. a PLA spoon).

Every chemical product is produced from some form of feedstock. In terms of organic feedstocks these resources may be virgin biomass, a fossil derived material, or intermediates made or extracted from either of these feedstocks (*e.g*. bio-ethanol or naphtha). 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) [KBBPPS D4.3]. Wastes including higher value recycled articles are also considered as resources and may incorporate elements and molecules from any of the five resources identified [Clark 2013].

After use, possibly after a number of reuses, when an article has served its intended purpose, it is then disposed of. Landfill disposal or analogous end-of-life options that act as a stopping point mean the article and its constituent elements are no longer part of a recirculating system of elemental and molecular renewal. Other processes of waste treatment can return the elements or molecules of an article into a useful form, a resource from which other articles can be produced. These are represented on the following diagram as incineration, biodegradation, and recycling (Figure 4).

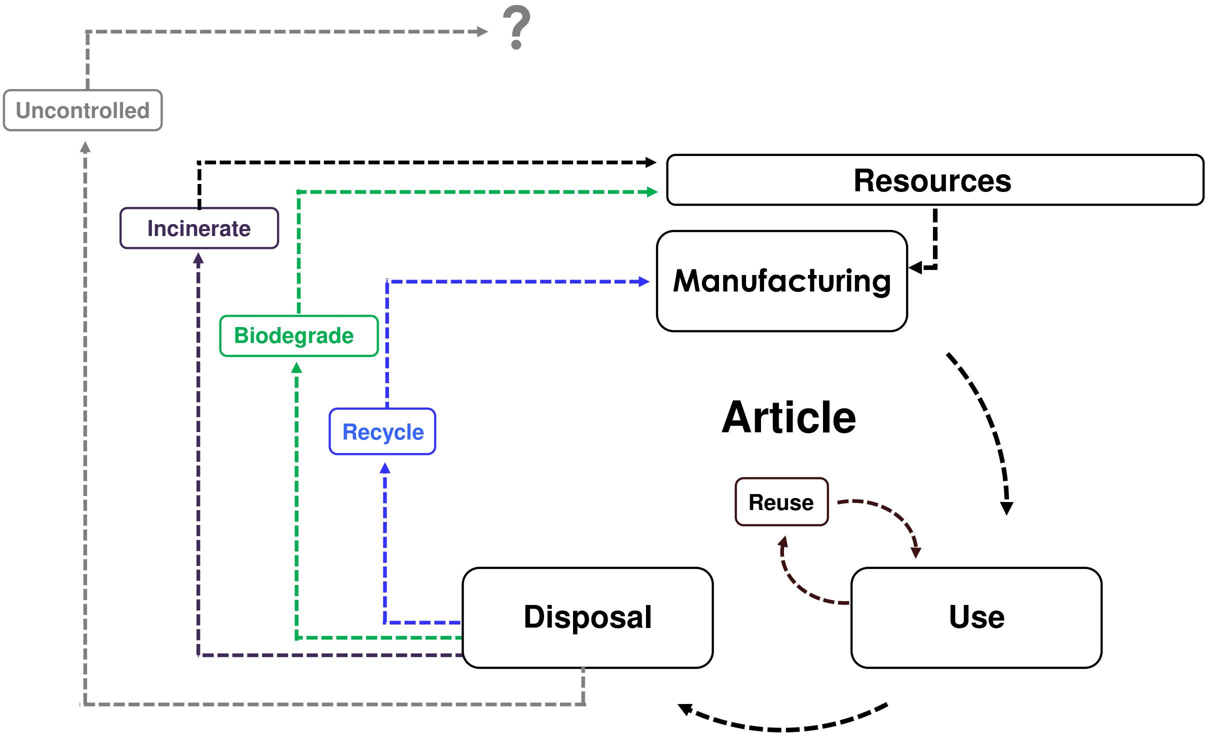

Figure 4: Circulation of atoms and molecules.

The concept of ‘biological recycling’, specifically corresponding to the “*aerobic (composting) or anaerobic (digestion) treatment of biodegradable plastics waste under controlled conditions using micro-organisms to produce, in the presence of oxygen, stabilized organic residues, carbon dioxide and water or, in the absence of oxygen, stabilized organic residues, methane, carbon dioxide and water*” is considered as incorporated within the more general biodegradation pathway presented in Figure 4 [ISO 2008]. It is important to mention that besides biodegradation other requirements with regard to disintegration and environmental safety have to be fulfilled for the product to be biologically recyclable or compostable. A biodegradable product is not always compostable but a compostable product is always biodegradable (under composting conditions).

Recycling, as it is presented in Figure 4, refers to the (physical or chemical) anthropogenic process of returning an article to a useable form, either in the same form or another chemical product or article [Soroudi 2013]. Incineration refers to combustion of organics, primarily to carbon dioxide and water. Other gases will be emitted depending on the composition of the material that is incinerated. Any solids remaining can be retrieved and used as a feedstock. Metal containing wastes are particularly valuable in this respect.

