Final report

Permanent Materials

Scientific background

Commissioner

APEAL asbl, Woluwe-Saint-Lambert, Belgium
BCME eeig, Brussels
EAA aisbl, B Brussels
Empac gie, Brussels

Authors

Flora Conte, Carbotech AG, Basel
Dr. Fredy Dinkel, Carbotech AG, Basel
Thomas Kägi, Carbotech AG, Zürich
Prof. Dr. Thomas Heim, University of Applied Science North Western Switzerland, Brugg

Pages: 29
Reference: 235.01
Basel, October 2014

Publishing information

Commissioner
APEAL asbl, Woluwe-Saint-Lambert, Belgium
BCME eeig, Bruxelles
EAA aisbl, Bruxelles
Empac gie, Bruxelles

Contractor
Carbotech AG
PO box, 4002 Basel
Office Basel
Venusstrasse 7, 4102 Binningen
www.carbotech.ch

Project lead
Dr Fredy Dinkel, Carbotech AG

Authors
Carbotech AG: Flora Conte, Fredy Dinkel, Thomas Kägi
University of applied science, Brugg: Thomas Heim

Advisory board
Norbert Egli, FOEN, Bern, Swiss environmental administration
Andreas Spörry, EBP, Zürich, expert on waste management and recycling
Günter Dehoust, Öko Institut i.V., Berlin, environmental expert on waste management and recycling
Stephan Rösgen, Ball Packaging Europe, Zürich
Steffen Seehausen, Ardagh Glass GmbH, Nienburg, Germany, sustainable manager and glass specialist
Prof. Jörg Lagemann, FHNW, Brugg, metal expert
Thomas Payer, Hydro, Aluminium expert

Contents

Abstract

Sustainable development (SD) is one of the most important goals recognised worldwide. One of its aspects is the responsible use of material resources. There are four main strategies:

1. Reuse and recycling of material resources
2. Use of renewable resources
3. Responsible primary material production
4. Efficient use

Whereas the first two can be used to classify different materials, strategies 3 and 4 have to be applied to all types of material to enable sustainable development. The metal industry proposed the material classification of Permanent Materials (PeM) with the aim of emphasizing the possible benefits of the strategy of repeated "reuse and recycling". The goal of this study was to find a scientific based definition for this new material category in the context of sustainable development – the Concept of Permanent Materials (CPeM). This definition needed not only to address the material properties but also the different aspects of SD and had to resonate with policy makers and the public at large as well as different experts.

First, it was necessary for the definition to unambiguously describe the properties of permanent materials. Two definitions were proposed - an explanatory definition and a scientific definition. The scientific definition is as follows:

> ***A material is defined as permanent if its inherent properties do not change during use and through solid-liquid transformation, it can revert to its initial state. This is the case when the material consists of basic components, which are either chemical elements or robust chemical compounds, making repeated use and recycling possible without change of inherent material properties.***

As repeated recycling can only be implemented if the material is preserved during use and transformation, the technical availability of recycling was a necessary prerequisite of the concept of material "stewardship" . Within the context of sustainable development, stewardship means that the material use must be legally compliant in order to prevent the unintended promotion of material applications having the properties and availability to be "permanent" but which may result in harm to humans or the ecosystem. In addition, recycling needs to have an added value compared to the production of virgin material. This added value can be on an economic, social and/or environmental level. As a result, the Concept of Permanent Materials (CPeM) specifically designates materials which have both permanent properties and respect a material stewardship consisting of material availability, legal compliance and enhanced sustainable development. The resulting concept is at two levels. The first comprises the material properties as quoted above and the second comprises the stewardship aspect. Materials can only be classified as in full compliance with the CPeM if the requirements of both levels are fulfilled.

The CPeM was discussed with experts and tested on selected material and the classification of materials into permanent and non-permanent categories was found to be credible. Recommended next steps are the integration into SD assessment tools such as Life Cycle Assessments (LCA) and the communication of the CPeM whilst taking into account that there is an optimal material, permanent or not, for each application.

Abbreviations

Al	Aluminium
BAT	Best available technology
BACT	Best available control technology
Cd	Cadmium
CFC	Chlorofluorocarbon
CPeM	Concept of Permanent Materials
Cr	Chromium
Fe	Iron
FHNW	University of Applied Sciences and Arts North western Switzerland
LCA	Life cycle Assessment
LCC	Life Cycle Costing
Mg	Magnesium
MPE	Metal Packaging Europe
PeM	Permanent Material
SD	Sustainable Development

1 Introduction

Sustainable Development (SD) is one of the most important goals recognised worldwide. It implies that we only use the resources and materials we really need, as efficiently as possible and in such a way that they will be available to future generations *[1]*. Sustainable resource management - or resource efficiency - is an important aspect of sustainable development. There are four main strategies for a responsible use of material resources:

1. Reuse and recycling of material resources
2. Use of renewable resources
3. Responsible primary material production
4. Efficient use

Although strategies 1, 2 and 3 are important, they are not sufficient to be a guarantee for sustainable development. A product is not only manufactured to be recycled or renewed but principally to satisfy a need. For example packaging is produced to fulfil different functions such as protection, logistics and marketing. Fulfilling these functions in an adequate and efficient way (strategy 4) is generally a very important contribution to SD, with the ability to recycle again and again giving added value.

However the strategy of "recycling and reuse" is not yet systematically connected to the concept of a responsible use of material resources. In contrast policy makers, industries and consumers are aware of the strategy of renewing and, in general, spontaneously associate the term "renewable resources" with sustainable development, as opposed to fossil fuels and materials for which the available quantities are also known to be limited, of which reserves cannot be recovered within only a few generations.

In an attempt to link repeated recycling to sustainable development various stakeholders of the European packaging industry chose the term "permanent material" to address the reusability and recyclability of a material. Chemical elements such as aluminium and iron, are not destroyed, and can be used or recycled again and again thus avoiding environmental and social consequences of extracting more primary resources. These and other metals can be described as "permanently available". The option of repeated use and recycling can also apply to other materials such as glass. By introducing the material category "permanent material", materials could be classified into three material categories:

- permanent
- renewable (out of renewable resources)
- non renewable and non permanent

This means that the first two strategies can be used to classify materials into categories whereas the strategies 3 and 4 have to be applied to all material categories to enable sustainable development.

Metal Packaging Europe (MPE) requested Eunomia Research & Consulting to conduct a preliminary study on material classifications, where the first definition of the term "permanent materials" (PeM) was proposed and common packaging materials were estimated to be permanent or not [2]. Eunomia stressed that the definition of PeM should more clearly describe the key characteristics of the PeM concept. It was also recommended to avoid dichotomous definitions such as "fossil vs. non-fossil", which were considered too simplistic.

Based on this research, Carbotech AG[1] (Environmental Projects and Consulting), in collaboration with the University of Applied Science Northwestern Switzerland (FHNW), was requested to conduct a study to draw up a new, more detailed and scientific based definition – the Concept of Permanent Materials (CPeM). The objectives were to

- Give a clear, unambiguous and simple but scientific basis for material classification
- promote a more sustainable development when using and spreading the CPeM

During this study, sustainability was a constant preoccupation and objective for the CPeM. This is why permanent materials were addressed on two levels those of the definition level and the level of material stewardship. This is not only because of SD, but also because of the fact that to enable recycling, two conditions have to be met namely the material properties are given for recycling and secondly that after use the material has to be available for recycling.

This study provides a theoretical and methodological basis to clearly classify different materials and their applications according to their compliance with the concept of permanent materials. The CPeM may then be used to introduce the permanent materials into existing polices, public communication and environmental assessment tools such as LCA.

