D4.1

Updated decision-support framework for building products and building designers

Circular design of the Circular case studies (CCS)

Lead beneficiary: EPEA GmbH – Part of Drees & Sommer

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0 Executive Summary

This deliverable represents an analysis of the circularity of product innovations developed within the ICEBERG project as proposed by the Cradle to Cradle® design concept. It is a follow-up on the report D3.2, which was completed in August 2021 and published internally for the project partners of the ICEBERG project.

The report includes a circular design guideline for products and an in depth analysis of each innovation product, corresponding to the circular design guideline.

The purpose of the circular design guideline is to provide guidance in the form of recommendations and practical steps to manufacturers who wish to implement circularity and ensure the health of their materials from the very beginning of the product design process.

The analysis of the innovation products was made in dialog with the project partners and consists of a circularity analysis as well as recommendations regarding the circularity optimization. A circularity analysis consists of both a product- and a closed loop analysis.

Throughout the product analysis, it became apparent, that an in house chemical control system compliant with regulations is often already implemented, which in turn shows that they developed an in depth expertise on their product and product components However, detailed information about product compositions is often missing. Therefore, one key recommendation for all project partners is to collect more information on their products components. This forms the basis for circular materials and products.

Another result of the analysis is, that some product partners do not have a dedicated collection system in place for the after use phase of their innovation products. Therefore, implementing a collection system was a recommendation for some project partners. This ensures that the material is recycled or reused in the future, as it is intended to be.

It can be concluded, that the later optimization measures are integrated into the product development, the harder they are to implement and the more likely it is that the circular loop is not fully closed. Thus, starting with a material health assessment right at the beginning of the product development is the key to a healthy circular economy.

0 Contents

0 List of abbreviations

BOM .... Bill of Materials
C2C .... Cradle to Cradle
C2CPII .... Cradle to Cradle Products Innovation Institute
CAS .... Chemical Abstracts Service
CDW .... Construction and demolition waste
FGD .... Flue Gas Desulphurization
FSC .... Forest Stewardship Council®
LWC .... Lightweight concrete
MDI .... Methylene diphenyl diisocyanate
MSDS .... Material Safety Data Sheet
PCDS .... Product circularity data sheet
PEFC .... Programme for the Endorsement of Forest Certification Schemes
PUR .... Polyurethane
RSL .... Restricted Substances List
TDS .... Technical Data Sheet
VOC .... volatile organic compound

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1 Introduction

1.1 Circular design in the construction sector

At the start of construction projects, the focus is increasingly on the sustainable benefits of buildings. This topic is no longer the exclusive domain of environmentalists and visionaries in the construction sector but is being advanced bit by bit as part of building requirements. To this end, the European Union published a taxonomy in 2020, which describes how investments are to be made in sustainable, technical developments in the future. The focus of financing sustainable growth is, accordingly, the following three main criteria, which are also part of the C2C concept:

1. low-CO_2 solutions
2. recyclable solutions
3. healthy solutions

This has the effect that investments in real estate must be more strongly oriented towards sustainability aspects. This is already evident in the stock market, where equity funds with sustainable orientation have increasingly higher shares.

It is clear though, that the current legal requirements – also those that represent standards that focus on sustainable solutions – are far off from a complete closed-loop circular economy and only represent the first step towards this direction. Therefore, it is crucial to reevaluate construction products designs and how they can contribute to this development.

The challenge that most stakeholders in the construction sector face today is that one can not manage what one can not measure. Currently, there are practically no standardized forms of measuring the circularity and sustainability of the built environment. For this reason, real optimization in the direction of a circular economy is not even initiated or merely results in isolated solutions that emphasize individual measures, but simultaneously disregard other important aspects.

To analyze the approaches of the ICEBERG project transparently, to measure their impact, and to potentially optimize them, we will first define how the circularity of products is measured. Based on this, the solutions of the ICEBERG project will be analyzed according to these criteria and compared to conventional practices. Finally, we will show what difference these solutions could make and what further optimization measures should be taken into account during the development of the solutions.

1.2 Structure and method of the report

In August 2021, the report D3.2, including recommendations for the innovation products, was released for the participants of the ICEBERG project. This report (D4.1) includes a follow up and represents an analysis of the circularity of the product innovations developed within the ICEBERG project as proposed by the Cradle to Cradle® design concept.

In D3.2, a circular design guideline was created for this innovation project, based on the Cradle to Cradle® design concept. This guidance explains all design steps of a circular design product in detail and highlights the specific issues at each step. It focuses mainly on the health and recyclability of designing a product. Based on the source of the material used in the product, the material can become either a biological or technical nutrient. For biological and technical nutrients, specified questions (think steps) are explained. Also, the product designer is required to take the after use scenario of a product into consideration. How to safely enter the next cycle (as healthy feedstock for future cradle) after the material is used, is an important aspect of the whole design of a circular product.