Though an appreciation of the processes represented in Figure 4, the definitions that describe the concept of renewability can be established. General life cycle thinking has been employed to assist the generation of definitions compatible with environmental sustainability. The material flows indicated in Figure 4 suggest that a complete cycle is required to return elements, molecules and entire articles back to use *via* a suitable resource. The concept of recirculation will be employed to convey this closed loop of resource valorisation, article use, and end-of-life treatment. The definition of a recirculated element, molecule or article must encompass all waste treatments and the replenishment of resources in such a way that environmental sustainability is secured.

Pre-existing definitions for renewability are directed at the feedstock. For instance, in the United States the term ‘renewable chemical’ means “a monomer, polymer, plastic, formulated product, or chemical substance produced from renewable biomass.’’ [US 2013] A renewable resource, including biomass, has the ability to be continually replenished by natural processes, as defined by BSI [BSI 2013]. The actual replenishment of the resource is ambiguous in the definition, and there is clearly no reference to where the constituent elements of the article will go after use. For compatibility with the notion of environmental sustainability, the entire life cycle from the perspective of the article must be considered.

Applied in the intended application (the use phase) the article may be reused many times. This is ideal for minimising the cost of energy and material demands required to manufacture the article, preferable to recycling which requires further energy input. Recycling is beneficial at end-of-life as it directs and thus shortens the loop from waste to resource. With recycling, synthetic chemical components can be put back to use as new articles without major deconstruction and re-manufacture as would be the case if the article was incinerated or degraded to a resource (such as biomass via the photosynthetic utilisation of carbon dioxide).

Conversely the article may decompose making it impossible to reuse or even recycle in some instances. This could be either an undesirable effect that is not preventable or designed deliberately as part of the article’s functionality. Lubricants fall into the former category, while fuels are intentionally combusted to fulfil their purpose. Some containment materials and packaging articles may be designed for the slow release of their contents, and will degrade in a controlled fashion during their life span. As such considering an article as the sum of its constituent molecules or elements is understandable. The combustion products of a fuel (or any incinerated wastes) can recirculate and form the basis of a new resource for making other articles. The decomposition products of a lubricant and what remains of the lubricant itself could biodegrade into the precursors of a future renewable resource. Either way the entire article as originally constructed is not preserved, and to consider the recirculation of an article only in terms of the complete object is flawed.

If by incineration or biodegradation carbon dioxide is produced then it might be reasonable to assume that this will provide the basis for the growth of biomass to then act as a resource in the production of articles. The average residence time for carbon dioxide in the atmosphere is debated, and does not necessarily provide an indication of the time it takes to recirculate the carbon atoms. Carbon dioxide may be sequestered in the ocean for example. It could be incorporated into a plant species that does not serve any food, fuel, or bio-based product market as a resource. Such plants may contribute to peat bogs and hence the carbon content is locked outside of any resource base for a very considerable length of time. The time permitted for recirculation to occur is important and raises questions such as should it match demand so that the present production volume of a given article can be continued? Or should a single cycle equate to a human lifetime or perhaps the defined age of biomass (less than 150 years) without additional recirculation considered?.

It is important to move beyond carbon focused cycles and establish a broader respect for all the elements present in articles. This is especially true of bio-based products, which should inherently have a significant degree of renewability associated with them as a whole, and not just to their carbon content. In some ways it is a hindrance to the renewability of elements as a whole that the carbon cycle is so well understood and important to modern society, for it overshadows the other elements which will regularly exceed the mass of carbon in an article. The severity of elemental scarcity across the periodic table is well known [Dodson 2012, EC 2010, Hunt 2013]. Furthermore, bio-based content is currently determined using radiocarbon techniques, reinforcing the carbon-centric view concerning renewability and bio-based products.

It is also essential not just to limit discussion to only biomass derived materials as many bio-based products contain a mixture of bio-based atoms and atoms from other sources, including petroleum. One common example is PET plastic made from bio-based ethylene glycol. The majority of the mass of this article is fossil derived (the terephthalate component). Articles produced from fossil resources such as PET plastic bottles can be recycled indefinately and hence once in circulation do not necessarily need to be automatically excluded from definitions relating to "*renewable*", "*reusable*", "*recyclable*" and "*recirculated*". It could be argued that it is better to obtain articles from expired products than from new resources, whether if that resource is renewable biomass.

The carbon, oxygen and hydrogen in molecules and articles subjected to biodegradation or incineration will become water and carbon dioxide if the process is complete. As the reactants of photosynthesis the recirculation of bio-based products composed solely of these three elements seems quite assured (See Figure 5).

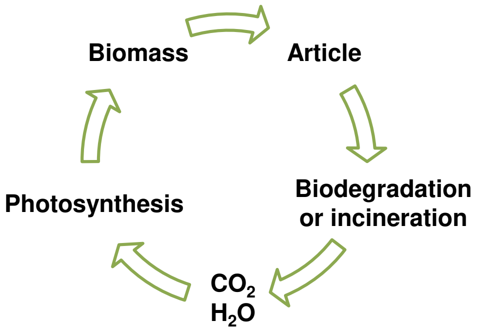

Figure 5: Recirculation of C, O, H in the case of a bio-based article subjected to a complete biodegradation or incineration.