[1] Carbotech AG is an independent private company specialising for more than 25 years in environmental consulting for industries, public administrations and international organisations. More than 30 employees, mostly with a scientific background, provide research and consultancy services as well as developing strategies, concepts and sustainable solutions using methods such as Life-Cycle Assessments, mass flow analysis and eco-efficiency analysis.

2 Approach

The CPeM should reach the larger public as well as policy makers. At the same time, the definition and concept should address a wide range of specialists with scientific background who acknowledge the definition's meaning, construction and wording. Expressing a simple and unambiguous concept that is new is a challenge. In this study, ideas were gathered, discussed, verified and modified. The definition finding process required an iterative approach involving a large field of experts coordinated by Carbotech comprising assembled stakeholders from the public and private sector, as well as theoretical and applied sciences, in order to enable a debate that was as objective as possible.

The first phase of the study consisted of literature based research, information gathering, brainstorming meetings of the core team and the selection of experts in different fields. A workshop facilitated a direct opinion and information exchange, and pointed out the chances and risks of defining permanent materials. The main points to be integrated into the new definition were collated

The second phase involved analysing and assessing the workshop results following which definition options were debated during further smaller meetings involving the appropriate experts. Between each discussion with the experts or the contracting entities, a new draft proposition was written and commented on internally or externally. This report contains the final definition of permanent materials and is based on ten definition proposition rounds.

During the definition finding process, expert opinions from the following fields were included:

- Chemistry
- Eco-toxicology
- Environmental sciences
- Industry (metal and glass)
- Metallurgy
- Physics
- Polymer science
- Public administration
- Resource efficiency
- Toxicology
- Waste disposal
- Waste recycling

Definitions

The term "materials" in "Permanent materials" designates materials in use for engineering/technical applications, i.e. metals, polymers, ceramics and composites ("*Werkstoffe*" in German). It is not to be confused with the more general term "substances". Accordingly, "recycling" means "material recycling" or "mechanical recycling", as opposed to energetic recycling or the recovery of raw material from a product.

3 Concept of Permanent Materials

First the context and structure of the concept will be discussed in chapter 3.1. The criteria to ensure compliance with this concept will be developed in chapter 3.2. Chapter 3.3 will detail the worked out definition for permanent materials and material stewardship.

3.1 Context and structure of the concept

There is no single material solution for a sustainable development, but there is an optimal material solution for each application or product. To find this optimal solution, clear concepts are needed which take into account the complex balance between the social, environmental and economic pillars of sustainable development. This report aims to give a simple and unambiguous definition for the new material category of permanent materials in order to highlight the potential of certain materials to be repeatedly recycled. This definition should be stated in such a way as to enable a general understanding on the one hand, while providing clear scientific explanations on the other hand.

Defining the category "permanent materials" should be a means to

1. emphasize the fact that there are different strategies for material resource efficiency, repeated recycling being one of them (cf. Figure 1, illustrating that the concept of permanent materials is placed into a general context of SD and comparing permanent materials to material from renewable resources and non-renewable/ non-permanent materials)
2. determine which materials can be repeatedly recycled and which not
3. differentiate how and under which conditions this recycling contributes to SD. So if - as is the case for the new category of "permanent materials" or the existing category of "renewable material resources" - materials are classified according to their strategy for sustainable development, e.g. renewing and recycling, material stewardship should be part of the classification criteria.

In point 2 above, the physical and chemical properties of permanent materials must be defined, allowing materials to be clearly and unambiguously classified as permanent or non-permanent. All materials categorised as permanent at this definition level must subsequently meet the stewardship evaluation criteria in order to be CPeM compliant.

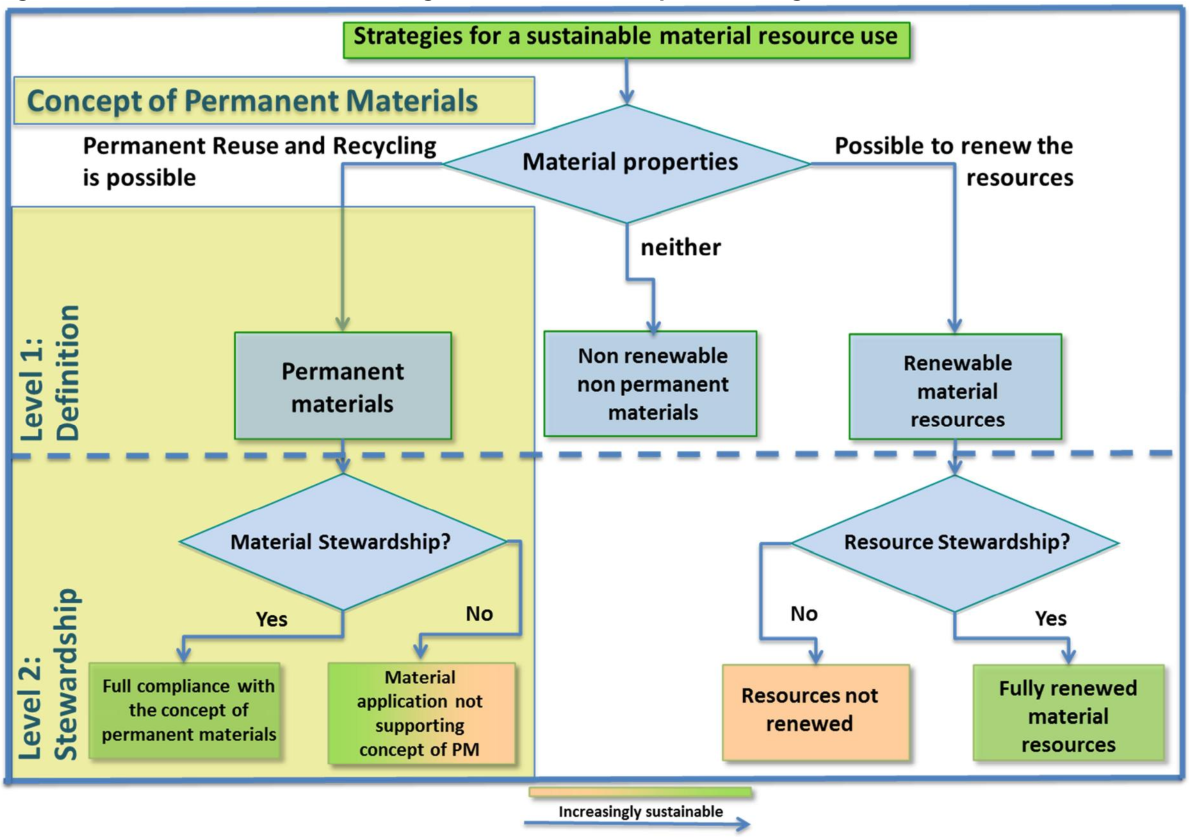
For recycling, not only do the material properties have to be considered, but also the use of the material has to enable the availability of the material for recycling after use. This means that a material stewardship in the use phase is essential for the concept of permanent materials.

This is one of the main differences with the material class of "renewable resources". In the concept of renewable resources, there is no need in the definition to include stewardship in the use phase although there is the need for resource stewardship. The recycling of materials made from renewable resources can also contribute to SD and is being promoted although the properties of materials made from renewable resources typically limit the potential for repeated recycling. Twenty years ago, most people thought that renewable resources would be the solution for energy (biofuels or heating) as well as for material uses. Later it was acknowledged that land is also a scarce resource and resource stewardship of it is necessary. Furthermore, different studies have shown that the overall environmental impact of bio based fuels or materials can be higher than the impact from fossil fuels or renewable materials [32], [33], [34] [35] [35]. For example, forests are not always sustainably managed and biofuels often imply water and soil pollution, as well as fossil energy consumption during agriculture and transformation. Its regeneration might induce the excessive use of other resources such as energy, water and land. Today it is well known that materials or energies from renewable resources can be but are not always sustainable.