A set of questionnaires (BOM, PCDS, etc.) was created based on this guideline and forwarded to all producers. Every project partner was required to fill out the templates with one market available product and the innovation product in the frame of ICEBERG project. This allowed the comparison of compositions, material health and circularity properties. Since then, EPEA held interviews with all partners again, educating them via visual meetings and in writing on filling out the questionnaires and their purpose.

Based on the feedback, the optimization potential of each product was analyzed and recommendations for the next steps were developed within the report D3.2. This information can be found as part of the current report, under the subchapters in chapter 3.

The questionnaires included the following :

- Which problem does the innovation solve compared with commercial used products in the branch?
- Which applications does it have?
- Composition / Rough BOM (generic material level).
- Cradle to Cradle RSL (restricted substance list) v4 check, if possible.
- Product circularity data sheet PCDS a questionnaire by the Ministry of Economy of Luxemburg as the industrial standard used in this report.

As preparation for the report D4.1, feedback from manufacturers was collected with feedback loops starting in September 2022. EPEA was informed by partners about the current status of the product development and changes of recipes through additional filled-out questionnaires, Emails and interviews as well as the public report D3.3[1]. Moreover, the partners were asked to fill out the PCDS and BoMs again.

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[1] ICEBERG circular economy of building materials.

The present report contains the current compositions and properties of the innovation products, the recommendations made based on the developments in August 2021 (D3.2) as well as the current updated recommendations for further development.

2 Generic circular design guidelines

Cradle to Cradle® is a design concept that was developed in the 1990s by Prof. Dr. Michael Braungart and William McDonough.

The basic concept of Cradle to Cradle® is to use the same strategy that occurs in nature: everything is a nutrient and can be returned to the environment or recycled without a loss of quality.

The generic circular design guideline, which is developed for the ICEBERG project, is based on the Cradle to Cradle® design concept. This design concept is based on several fundamental principles: One of them is the thesis that every nutrient remains a nutrient. This means that there are no waste products and all materials can be reused an infinite number of times. For this principle to work, two different material cycles are assumed. The following figure shows the biological cycle on the left, which includes products that are directly related to the natural environment. Here, products go through a process from production to use and subsequent decay, which in turn serves as a nutrient for new products. In order to preserve the biosphere, it is imperative that all materials in this cycle are safe for human health and compostable. In the technical cycle, on the other hand, the products are reprocessed as technical nutrients after their life cycle in a specific application so that they can be used again in another application.

The second fundamental principle that is firmly integrated in the Cradle to Cradle design concept is the exclusive use of renewable energy sources. In addition, as the third principle, diversity needs to be taken into account and supported, as it is also common in nature.

In terms of product development, the five Cradle to Cradle® certification categories can be used as a practical guideline to apply the Cradle to Cradle® design concept: material health, product circularity, clean air and climate protection, water and soil stewardship and social fairness.

Some aspects can not be regarded in the scope of the ICEBERG project. But to design a product according to Cradle to Cradle®, a holistic approach and pay attention has to be applied and all categories need to be taken into account.

The present report focuses on the material design framework, which relates to the aspects material heath and product circularity.

The following design guideline is a response to future human needs in terms of product design and to the question of how to maximize the use of limited resources, based on the precautionary principle and the principle of voluntary compliance. It meets the most stringent circular economy requirements of current regulations for building products.

2.1 Understanding Circular Flows

Cradle to Cradle® describes the safe and potentially infinite circulation of materials and nutrients in cycles (technical and biological). All constituents are chemically harmless and recyclable. Waste as we know it today, and which is generated according to the pre-existing take-make-waste model, will no longer exist. Instead: Cradle to Cradle® develops supply chain partnerships where manufacturers offer a "future guarantee" that materials can be used safely and recovered as resources either as biological nutrients supporting living systems or as technical nutrients returning directly to the industry managing their flow.