Non-biodegradable bio-based products would have to be incinerated when recycling is not possible, in order to be recirculated. A large number of bio-based products will contain carbon, oxygen and hydrogen and no other elements (*e.g.* PET, PLA, bio-ethanol, FAME). The vast majority of bio-based products will be predominately comprised of just these three elements with only small quantities other elements present. Notable additions of other elements, although not as major mass contributors, might include nitrogen, sodium in plant derived anionic surfactants, and other metals in composite materials. The metal will usually be contained as a salt for bio-based products, such as in the PLA-calcium sulphate composites that are moulded into cutlery and other functional objects.

In the following table are the elements most commonly present in bio-based materials with their expected full decomposition products after biodegradation and incineration (Table 1). Sometimes the end product is the same regardless of the treatment process (hydrogen, carbon, oxygen, phosphorus and chlorine included). In some cases incineration tends to oxidize elements while biodegradation can result in reduced species. In the case of nitrogen and sulphur, anaerobic biodegradation may return the element back to the molecule found in the original feedstock resource.

Research has shown that silicates can be retrieved from incinerator ashes and used as a resource [Dodson 2013]. Often the form of silicon present in incinerated materials will be silicate anyway and so this is simply a means of processing the material, not transforming it. Siloxane fluids, as an example of an organosilicon product, have a different mechanism of decomposition to silicates. In a furnace full oxidation is expected. However biodegradation tends to lead to volatile silanols which are oxidised to silicon dioxide in the atmosphere in an uncontrolled fashion [Ab Rani 2014]. When controlled biodegradation is not applicable, incineration must be considered as a method to achieve recirculation back to a useable resource. At present most producers of so-called renewable or recyclable articles have no role in the end-of-life options for their products, and as a result true renewability cannot be ensured.

Table 1: The origin and fate of elements after destructive end-of-life options.

Element	Source	Biodegradation fate	Incineration fate
Hydrogen	Water and natural gas	Water	Water
Carbon	Biomass or fossil	Carbon dioxide	Carbon dioxide
Nitrogen	Atmosphere	Ammonia (anaerobic), Nitrogen oxides (aerobic)	Nitrogen oxides
Oxygen	Atmosphere and water	Carbon dioxide, water	Carbon dioxide, water
Sodium	Brine	n/a	Ash (unmodified)
Aluminium	Ore	n/a	Ash (unmodified)
Silicon	Ore	Silicon dioxide	Ash (silicates)
Phosphorous	Ore	Phosphates	Ash (phosphates)
Sulphur	Natural gas, Ore	H_2S, thiols	Sulphur oxides
Chlorine	Brine	Hydrogen chloride	Hydrogen chloride
Calcium	Ore	n/a	Ash (unmodified)
Iron	Ore	n/a	Ash (unmodified)

Chlorine is incinerated to hydrogen chloride, whereas the resource for chlorine in manufacturing is brine, which is electrochemically hydrolysed to give chlorine gas and sodium hydroxide. If the hydrogen chloride is left to naturally return to the ocean as its sodium salt it may be recirculated but this is uncontrolled and unverifiable. The direct use of waste hydrogen chloride would be preferable as this is controlled and traceable, and also eliminates a source of pollution. Ultimately the abundance of chlorine (and sodium) in the ocean means that recirculation is not a priority and does not need to be controlled to sustain production of chlorinated articles. Biodegradation of chlorinated compounds is possible for some solvents [Field 2004], but many compounds are purposely made with antibacterial functionality with the introduction of chlorine, and may resist biodegradation. Sodium and other metals are not subject to biodegradation or incineration, and are present in the ashes of incinerators [Jung 2004], from which they can be reclaimed. Dedicated recycling presents a better option for metal and alloy recovery.

It is clear that there is a difference between the disposal options available to renewable products, and this impacts how a resource is replenished. The question is whether to reflect this in its definition, perhaps making a distinction between anthropogenic and natural recirculation processes, or to make no statement regarding this and only concern the feedstock in renewability definitions.

2.2 Glossary of renewability definitions

The following definitions of renewability (and related terms) have been generated to treat articles as the sum of their constituent elements (Figure 3). If all the atoms in a molecule adhere to a definition, that same definition can be applied to the molecule. Similarly, if all the different chemicals within in an article adhere to a definition, that same definition applies to the article as a whole.

The definitions for '*recyclable*', '*renewable*', and '*reusable*' are subsets of the recirculated element definition (Figure 6), as all three involve the constituent elements of an article being returned to use. During discussions it seemed that the clearest and most useful framework for any renewability terms was to make a distinction between anthropogenic and natural recirculation processes, but not to monitor precisely the chemical pathway after end-of-life processing back to a resource.

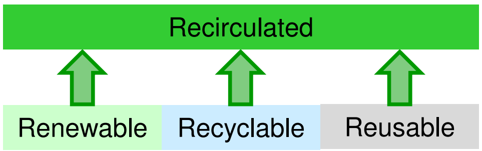

Figure 6: Hierarchy of renewability definitions.