The situation is similar for permanent materials. Because the range of applications is very large and the materials do not re-grow, stewardship has to be taken into account in the use phase, including the availability for recycling as well as benefits to the three pillars of SD. Only if these conditions are also fulfilled, materials can fully comply with the CPeM.

Hence, to promote sustainable development, material resources do not only need to have certain characteristics but they should also be required to be used responsibly at all stages of their life cycle: extraction of primary material, production, use, (repeated) recycling and disposal.

Figure 1 Material classification according to sustainable development strategies



Both the expression of a clear and concise definition of a complex situation on the one hand and the evaluation of material stewardship on the other hand are addressed in this report through the CPeM, which is structured as follows:

- Level 1: The definition of permanent materials based on the material properties, structured into
  - An explanatory definition referring to its macroscopic material properties
  - A scientific definition referring to the material's physical and chemical properties. The terms used in the scientific definition are specified.

- Level 2: The material stewardship of permanent materials determined according to the
  - Compliance with legal frameworks etc.
  - Preservation of the material through repeated recycling and during use
  - Contribution to a sustainable development.

For all material categories material stewardship also includes the responsible primary material production according to one of the strategies for sustainable material use, see chapter 1. In the CPeM this means that the stewardship evaluation will be done on the basis of a primary production according to best environmental and social conditions.

3.2 Criteria for compliance with the CPeM

The two levels of the CPeM are linked and should never be considered separately to classify a material. This is because showing that a material corresponds to the definition of PeM, i.e. has the physical and chemical properties of PeM (level 1), is not sufficient as it does not emphasize the importance of recycling in the framework of sustainable development. Its recycling may be technically too challenging or detrimental to the environment compared to the use of primary material. The use of a certain material, despite optimal material properties and recyclability, may not be recommended from the CPeM as it may harm humans or ecosystems. In this case it is not advisable to promote its use by classifying it as permanent. This is why the classification of materials according to their compliance with the CPeM takes place in various steps.

In the first step, materials are classified according to the following criteria:

- Permanent/non permanent material
- Made of renewable/non-renewable material resources

In the second step, the material stewardship of materials defined as permanent is evaluated.

In order to be fully compliant with the CPeM two conditions are necessary:

1. The material has the inherent properties that define a PeM
2. The material stewardship ensures that
   (i) the material is technically available for repeated recycling,
   (ii) the material application is legally compliant and
   (iii) there is an added value in the framework of sustainable development.

Remark: If an application does not support the CPeM, it does not necessarily follow that this material application does not meet sustainable development criteria.. The material application in question may be classified in a category other than permanent materials and/or may promote sustainable development in a different way than reuse and recycling.

3.3 Definition of permanent materials

The definition of PeM is given at a macroscopic level ("explanatory definition") and a microscopic, i.e. physical and chemical level ("scientific definition"). The specific terms used in the scientific definition and the explanatory definition are defined separately.

Remark: The definition of permanent materials, as well as the explanations of the used terms, is based on existing scientific models. The terms employed are explained and illustrated according to the meanings usually attributed in this context so as to allow general understanding.

3.3.1 Explanatory definition

The following explanatory definition of permanent materials was elaborated based on macroscopic properties. It should be easily understood by the general public, many of whom would not necessarily have scientific background knowledge.

> ***A permanent material is one for which the inherent properties do not change during use regardless of repeated recycling into new products. Its recycling does not necessarily require the addition of primary material or additives to enable the basic material function / properties.***

Because the explanatory definition is easier to understand, it can be used to explain the general idea of PeM.

3.3.2 Scientific definition

The following scientific definition of permanent materials is based on physical properties and the chemical structure:

> ***A material is defined as permanent if its inherent properties do not change during use and through solid-liquid transformation, it can revert to its initial state. This is the case when the material consists of basic components, which are either chemical elements or robust chemical compounds, making repeated use and recycling possible without change of inherent material properties.***

Because the scientific definition is more precise it has to be used for the classification of the materials.

3.3.3 Explanation of specific terms in the scientific definition

In this paragraph specific terms used in the scientific definition will be explained.

Basic components

Fundamentally, every material can be transformed into the chemical elements it is consisting of and, after this, synthesized again back to the original material. Typically the effort involved in this transformation will be very high and the yield can be very poor (e.g. complicated organic molecules). However in this report, a material approach is used implying that during solid/liquid transformation, i.e. recycling, materials revert to their basic components. These components can be chemical elements in the case of metals, or chemical compounds such as SiO_x for glass, macromolecules for polymers or cellulose fibres for paper etc. In the case of PeM, robust chemical compounds are required.

Robust

Chemical compounds are defined as robust when, during use or (solid/liquid) transformation there is no destruction of the chemical bonds: A permanent material is stable on a micro- and on a macro-level. This is the case when:

- in the use phase: the chemical elements or basic compounds are not affected by natural degradation / aging processes under normal conditions (20°C, 1 atm.) or conditions of the designed use.
- in (solid/liquid) transformation: intramolecular bonds are stronger than intermolecular bonds within the material (see Figure 2 and Figure 3).

Degradation in the use phase

Nearly all materials are ageing in their daily use due to temperature, corrosion, sunlight and other reactions with their environment. For this reason, materials are typically selected and protected from degradation according to their designed use[2]. In this report, degradation addresses "chemical elements and robust basic components". This means that after degradation the function and properties of a material cannot be entirely fulfilled anymore.

Degradation during the use phase can have two types of impact:

1. Chemical components are being destroyed: the inherent properties of the material change.
   The destruction of materials will be addressed in the first level of the CPeM.
2. Dispersion of the degraded material, which is being lost for future recycling: the remaining material keeps the same inherent properties.
   The dispersion will be addressed in the second level of the CPeM because it is strongly associated with the stewardship during use phase.

Table 1 lists the major factors influencing degradation of materials during the use phase and informs whether the material is destroyed or dispersed. Some factors are extreme compared to normal conditions. This is why they are generally avoided during a designed use.

[2] For example, construction steel is prone to corrosion and can be protected from degradation by different alloys. Similarly, additives can protect plastics; paint can protect wooden house walls etc.

Table 1: Types of degradation

Factors leading to material degradation during use	Explanation and examples	Impact on material
Biological degradation	Materials of natural origin are generally concerned (e.g. wood). Fungi, bacteria, plants and animals may destroy molecules	Destruction
Dissolution through salt or acidity	Acid rain or proximity to seaside. Metals: see oxidation. Synthetic and natural polymers: hydrolysis → destruction. Glass. inert	Dispersion (metals) Destruction (polymers)
Extreme temperatures	Extreme temperatures can destroy any type of material. To avoid this, materials are chosen according to their designed use.	(Avoided through designed use)
Mechanical stress	Extreme mechanical stress can destroy any type of material. To avoid this, materials are chosen according to their designed use.	(Avoided through designed use)
Oxidation	Oxidised material is spread in the environment and cannot be recycled. In the case of Aluminium, the Al-oxide layer at the surface protects the material from corrosion. Rusting of iron is not a problem for recycling, rather an advantage, but can result in iron oxide dispersion. To avoid it, protection such as alloying is necessary.	Dispersion
Radiation, mainly solar radiation	Glass and metals are not affected by natural sunlight, while organic materials are. (cf. appendix).	Destruction
Water or wind erosion	Outdoor materials are exposed to erosion on a longer time scale. Materials is being dispersed.	Dispersion
Others	There is always a chemical or physical factor that, in extreme condition, can lead to material degradation. Material application are generally designed according to these possible factors.	(Avoided through designed use)

The factors, which lead to the destruction of basic chemical components despite a design appropriate to the material use, are mainly, sun light (direct and indirect photolytic reactions) and biological degradation. This generally concerns plastic and natural materials, i.e. organic materials. Organic materials are defined as being molecules with carbon (C)[3]. e.g. the energy of the bonds with carbon (C-C, C-H, C-O, etc.) can be in the same energy range than sunlight, so these bonds can be broken up if no special protection measures are taken. In contrast, the energy of metal bonds, ionic bonds as well as Si-O bonds, basic elements of glass, is far beyond the energy of sun's radiation and, hence, will not be affected by sunlight at all.