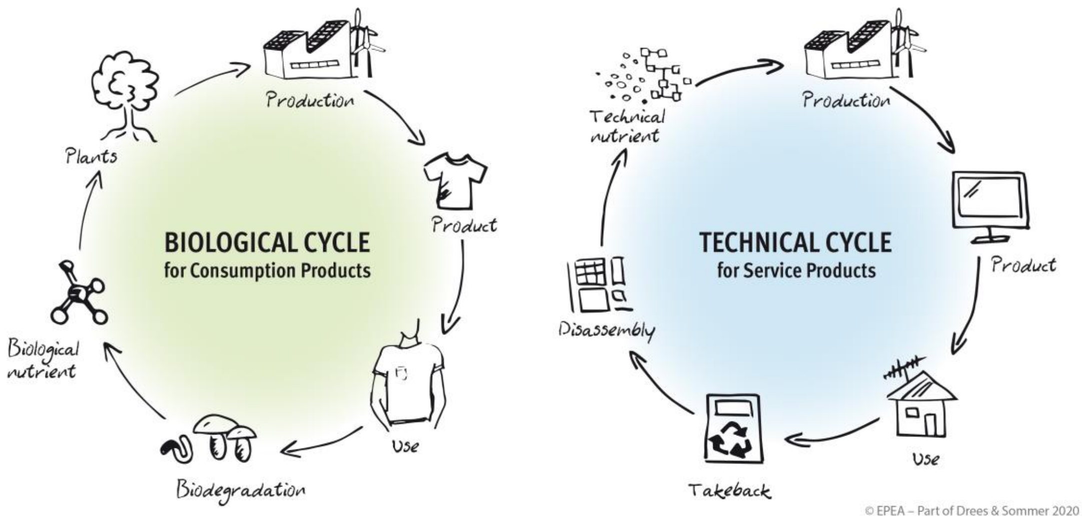


Figure 1: The two cycles of the Cradle to Cradle® Principle

2.2 Safe and circular material choices

Materials play an essential role in a circular economy and designing, according to Cradle to Cradle®. Key is choosing materials with safe ingredients that can be continuously cycled. By designing products with materials that come from and safely flow into their respective nutrient cycles, one can create an optimized materials economy eliminating the concept of waste.

Step 1: Create a bill of materials

A bill of materials (BOM) is a centralized source of information used to manufacture a product. It is a list of the items needed to create a product as well as the instructions on how to assemble said product. Manufacturers that build products start the assembly process by creating a BOM.

Creating a BOM is an excellent method to provide an overview of all the different materials in a product:

- The BOM usually consists of “Inputs” i.e. the products that are bought from third parties to produce their product. It is crucial to distinguish those from “Components” or “Chemicals”. An Input may simply be used as a Component of a product but as soon as a chemical reaction takes place or the Input is processed in any way, the component of the final product is different. An Input also needs to be clearly distinguished from a Chemical. Chemicals are general descriptions of molecules and their properties. An Input on the other hand is produced by a specific manufacturer and may consist of only one chemical. As it is crucial to know how the Input is produced, identical chemicals produced by different manufacturers must be assessed separately. As such, a BOM should always consist of solely “Inputs”.

Step 2: Classify the type of cycle

For each homogenous component, the type of cycle from which it comes and where it can go after use must be identified.

Consumables like natural fibers, cleaning agents, or biodegradable packaging circulate in a biological cycle to which they can be safely reintroduced after use. They degrade into compost or other materials which are in turn used to make new products. In this way, old products do not turn into waste but become “nutrients” for a new product.

Consumer goods such as electronic items or flooring circulate in a technical cycle. These products are already optimized during the design and manufacturing process as material resources for their next service life as new products. Components can be sorted according to their constituent materials after use and then reintroduced to a technical cycle. In doing so, a high material's quality is maintained, and downcycling can be prevented.