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.*

2.3 Proper use of renewability definitions

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 bio-based products. This leaves biodegradable fossil derived articles unclassified with respect to the three subset definitions for ‘*recyclable*’, ‘*renewable*’, and ‘*reusable*’ (Figure 7). However if the substituent elements of that article can be proven to replenish a resource used to produce more articles (most obviously a biomass resource) than the term ‘*recirculated*’ can be applied. Validation of the recirculation must be obtained to apply the term ‘*recirculated*’ with its derivational suffix as written here. The new article does not have to be chemically equivalent to its predecessor, so for example polyesters could be hydrolysed to give alcohols and carboxylic acid intermediates for producing different chemicals.

Different types of end-of-life options are differentiated in the field of packaging and waste packaging into mechanical recycling, chemical or feedstock recycling, and biological or organic recycling and energy recycling (incineration). [EC2008] [Directive1994] All these end-of-life option categories have been covered within our definitions although they are not explicitly stated as such, because our goal is to emphasise the recirculation of chemical elements. For instance, if an article is compostable, then a portion of the elements of the article will be returned to use through a biodegradation process (producing CO_2 and H_2O), while the remaining part of the elements corresponding to stabilized organic residue (compost) – although valuable as an organic soil amendment – will not be returned to use. Therefore, the use of terminology relating to packaging is not broadly suitable for our purpose because they do not demand the return to use of the chemical elements.

Incineration is not directly addressed in the aforementioned definitions as it is out of the scope of the Open-BIO project. However an article incinerated after use, although not qualifying as recycling in the conventional sense, can be considered as ‘*recyclable*’ in terms of its constituent elements for the potential of replenishing biomass resources (*via* carbon dioxide and water), while reclaiming any metals and silicates from the incinerator ashes. However the general term ‘*recirculated*’ is more appropriate in this instance if the process is tracked and confirmed as circular. ‘*Recycled*’ (note the inflectional suffix -*ed*) should not be used for returning elements/molecules/articles to use by incineration.

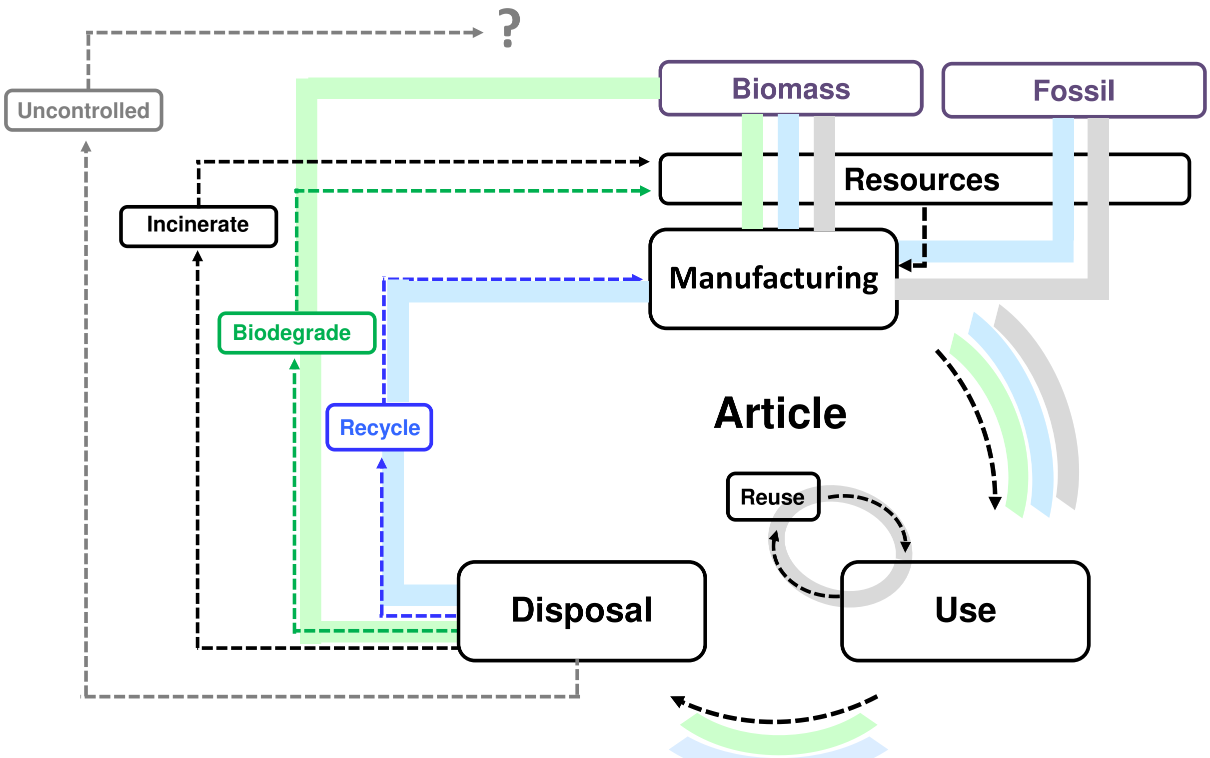

Figure 7: Coverage of the renewability definitions within the life cycle of bio-based products (green colour refers to "renewable", blue to "recyclable" and black to "reusable").