Robust during solid/liquid transformation

Materials can be recycled if they are transformable. PeM are transformable without losing their inherent properties. In the recycling process the materials are reshaped and cleaned from impurities. This can be done by melting or vaporization. So, for materials to be recycled in this way into the same or a new product without adding primary material, i.e. for materials to be permanent, the basic components of the material should have, at working pressure, a temperature range between melting and vaporization, so allowing this process. This means that the basic components do not get destroyed even when melted or vaporized. For instance, metals and glass can be heated to vaporize impurities and reshaped. After cooling down, metal or glass (SiO_x) is still available and, because of their structure being crystalline for metals and liquid for glass, they revert to their "original properties".

[3] Exceptions are carbon oxides and carbonates, etc.

Since metals are elements, they are basic components per se. In the cases of chemical compounds, if the intramolecular bonds (covalent or ionic bonds) are stronger than the intermolecular bonds (Coulomb forces such as van der Waals forces) the basic material components are not necessarily affected by transformation processes. Coulomb forces are much weaker than intramolecular bonds. But if the molecules are large enough, e.g. in macromolecules, the sum of the Coulomb forces can be higher than those of the intramolecular bonds. This can lead the latter bonds to break during transformation.

The condition "intramolecular bonds are stronger than the intermolecular bonds" is met when the elements or molecules constituting the material do not get destroyed by supplied energy until vaporization is reached.

Figure 2 Inter-and intramolecular bonds in small molecules

Source: The Chemogenesis web book (van der Waals), rheothings.com (fringed micelle)

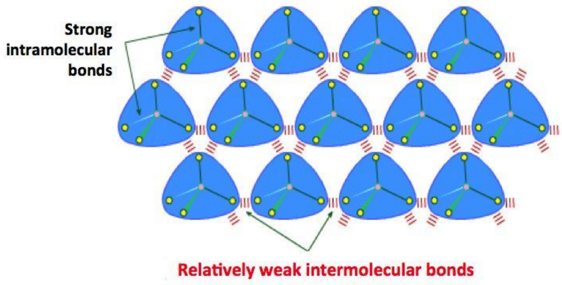
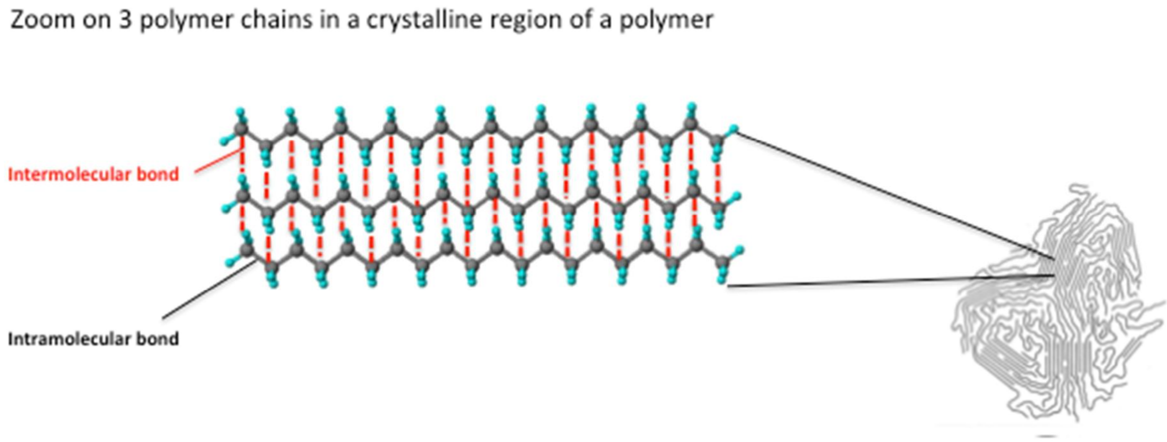


Figure 3 Inter-and intramolecular bonds in large molecules (zoomed)



Typically large molecules such as most polymers are not permanent because, in transformation processes, intramolecular bonds can break before inter-molecular bonds. This does not mean that polymers cannot be transformed by melting (solid liquid transformation). This is the normal procedure to reshape and recycle visco-elastic polymers such as polyethylene or polystyrene, but during this process the macromolecules can break. In consequence the molecular weight distribution will change and so will the mechanical properties of the polymer. In contrast, metals, which are chemical elements, are permanent by definition and molecules like SiO_x are small enough to reach vaporization without being destroyed. Table 2 describes how the most frequently used materials have permanent properties with respect to robustness during transformation.

Table 2: Classification of materials according to their permanent/non-permanent properties during recycling, examples

Material	PeM properties?	Rationale/Issue
Paper/Cardboard	No	Fibres shorten with every recycling [25]
Wood	No	Can change properties during transformation
Natural fibres (wool, cotton etc.)	No	Fibres shorten with every recycling
Thermoplastics	No	During use, molecules can be damaged and contaminated. In the extrusion process during recycling, macromolecules are shortened [30]
Duroplastics	No	No further recycling possible [31]
Elastomers (rubbers)	No	No material recycling possible because of molecular network
Aluminium	Yes	Inherent properties do not change (basic components are atoms). Seek separating alloys and grads for recycling
Steel	Yes	
Copper, Cadmium, Lead, Platinum group elements	Yes	Inherent properties do not change (basic components are atoms).
Rare earths	Yes	Normally low concentrations in applications
Semiconductors	Yes	
Glass	Yes	The basic components do not change during transformation, but different types of glass need to be separated for recycling
Minerals (limestone, ceramic, granite)	No	A ratio of recycled material can be added to primary material [24]

3.4 Material stewardship of permanent materials

The stewardship of permanent materials involves different aspects:

- the concept of PeM is based on the possibility of repeated recycling of materials. The potential for repeated recycling does not only depend on the material properties, but also significantly depends on the application the material is used for. A material can only be recycled if it is technically available for recycling in practice. To promote sustainable development, it should be legally compliant and positively contribute to sustainable development. Stewardship of permanent materials therefore requires technical availability for recycling,
- respecting legal frameworks according to each material application.
- contribution to sustainable development,

3.4.1 Preliminary condition for Material stewardship of PeM: technical availability for recycling

To support the concept of permanent materials, the application of a material should allow the material to be preserved during use and recycling to the extent that it is available for future recycling. Every kind of use and recycling process is linked to a certain amount of losses. No material can be entirely preserved during use and recycling because of degradation processes and because repeated recycling with an efficiency of 100% is not attainable in practice.

Material losses during use can generally be constrained according to the specific material application and its compatibility with the environment of use. Most materials are applied according to their designed use. A chosen use of a material application may result in material dispersion; this application would not comply with the CPeM because sufficiently high recycling rates are in that particular case technically not possible or would have a negative environmental impact, which is substantially higher than that of a non-dispersed application:

> *Only material applications for which recycling is possible because it was not substantially dispersed during use can be considered to evaluate material stewardship and so comply with the CPeM.*

Since permanent materials cover materials which can be repeatedly recycled into the same or other products involving the same material, the quantification of losses during use can be very complex. Certain applications generally known to be very dispersive during use are excluded from the CPeM, being:

- dispersive uses such as in explosives, paint or sprays
- application of unprotected, highly corrosive materials

The waste collection rates of different materials vary significantly on an individual, local, regional and international level due in most part to the awareness of the local population. This is why typical collection behaviour associated with materials is not taken into consideration to determine the technical possibilities for recycling. Losses during the recycling processes are however taken into account. These losses are limited if the best available technique is applied (BAT[4] for EU and BACT[5] for US). The evaluation of the stewardship of a material application will thus be based on this best available technology. It is therefore possible that in the future, better technologies will exist and allow a material application, which cannot be sufficiently preserved during recycling at present, to comply with the CPeM.

3.4.2 Material stewardship: legal compliance

Throughout this report, where "compliance to legal frameworks" or "legally compliant" or "legal compliance" are referred to, the following is what is intended by such compliance, namely

> *The use of a material can only be compliant with the concept of permanent materials if it respects all legal frameworks, protocols, international treaties and recommendations of international organisations commonly applicable to that material use from a best practice point of view*

Whilst the characteristics of certain materials may correspond to the definition of PeM, some or all of their applications may not comply with international or national legal frameworks due to their detrimental health or ecological impact. A famous example of banned chemicals are CFC[6], whose impact on the ozone layer was estimated more harmful than their use was considered to be beneficial, despite the fact that, in the controlled and safe conditions, using CFC may not have any environmental impact. The risk of CFC escaping to the atmosphere was too high to consider it being ecologically worth producing and being used. Furthermore, CFC molecules could be replaced by less harmful chemicals. Other materials such as cadmium, lead or mercury are still allowed for certain applications, while for other applications their use is generally pro-

[4] BAT: Best Available Technology
[5] BACT: Best Available Control Technology
[6] CFC: Chlorofluorocarbon

hibited, e.g. the production of thermometers or cadmium as stabilizer is banned. Policies are continuously being developed to proscribe the use of hazardous materials, which are still in use due to their technical properties.

The CPeM aims at raising awareness of the potential for recycling. However, in order to avoid the use of very hazardous and/or legally banned materials increasing, if they are classified as permanent, material applications also need to be legally compliant to meet CPeM requirements. This legal compliance is an important aspect of material stewardship.

Being chemical elements, metals fulfil the definition of PeM. The legal compliance of applications however should not be generalized. Some metal applications involving cadmium, lead and mercury are legal today within certain boundaries. However it is possible that in the future their use will be completely banned and replaced by other materials. The toxicity of Chromium depends on its oxidation states and the released bioavailable concentrations. While Cr(VI) is known to be highly toxic, Cr(III), which is generally used in alloys is an essential micronutrient for humans. The stewardship of Chromium can thus be assessed in order to determine if it complies with the CPeM, depending on its specific applications.

Glass, which also corresponds to the definition of permanent materials (see table 2), is inert, impermeable and chemically stable and it can only be dissolved with strong acids or bases such as hydrofluoric acid. Glass is therefore legally compliant with the CPeM.

3.4.3 Material stewardship: Contribution to a sustainable development

After testing the legal compliance of an application and determining its technical availability for recycling, the CPeM aims at contributing towards sustainable development by ensuring material stewardship. Repeated recycling processes have to add value in the context of sustainable development compared to the use of virgin materials. Sustainable development includes the three pillars: **economy, ecology and social:**

- The **economic** aspect is fulfilled when there is a market for recycling products and the recycling process does not result in economic losses. No further conditions are necessary but of course the economic benefits can be shown using economic evaluation tools like life cycle costing (LCC).
- **Ecological aspect**: The ecological impact of the production of raw material is compared to recycling the already existing material in order to determine whether there is an added value in recycling. The substitution of primary production by end of life recycling should have an overall benefit compared to the use of virgin material.
- For the **social** aspect, there is strong evidence that a circular economy will improve societal development. Today there are different initiatives by scientists, enterprises as well as NGOs to increase and achieve the same social and environmental standards worldwide. There are methodologies for the measurement of specific aspects of the social impact of material use. However no comprehensive methodology has been developed yet that could quantify the overall impact of such a complex system in which PeM are being repeatedly used and recycled for very different applications. This is why for the moment the social aspect of SD is not taken into account quantitatively in assessing a PeM. But social standards must be taken into account and if an approved new assessment method is developed, the social impact of recycling should become an explicit part of the CPeM. The material stewardship level would then include environmental, economic and social aspects.

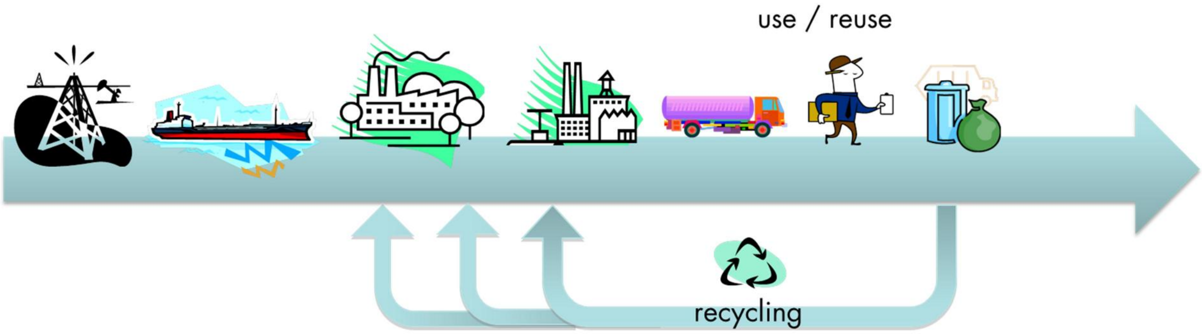
Assessing and comparing the environmental impact

> *The application of a permanent material is supporting sustainability, hence ensuring material stewardship, if the environmental impact of the recycled material is significantly lower than the environmental impact of virgin material production, even if primary production takes place according to best environmental and social conditions.*

To assess the environmental impact of repeated recycling compared to the production of virgin material on a quantitative basis, it is proposed to use the methodology of life cycle assessment (LCA) because it is a method accepted worldwide and according to the European Union *"LCAs provide the best framework for assessing the potential environmental impacts of products or systems currently available"*.

LCA is a *quantitative method* for the assessment of the environmental impacts of human activities. The essential characteristics of the life cycle assessment method are the calculation of substance and energy flows (in and outputs), in principle over their entire life cycle within a system, and their evaluation against environmental criteria.