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 applies 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. The use of '*recyclable*', '*renewable*', and '*reusable*' is advocated however as the burden of proof of recirculation is quite high and furthermore it is left unspecified in this report. Thus, these definitions imply a potential, and not a certainty that recirculation is achieved. The associated terms '*recycled*', '*renewed*', and '*reused*' can be used for occasions where the movement of elements, molecules, or the entire article has been tracked and is well understood in both its timeframe and reclamation efficiency.

It is also notable that the definitions have a focus on end-of-life that has previously been absent in the terminology of bio-based products and renewable resources. However some aspects of the definitions are not specific to firstly comply with public and expert perception, but also to avoid introducing a bottleneck into the bio-based economy. As a result the timeframe within which recirculation must occur is not specified, but must be understood and will form part of the subsequent sustainability criteria. Also the resource to which the elemental constituents of an article are returned to does not need to be the same as that which is required to manufacture more of that same article (*e.g.* a petrochemical polyester could be biodegraded and the resulting carbon dioxide and water used by plants to produce biomass). This means that the recirculation process is not closed loop. Subsequent articles do not need to be of the same value, although this is preferable.

3 Generating definitions of renewability

3.1 Pre-consultation

During the development of the renewability definitions, a series of dissemination sessions and three rounds of questionnaires (See annex) were used to guide the process. The responses were analysed to show trends in current thought and also to highlight any common misunderstandings in terminology that these definitions could rectify. It was decided before any consultation, by deriving aims from the description of work that governs the research goals of Open-BIO, that the terminology needed to balance the cradle-to-gate and gate-to-cradle portions of a life cycle respectfully and not focus just on resources. This is compatible with the circular economy of material reuse and the concept of environmental sustainability. It was also decided for simplification purposes that it is the elements that should be tracked, not fully formulated articles. Then if a definition applies to all its constituent atoms, it applies to the molecule itself. In turn if all the compounds in an article adhere to a definition then the same definition applies to the article. This is because some end-of-life management choices may not be fully applicable to an entire article, and that biodegradation for example produces decomposition products that may not necessarily be a direct feedstock resource.

It also seemed inevitable that a family of definitions would be required, which we have placed under the umbrella term of '*recirculated*' in the context of either elements, molecules or entire articles. One of these definitions, '*reusable*' was conceptualised without consultation. For the remaining terms a questionnaire was prepared asking respondents about '*recirculated*', '*recyclable*' and '*renewable*' (with respect to an element) within the context of the feedstock for an article, if it should be returned to use, and if so how should the article be returned to use. From fifty two responses (see Figure 8) the current opinion of partners, advisors and stakeholders involved in bio-based products are discussed in the following sections of this report.

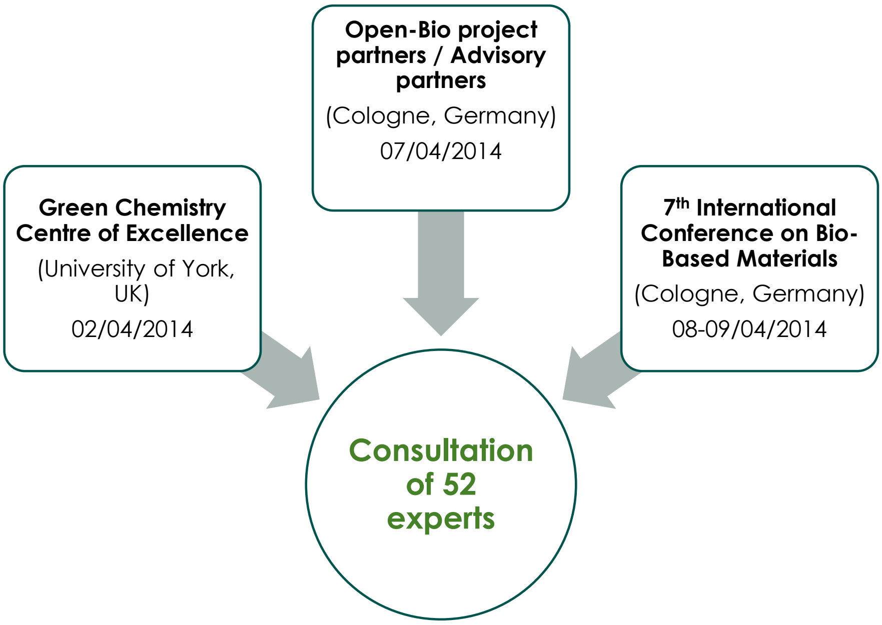

Figure 8: Persons that participated in the questionnaire and that helped refine the definitions.

3.2 Consultation on resource terminology

Respondents were asked whether '*recirculated*', '*recyclable*' and '*renewable*' elements within an article should be sourced from biomass, petroleum, a waste (written as '*a used article'* in the questionnaire), or if the resource is not relevant (*i.e.* any resource is valid). The results are presented in the following chart (Figure 9). It is clear that there is a very strong perception that a '*renewable*' element must be bio-based. This is also reflected by the fact that no respondents said that a '*renewable*' element can come from a petroleum feedstock. Few respondents believed the resource for a '*renewable*' element did not matter. There is also a clear association between '*recyclable*' and returning used articles back to use, while the origin of the resource is not of concern to most.