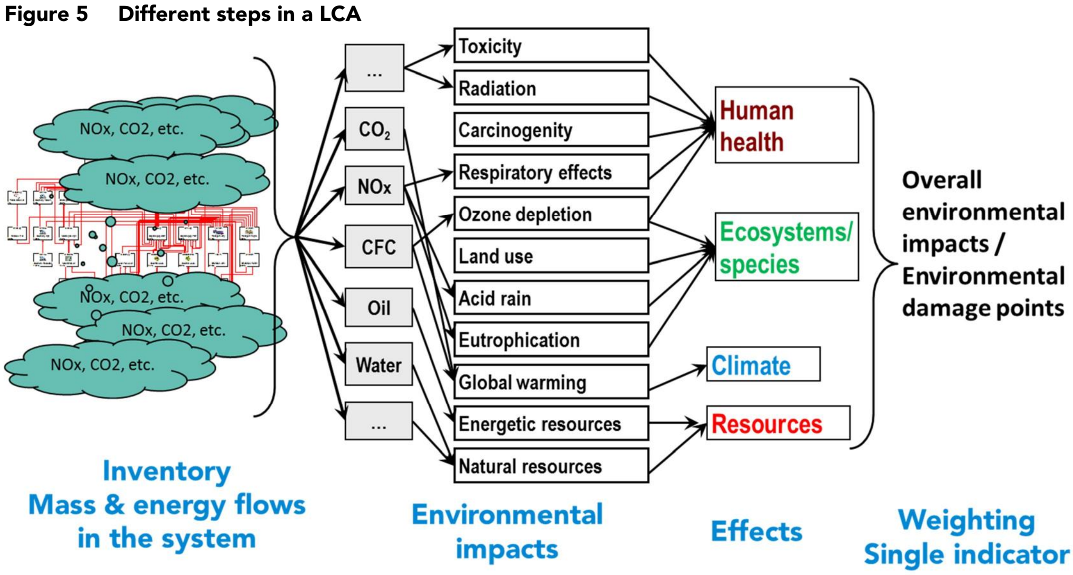
Figure 4 A life Cycle Assessment (LCA) takes into account the whole life cycle



The procedure to perform a LCA is defined in ISO 14'040 [8], [9] and involves the following steps:

- Goal and scope definition: defining the system under study and the procedures.
- Inventory: calculating the mass and energy flows, needed resources and emissions.
- Impact assessment: determine the effects on the environment of emissions and resource use.
- Interpretation: to interpret the results methods weighting the different impacts to one single indicator can be used.

Figure 5 Different steps in a LCA



To evaluate if recycling fulfills the environmental condition of the CPeM the ratio of the environmental impact of virgin material production and recycling is considered. The evaluation will be based if possible on existing life cycle assessment (LCA) studies using at last two of the following internationally accepted LCA methods aggregating the different impacts to one single indicator:

- ReCiPe [10]
- Ecological scarcity [3]
- Impacts 2002+ [6]
- EDIP [4], [5]

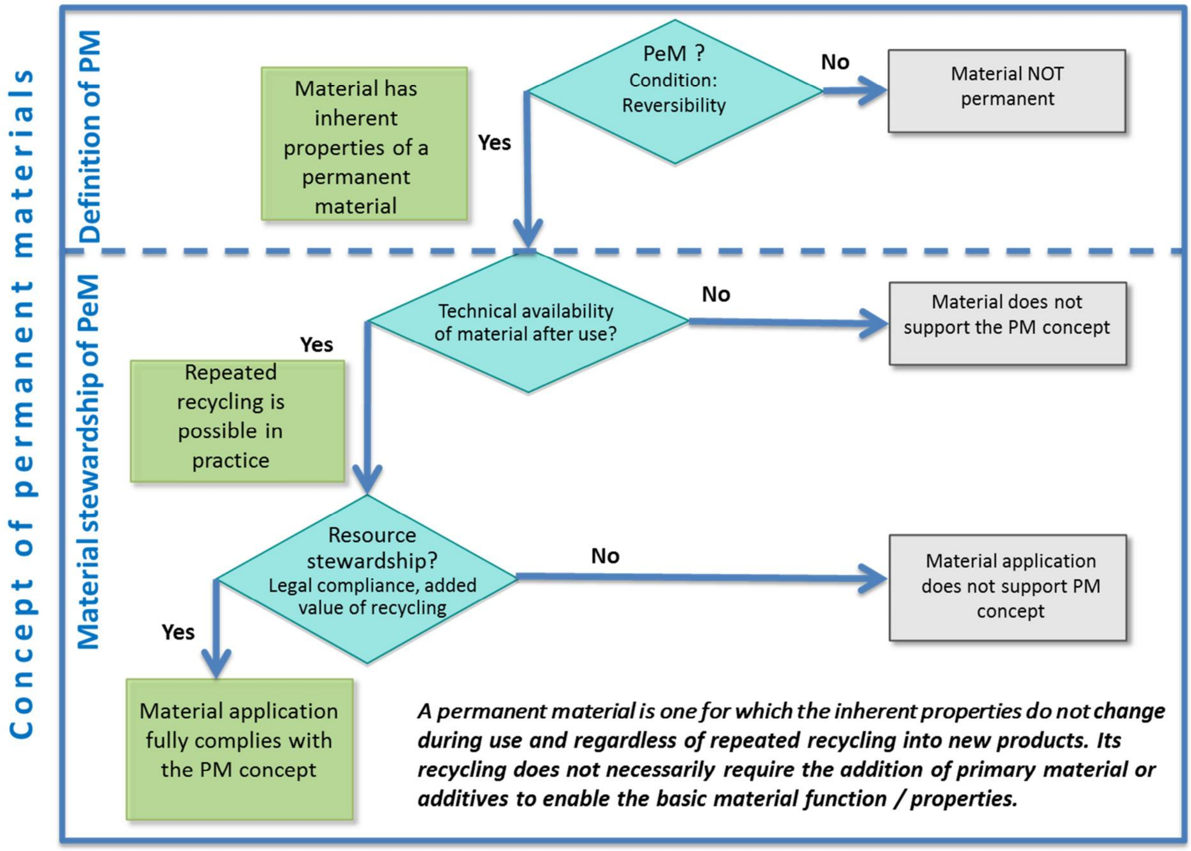
If there will be others methods with an international acceptance they can be used as well. In view of the topicality of climate change, Global warming potential (GWP) measured in CO_2 equivalents could be used [7]. Since it is estimated that the environmental impact of virgin material production as well as recycling of materials with permanent properties is strongly linked with energy consumption, GWP is an acceptable indicator.

The benefit of recycling can be very high, e.g. recycled aluminium needs more than 10 time less energy than virgin aluminium [18]. For other materials the benefit will be lower and it is possible that recycling has the same environmental impact as primary production, or even have a higher negative impact compared to primary production. This is why a scale of -10 to 10 was chosen for quantitative comparisons, with a threshold of 0. On this scale, the number 10 means a 95-100% reduction (or “saving”) of environmental impacts due to recycling compared to primary production. The number -10 would mean >95% more environmental damage due to recycling compared to primary production. There is an added value of recycling if at least 1 is reached. This evaluation can vary because of changes in the production of virgin materials - e.g. due to different raw material sources or production technologies - as well as changes in recycling technologies etc.

4 Assessment of a material selection

In Figure 6 the steps to follow in order to evaluate if a material and its applications partially or fully comply with the CPeM are summarized.

Figure 6 Conditions to comply with the CPeM



Selected materials were assessed according to their full or partial compliance to the CPeM using the steps set out above. The results are shown in Table 3 below. Different materials and applications were evaluated according to their material properties, their legal compliance, and their material stewardship. The scales and the threshold of 5 for technical availability and 0 for environmental impact have been detailed in chapter 3 above. Social impact criteria could not be included in the table due to a lack of adequate assessment methods.

As soon as a level is not reached, the assessment can go no further. This means that if a material is technically recyclable and has an added value with respect to sustainable development, but does not have the physical and chemical properties of a permanent material, it is not classified as a permanent material.

Different applications were compared to highlight the importance of the choice of the appropriate application for a designated use as set out in Table 3 below.