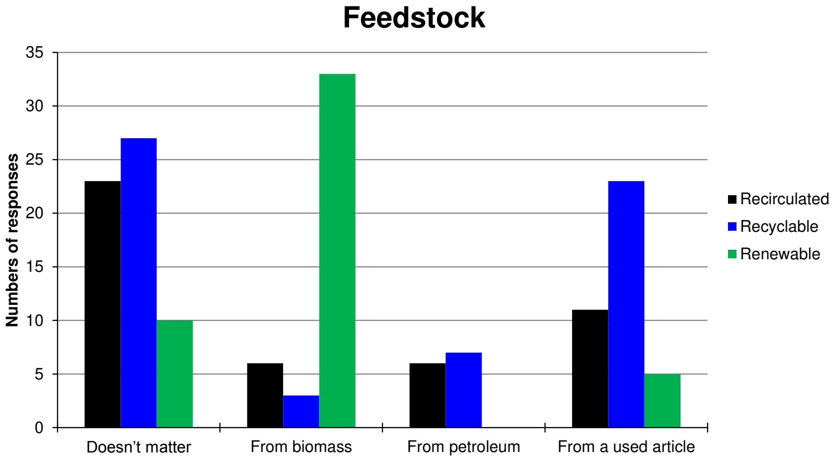

Figure 9: Association of renewability terms with a feedstock.

The perception of '*recirculated*' as a term was viewed as independent of a particular resource, although there is a spread of opinion, with some support with '*recirculated*' elements coming from used articles. The idea of elemental circulation must include the returning of use of expired articles, but of course there must be an original, virgin resource to make the original article. However near equal numbers of correspondents answered that biomass or petroleum are suitable feedstocks for articles composed of '*recirculated*' elements.

The feedback collected on the permitted resources allowed within the renewability definition set instigated a revision to the definition of '*renewable*'. This was changed to specify a bio-based resource (*i.e.* "*comes from renewable resources and is returned to use within a certain timeframe by a natural process*"). This obviously created a gap in the coverage of the definitions where biodegradable fossil based articles are concerned. However this is not a direct issue when applying these definitions to describe bio-based products, and such an article could be covered by the definition of '*recirculated*' anyway if required. To oppose the ingrained perception of renewability being associated with biomass resources (and not an actual renewing of an article) would have diminished the acceptance and uptake of these definitions.

3.3 Consultation on returning articles to use

Respondents to the questionnaire also commented on whether articles need to be returned to use to qualify under the proposed renewability terminology. We found that rather than stating definitively that the elements that comprise an article should not be returned to use, respondents suggested that being returned to use is only implied and not necessarily monitored or ensured. So in terms of the feedback represented in Figure 10, entries under 'Not returned to use' generally apply to articles containing elements that are capable of being returned to use, and entries under 'Returned to use in a certain timeframe' demand recirculation. Some respondents answered both options. This situation has arisen from a number of perceptions imposed by sectors related to bio-based products. At present articles are sold with the intention that they can be recycled, and some articles are produced from recycled materials. These two types of articles and their constituent elements are not necessarily going to be returned to use again. There is no guarantee that recyclable articles will be recycled which may have caused some confusion amongst respondents.

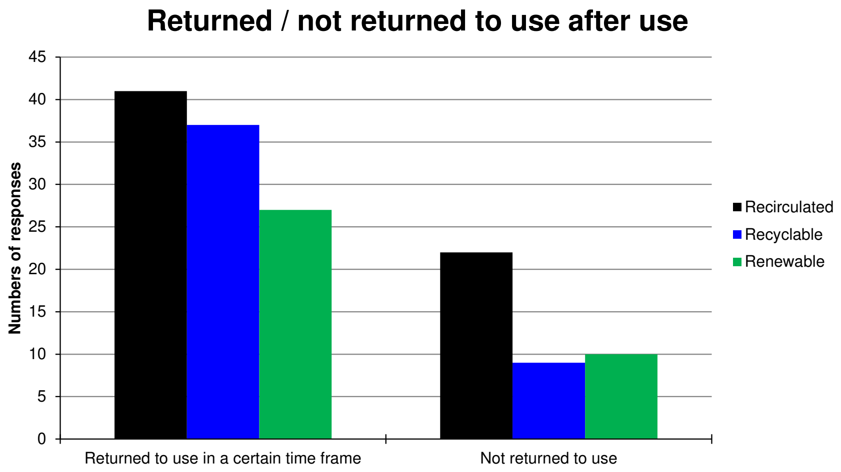

Figure 10: Association of the renewability terms with whether elements are returned to use or not returned to use.

In light of the results of the questionnaire, in which a majority of respondents said return to use is necessary for all definition categories, a phrase was inserted into all the definitions presented in this work to state the element, molecule, or entire article is "*<u>returned to use within a certain timeframe</u>*". Without return to use, an article is not environmentally sustainable. To alleviate the problem surrounding articles capable of being recirculated but not necessarily actually being recycled or renewed, the suffixes of the definition terms were chosen to be inflectional to state that articles (or their components) are either '*recyclable*', '*renewable*', or '*reusable*'. However a derivational suffix is given to '*recirculated*' as it is important to be able to distinguish truly '*recirculated*' articles from those that are only compatible with the concept.