Table 3: Combination of the factors contributing to the levels within the CPeM of chosen materials

Factors	**Materials**													
	Aluminium		Steel			Glass	Copper		Mn	Paper	Thermo-plastic	Duro-plastic	Cd	Max
Application	Al, (motor, can, window frame)	Al, (explo-sives)	Stainless steel	Galvanized Steel	Galvanized can	Bottle	Construction, electrical and communication	Electronics	Die-cast				Batter-ies	
No change during use and material can revert to its initial state through transformation: repeated recycling possible	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	(Yes)
Technical availability: material application one-off: Yes/No Multiple: Yes/No	No Yes	Yes No	No Yes	No Yes	No Yes	No Yes	No Yes	No Yes	No Yes	No Yes	No Yes	Yes No	No Yes	No Yes
The material application is legally compliant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes[7]	Yes
Environmental impact: overall benefit of recycling substitut-ed to primary production (threshold: 0)	9 [18], [23]	-	5 - 8[8]	4 – 9 [23]	4 – 8 [23]	3 – 4 [15], [16]	5 – 10 [23]	5 – 10 [21]		2 – 6 [26]	2 – 6 [28], [29]	-		10
PeM according to definition?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes
Material available?	Yes	No	Yea	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Added value?	Yes	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	Yes	Yes
Material stewardship?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	No	Yes	Yes
Full compliance with CPeM?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	(Yes)[7]	

[7] Depending on the application

[8] Only if the scrap is adequately sorted

The results given in Table 3 seem to be credible and meaningful not only for general material groups but specific material applications as well. This list is not complete but rather a small selection of materials and applications so as to provide a first check of the CPeM: the classifications given in the table could change according to the application, material and technology used.

From the list of materials and applications, aluminium, steel and glass were assessed as fully complying with the concept of PeM, while Cadmium was only defined as a PeM through its properties and for limited usages, like for batteries. Manganese has permanent properties, is legally compliant but has a low recycling availability as yet.

Material applications, which fully comply with the CPeM, can, after this evaluation, be considered to promote resource efficiency. However further considerations need to be taken into account before valuating a material application according to its overall benefit. A few examples of such considerations are set out below.

Generally the function of the material is, environmentally speaking, at least as important as the material itself. E.g. in the case of packaging the ecological impact of the product within the packaging often represents 90% of the total impact see e.g. [12]. Thus, the optimal material for packaging is considered to be the material that protects the content better, not the material that can be better recycled. However, this could lead to a rebound effect where preserved and packed products are preferred to fresh and local ones.

Some materials provide an additional use to the one they were designed for. For instance, heat transfer or isolation properties of material can help saving energy during use.

Certain materials cannot be replaced by others or are simply preferred by consumers. For example, there could be lighter alternatives than glass packaging, which could also be recycled, but glass is the preferred packaging for wine. Similarly, in research laboratories, there are no alternatives to glass to contain very corroding substances.

These examples show that for sustainable solutions the whole system has to be taken into account. Whilst this goes beyond the CPeM, the CPeM can nevertheless provide a valuable contribution to SD.

5 Conclusions

The objective of this report was to define a category of materials, namely permanent materials, with the purpose to implement a new material cluster to better define materials with regards to their resource efficiency and environmental performance. A generally understandable definition of permanent materials together with a scientific definition was proposed, discussed with experts and applied to a variety of materials and applications before reaching the result given in this report.

This study clearly showed that a simple physical and chemical definition of PeM is not sufficient with regard to sustainable development. Material stewardship, taking into account the production and fate of the material should be of equal importance. Including material stewardship in the CPeM ensures the assessment of the technical availability of the material with permanent properties, respect of legal frameworks for each material application and takes into account the economic, social and ecological impact of the material use and recycling compared to virgin material produced under fair and environmentally sound conditions. Full compliance with the CPeM can only be obtained when the requirements on both the definition and stewardship levels have been fulfilled.

The CPeM does not only allow a more specific classification of materials in the context of sustainable development, it also generates higher expectations regarding material stewardship on a logistic, legal and technical level. For example, the introduction of more suitable alloys could allow better material preservation during use. However this might influence recycling and could either facilitate or complicate repeated recycling. This demonstrates how the overall context has to be taken into account. Raising expectations can lead to overall improvements in more responsible material use.

The CPeM could also be a basis for a re-structuration of definitions of other material categories aiming at increased resource efficiency. For example in the case of wood, a renewable resource, it is well recognized today that only with a stewardship label such as FSC, taking into account the protection of the resources, can the use of wood contribute to sustainable development.

It should be noted that requirements concerning the stewardship of primary material production for PeM were not included in the CPeM because it was not in the scope of this project. Nevertheless this prove to be a valid complement to the present concept and could lead to a label including the four components of:

- sustainable production
- permanent material properties
- sustainable use
- efficient recycling

The implementation of the CPeM in its present format would represent a major step forward toward the goal of sustainable use of material resources.

6 Recommended next steps

Finding a definition to best suit the aims of this project was a long process.

With regard to further steps the following can be recommended:

- the concept should first be promoted at an academic and political level after identifying the concerned stakeholders.
- the CPeM should be communicated to the larger public, policy makers and experts, and discussed with them in order to show the link between sustainable development and repeated recycling. This would also include the testing of this concept in applying it to different materials and its applications. These tests could potentially lead to a refinement of the concept.
- the development and inclusion of requirements concerning the stewardship of primary PeM production (as noted in chapter 5). This would add to the utility of the CPeM and enable the development of labeling covering the four components of sustainable production, permanent material properties, sustainable use and efficient recycling.
- the implementation of the CPeM in the methodology of Life Cycle Assessment.

Ecological assessment methods currently considered to be state-of-the-art will undoubtedly change over time. New materials are being introduced all the time, bringing new opportunities and risks yet to be identified. Although the definition of permanent materials will not change, technical options for recycling, legal frameworks and the environmental impact of material applications can and will all change over time. Also, issues of resource scarcity and social impact have not yet been completely integrated within the permanent material stewardship requirement due to the fact that quantitative tools are not yet sufficiently developed. The evaluation requirements for stewardship may well have to be adapted to the latest assessment methods in the future. All these aspects should be kept under review when considering the recommended next steps.

Finally, if the implementation of the CPeM has the expected positive influence on targeted material selection in the framework of sustainable development, then the concept could be enlarged to apply to other material categories.

7 References

Methodological references

[1] Brundtland Commission, 1987. Report of the World Commission on Environment and Development, United Nations.

[2] Eunomia Research and Consulting, 2013). Literature Review, Permanent Materials.

[3] Frischknecht, R., Büsser Knöpfel, S., 2013. Ecological scarcity 2013 - Ökofaktoren Schweiz 2013 gemäss der Methode der ökologischen Knappheit. Methodische Grundlagen und Anwendung auf die Schweiz. Bundesamt für Umwelt, Umweltwissen Nr. 1330, Bern.

[4] Hauschild, M. and Wenzel, H., 1997. Environmental Assessment of Products. Vol. 2: Scientific background. Chapman & Hall, London, Weinheim, New York.

[5] Hauschild, M. and Potting, J., 2005. Background for spatial differentiation in LCA impact assessment: The EDIP03 methodology. Environmental Project No. 996. Institute for Product Development Technical University of Denmark.

[6] Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., Rebitzer, G. and Rosenbaum, R., 2003. IMPACT 2002+: A new life cycle impact assessment methodology. Industrial Ecology & Life Systems Group, GECOS, Swiss Federal Institute of Technology Lausanne (EPFL), 2007.

[7] IPCC, 2007. Climate Change 2007: The Physical Science Basis. In: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). IPCC, Intergovernmental Panel on Climate Change, Cambridge University Press.

[8] ISO, 2006a. ISO 14040, in Environmental management - Life cycle assessment - Principles and framework, Geneva.

[9] ISO, 2006b. ISO 14044, in Environmental management - Life cycle assessment - Requirements and guidelines, Geneva.