The concept of a timeframe within which recirculation needs to occur is important. This could be done on either of the following principles:

1. How long does it take for the recirculation of a given percentage of the elements within the article? Complete (100%) recirculation or a lower more attainable value (*e.g.* 25%), or only the carbon or organic portion of the article might be considered.

2. What percentage of the elements in the article is recirculated after a set time? This time frame could reflect a human generation, or the maximum age of biomass (150 years) for example. The time between applications of recirculated articles could also be used as the basis of the timeframe, but this is dependent on the article.

Ultimately respondents were mostly confined to cradle-to-gate interpretations of renewability because of the established but conflicting terminology used in the renewable energy sector, and so the timespan has not been precisely defined in this report. Also because of the use of inflectional suffixes in the terms '*recyclable*', '*renewable*', and '*reusable*', articles should be compatible with the concept of "return to use" but not necessarily proven definitively to be '*recirculated*'. However it is clear that this timespan should not be so long as to cause depletion of resources that in turn strains environmental sustainability. '*recirculated*' elements and molecules should have a known return to use period.

3.4 Consultation on methods of returning articles to use

Finally respondents to the questionnaire were asked about the methods by which the elements within articles ('*recirculated*', '*recyclable*', '*renewable*') are returned to use (Figure 11). There is a clear preference that '*renewable*' substances return to use through natural processes. Biodegradation serves this purpose, and can be controlled by restricting the release of waste articles and operating dedicated biological treatment plants under monitored conditions. A similarly strong preference is clear for '*recyclable*' articles to not be returned to use by natural processes, but the actual process required for recycling divided the respondents. Approximately half the responses suggested recycling through typical anthropogenic means associated with present day recycling practices, and a similar number of respondents said it did not matter. There was a consensus that '*recirculated*' elements can be returned to use by any means. This is consistent with the presentation of the definitions provided earlier, in which '*recyclable*' refers to anthropogenic processes of recirculation and '*renewable*' refers to natural processes of recirculation.

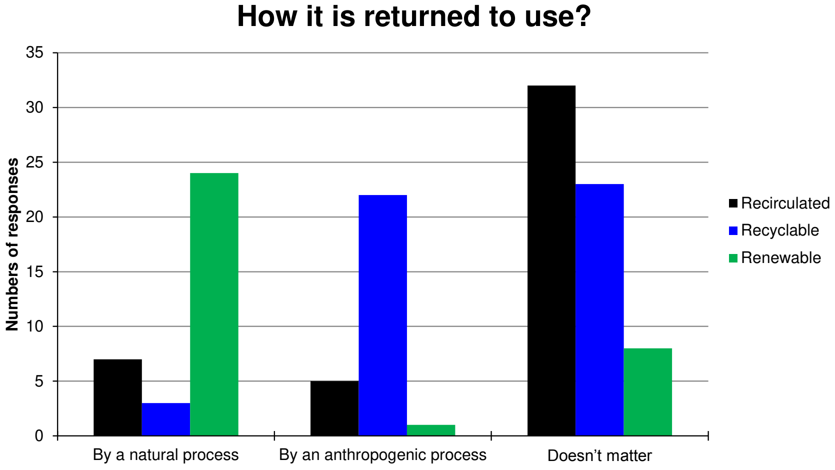

Figure 11: Association of the following terms recirculated, recyclable and renewable elements with the process in which it is returned to use.

4 Conclusion

It is important to appreciate renewability as a cradle-to cradle, circular concept. This is often neglected in favour of narrower feedstock arguments. In this report a collection of definitions relating to renewability have been proposed. These definitions have a general utility across the bio-based product sector and related disciplines, and will assist the Open-BIO consortium to prepare sustainability criteria for the indirect assessments of bio-based products.

The four terms “renewable”, “reusable”, “recyclable” and “recirculated” can be applied to bio-based products in order to enhance the understanding of their position in the bio-based economy and establish compatibility with relevant sustainability schemes.