[10] Goedkoop, M.J., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., Van Zelm, R., 2008. ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: Characterisation; 6 January.

[11] US Environmental Protection Agency, 1996. List of extremely hazardous substances and their threshold planning quantities. http://www.epa.gov/oem/docs/er/355table01.pdf

[12] Dinkel, F. and Kägi, T., 2014. Ökobilanz Getränkeverpackungen, BAFU, Bern.

Glass

[13] Enviros Consulting Ltd, 2003. Glass Recycling - Life Cycle Carbon Dioxide Emissions. Enviros Consulting Ltd, prepared for British Glass.

[14] PE Americas, 2010. Complete Life Cycle Assessment of North American Container Glass. PE Americas, prepared for Glass Packaging Institute (GPI). http://www.gpi.org/sites/default/files/N-American_Glass_Container_LCA.pdf

[15] Hischier, R., 2007. Life Cycle Inventories of Packagings Glass. Ecoinvent report No. 11, Swiss Centre for Life Cycle Inventories, Dübendorf.

[16] Stettler C. and Dinkel, F., 2008. Ökologischer Nutzen der Verwertungen von Altglas. Carbotech AG, im Auftrag des BAFU.

Metals

General

[17] Classen, M., Althaus, H.-J., Blaser, S., Tuchschmid, M., Jungbluth, N., Doka, G., Faist Emmenegger, M., and Scharnhorst ,W., 2007. Life Cycle Inventories of Metals. Final report ecoinvent data v2.0, No 10. EMPA Dübendorf, Swiss Centre for Life Cycle Inventories, Dübendorf, CH, Online-Version under: www.ecoinvent.ch

Aluminium

[18] EAA, 2013. Environmental Profile Report for the European Aluminium Industry - Life Cycle Inventory data for aluminium production and transformation processes in Europe. European Aluminium Association.

[19] PE Americas, 2010. Life Cycle Impact Assessment of Aluminium Beverage Cans, PE Americas, prepared for Aluminium Association, Inc., Washington, D.C.

[20] Gilstad, G., 2013. Life cycle assessment of secondary aluminium refining. Master thesis, Norwegian University of Science and Technology.

Mangan, Cadmium etc.

[21] Wäger, P.A., Hischier, R. and Eugster, M., 2011. Environmental impacts of the Swiss collection and recovery systems for Waste Electrical and Electronic Equipment (WEEE: A follow up. Sci Total Environ, doi: 10.1016/j.scitotenv.2011.01.050

Steel

[22] Yellishetty, M., Mudd, G.M., Ranjith, P.G., and Tharamurajah, A., 2011. Environmental life-cycle comparisons of steel production and recycling: sustainability issues, problems and prospects. Environmental Science & Policy 14, 650-663, doi: 10/1016/j.envsci.2011.04.008

[23] Classen, M., Althaus, H.J., Blaser, S., Tuchschmid, M., Jungbluth, N., Doka, G., Faist Emmenegger, M., and Scharnhorst, W., 2007. Life Cycle Inventories of Metals. Final report.

Minerals

[24] Martens, H., 2011. Recyclingtechnik, Springer.

Paper

[25] Merrild H., Damgaard, A., Christensen, T.H., 2008. Life cycle assessment of waste paper management: The importance of technology data and system boundaries in assessing recycling and incineration. Esources, Conservation and Recycling 52/12 1391-1398. Doi: 10.1016/j.resconrec.2008.08.004

[26] Franov, E. and Kägi, T., 2011. Ökobilanz grafischer Papiere, Carbotech AG, im Auftrag des BAFU. http://carbotech.ch/projekte-ub/okobilanz-grafischer-papiere-vergleich-von-recycling-und-frischfaser-fsc-buropapier/?lang=de.

Plastics

[27] Chilton, T., Burnley, S., and Nesaratnam, S., 2010. A life cycle assessment of the closed-loop recycling and thermal recovery of post-consumer PET. Resource, Conservation and Recycling 54/12 1241-1249. Doi:10.1016/j.resconrec.2010.04.002

[28] Dinkel, F., 2008. Ökologischer Nutzen des PET-Recycling Schweiz PET Recycling im Vergleich zur Entsorgung in einer KVA. Carbotech AG, im Auftrag des BAFU.

[29] Dinkel, F. and Stettler, C., 2012. Ökologischer Nutzen des PE-Folien-Recyclings Schweiz (Landwirtschaft, Industrie und Gewerbe). Carbotech AG, im Auftrag des Bundesamtes für Umwelt. http://carbotech.ch/cms2/wp-content/uploads/Carbotech_PE-Folien-Recycling_d.pdf.

[30] Brandrup, J., Bittner, M., Michaeli, W. and Menges G., 1995. Die Wiederverwertung von Kunststoffen, Hanser.

[31] Schwarzl, F., 1990. Polymermechanik, Springer.

Renewable resources

[32] Zah, R., Böni, H., Gauch, M., Hischier, R., Lehmann, M., Wäger, P., 2007. Ökobilanz von Energieprodukten–Ökologische Bewertung von Biotreibstoffen. Studie des EMPA im Auftrag der Bundesämter für Umwelt, Landwirtschaft und Energie der Schweiz, EMPA Materials Science & Technology, Zurich/St. Gallen/Dübendorf. EMPA Materials Science & Technology, Zurich/St. Gallen/Dübendorf.

[33] Althaus, H.-J., Dinkel, F., Stettler, C. and Werner, F., 2007. Life Cycle Inventories of Renewable Materials. Final report ecoinvent data v2.0 No. 21. EMPA, Swiss Centre for Life Cycle Inventories, Dübendorf, CH, Online-Version under: www.ecoinvent.org.

[34] Pladerer, C., Dinkel, F., Dehoust, G., 2008. Vergleichende Ökobilanz verschiedener Bechersysteme beim Getränkeausschank an Veranstaltungen, BMLFUW Österreichisches Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft und BAFU Schweizer Bundesamt für Umwelt

[35] Dinkel, F., Stuber, A., 2005. Ökologisch orientierte Materialwahl, swiss olympiqu, Berne.

[36] EMPA, 2012. Most biofuels are not green, http://news.bbc.co.uk/2/hi/uk_news/8493660.stm.

Appendix

A1 Evaluating legal compliance

The USEPA List of Extremely Hazardous Substances [11] and the WHO list of “Ten Chemicals of Public Health Concern” both are a possible basis for a first evaluation on materials legal compliance. The WHO “Ten Chemicals of major public health concern” whose use should be reduced include:

- Air pollution
- Arsenic
- Asbestos
- Benzene
- Cadmium
- Dioxin and dioxin-like substances
- Inadequate or excess fluoride
- Lead
- Mercury
- Highly hazardous pesticides

A2 Solar radiation in organic materials

The solar light on Earth has wavelengths between 280 nm and 780 nm, which is equal to frequencies between 790 THz and 385 THz.
The energy of the light radiation is given by the equation:

$$E = h * \upsilon$$

for sun light between $2.55\ 10^{-19}$ J and $7.1\ 10^{-19}$ J
h: Planck constant = $6.626\ 10^{-34}$ J s
υ: Frequency

The energy of the chemical bonds within organic molecules is:
C-C: $5.8\ 10^{-19}$ J (magnitude typical for bonds with carbon)
Si-O: $15.1\ 10^{-19}$ J

Carbon bonds have the magnitude of energetic sunlight and can thus be affected by solar radiation. In contrast the bonds of silicon oxides - the basic elements of glass - have a much stronger bonding energy. Metals, which are chemical elements, and glass are not affected by sun light