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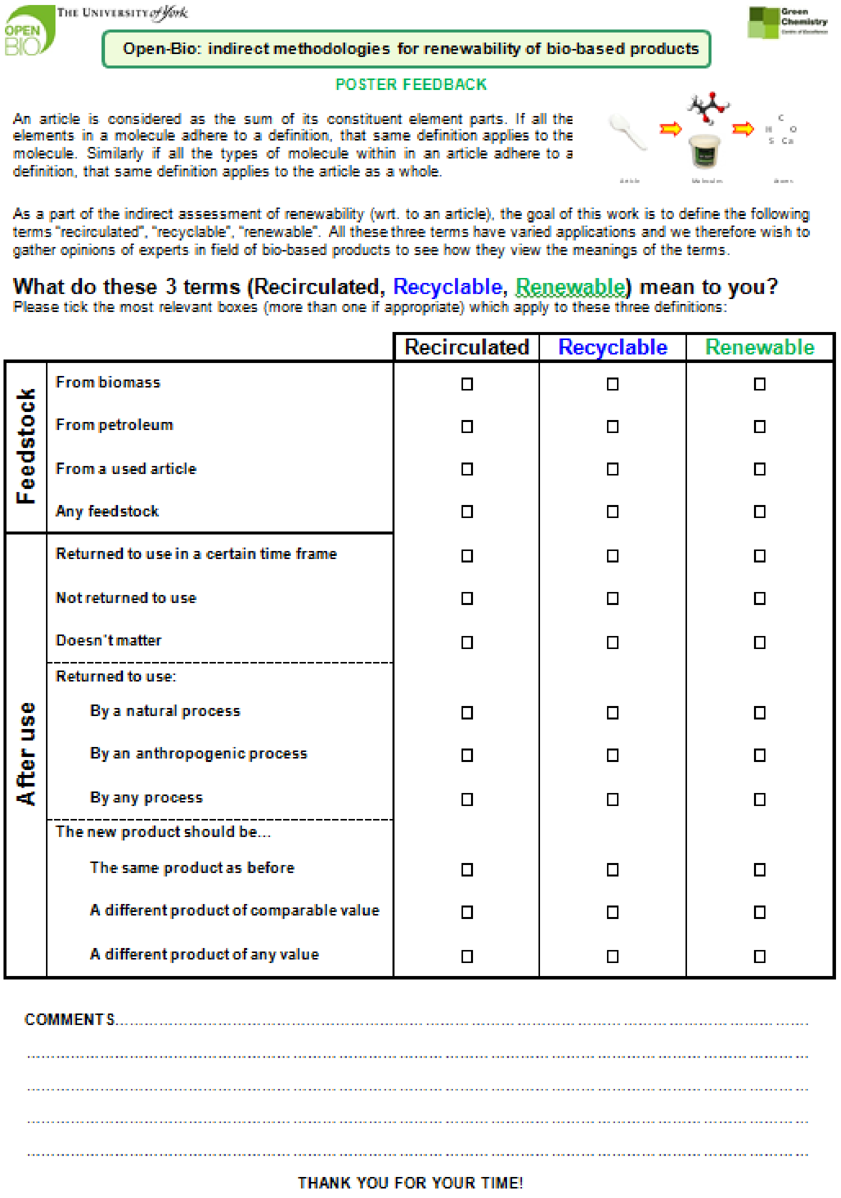
Annex – Questionnaire



THE UNIVERSITY of York

Green Chemistry

Open-Bio: indirect methodologies for renewability of bio-based products

POSTER FEEDBACK

An article is considered as the sum of its constituent element parts. If all the elements in a molecule adhere to a definition, that same definition applies to the molecule. Similarly if all the types of molecule within in an article adhere to a definition, that same definition applies to the article as a whole.

As a part of the indirect assessment of renewability (wrt. to an article), the goal of this work is to define the following terms "recirculated", "recyclable", "renewable". All these three terms have varied applications and we therefore wish to gather opinions of experts in field of bio-based products to see how they view the meanings of the terms.

What do these 3 terms (Recirculated, Recyclable, Renewable) mean to you?
Please tick the most relevant boxes (more than one if appropriate) which apply to these three definitions:

		Recirculated	Recyclable	Renewable
Feedstock	From biomass	☐	☐	☐
	From petroleum	☐	☐	☐
	From a used article	☐	☐	☐
	Any feedstock	☐	☐	☐
After use	Returned to use in a certain time frame	☐	☐	☐
	Not returned to use	☐	☐	☐
	Doesn't matter	☐	☐	☐
	Returned to use:			
	By a natural process	☐	☐	☐
	By an anthropogenic process	☐	☐	☐
	By any process	☐	☐	☐
	The new product should be...			
	The same product as before	☐	☐	☐
	A different product of comparable value	☐	☐	☐
	A different product of any value	☐	☐	☐

COMMENTS...

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THANK YOU FOR YOUR TIME!

Annex – University of York

The University of York is a top ranked university in the UK. Biology and Chemistry are particularly strong departments in relation to research into use of plant-based renewable resources. The Green Chemistry Centre of Excellence GCCE carries out both exploratory and translational research in areas including the environmentally benign extraction of chemicals from biomass and wastes; the microwave processing of biomass to chemicals and fuels; the clean synthesis of chemicals, including the use of catalysis; and bio-resource derived materials including modified polysaccharides. They specialize in the creation of new supply chain consortia to deliver genuinely green and sustainable chemically intense products including personal care products, furnishings, floor coverings and fuels. The GCCE was the initial home of the Green Chemistry Network (www.greenchemistrynetwork.org), now one the largest networks of its kind in the world. The GCCE is dedicated to research, education and outreach in the area of green and sustainable chemistry and has run and administered a number of successful multi-partner projects involving industry and including international programmes including European RTD-projects. The centre has previously coordinated the FP7 project SUSTOIL and participated in the FP6 TESS project, and is also associated with the Centre for Novel Agricultural Products (also at the University of York) which is coordinating two FP7 projects titled RENEWALL and SUNLIBB. GCCE is also the coordinator of the FP7 biorefinery project SUSTOIL and a partner in KBBPPS, where it leads the work on bio-based content determination.