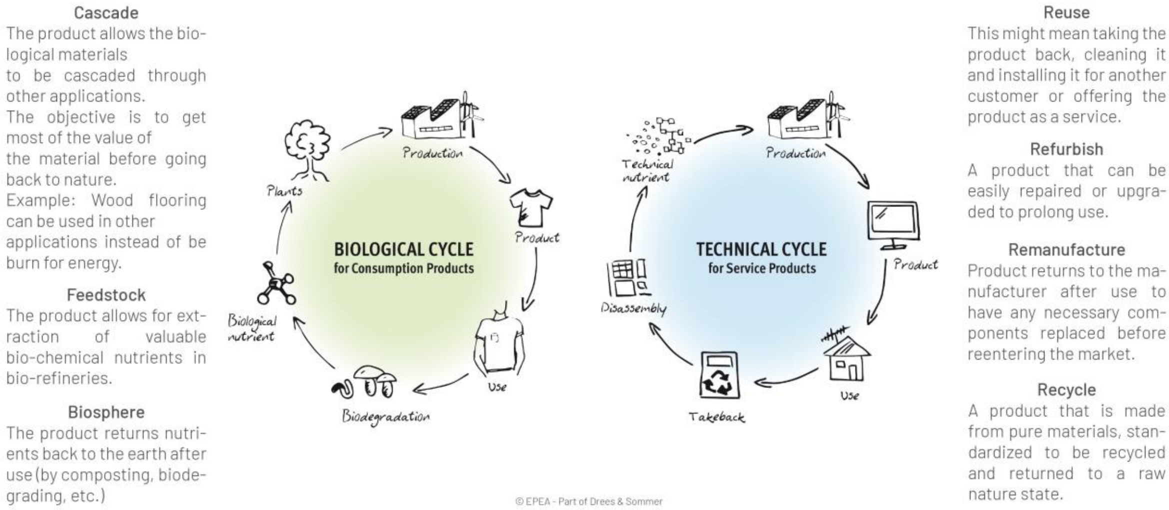


Figure 2: Description of different types of cycles

Step 3: Feedstock selection

In a circular economy, the materials of new products today will become feedstocks for products in the future. Designing new products that are free from problematic contaminants will reduce possible future harm and increase the quality and market value of the future recovered feedstock.

If a product is part of the **biological cycle,** the following questions can steer discussions on possible circular features**:**

- Can this material also be derived from waste, such as agricultural byproducts or food waste?
- Can resource extraction occur while maintaining biodiversity and supporting critical ecosystems? (Here advice may be required from a sustainability team).
- Does consumption of this material occur at a slower rate than the resource can regenerate? (Here too advice may be needed from a sustainability team).
- Is there proof that these materials are responsibly managed to ensure environmental, social, and economic benefits? Some certification programs include FSC, PEFC, and the Sustainable Agriculture Standard. (Here too advice may be needed from a sustainability team).

If the product is part of a **technical cycle**, explore how it can be sourced with circularity in mind:

- Can this material be derived from waste from another industrial process?
- Is it possible to derive it from post-consumer waste?
- For both options, the recycled feedstock must be properly defined, and the composition of the recycling material must be checked.

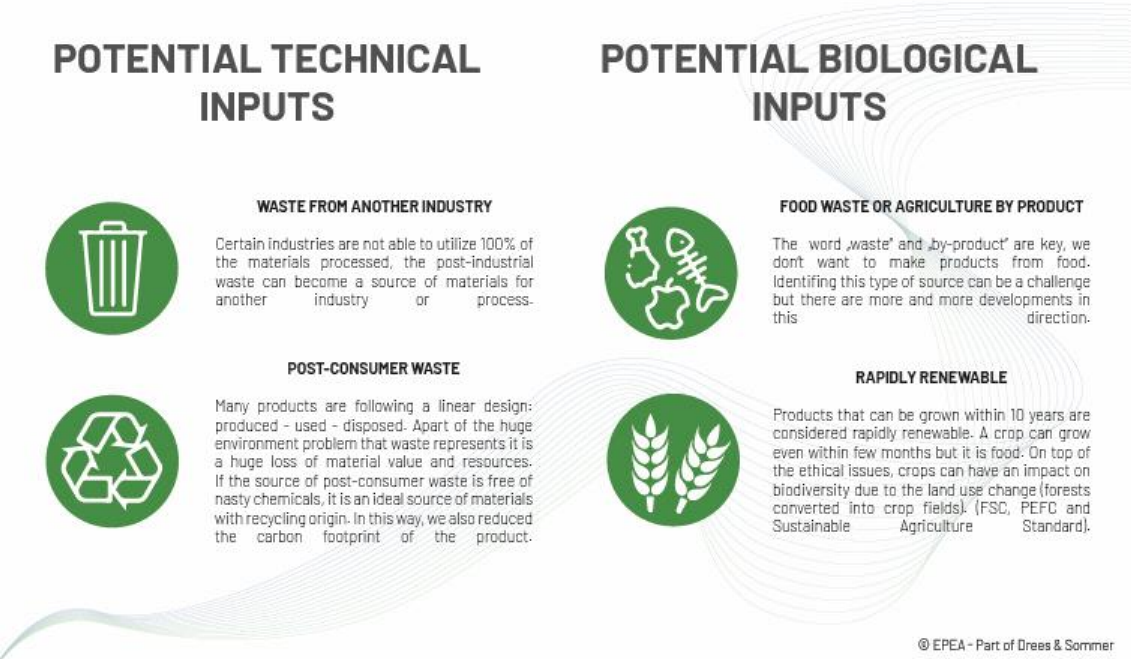


Figure 3: Exemplary sources for technical or biological inputs

2.3 Testing material choices

Once the available materials are known and understood, the following decision tree can be used for each material to make sure the decision was completely thought out and to identify if there are any further optimization required. If materials are identified as not yet fit for a circular product, then following points must be discussed: Are there better alternatives and/or Is it possible to meet the user need without wasteful materials?

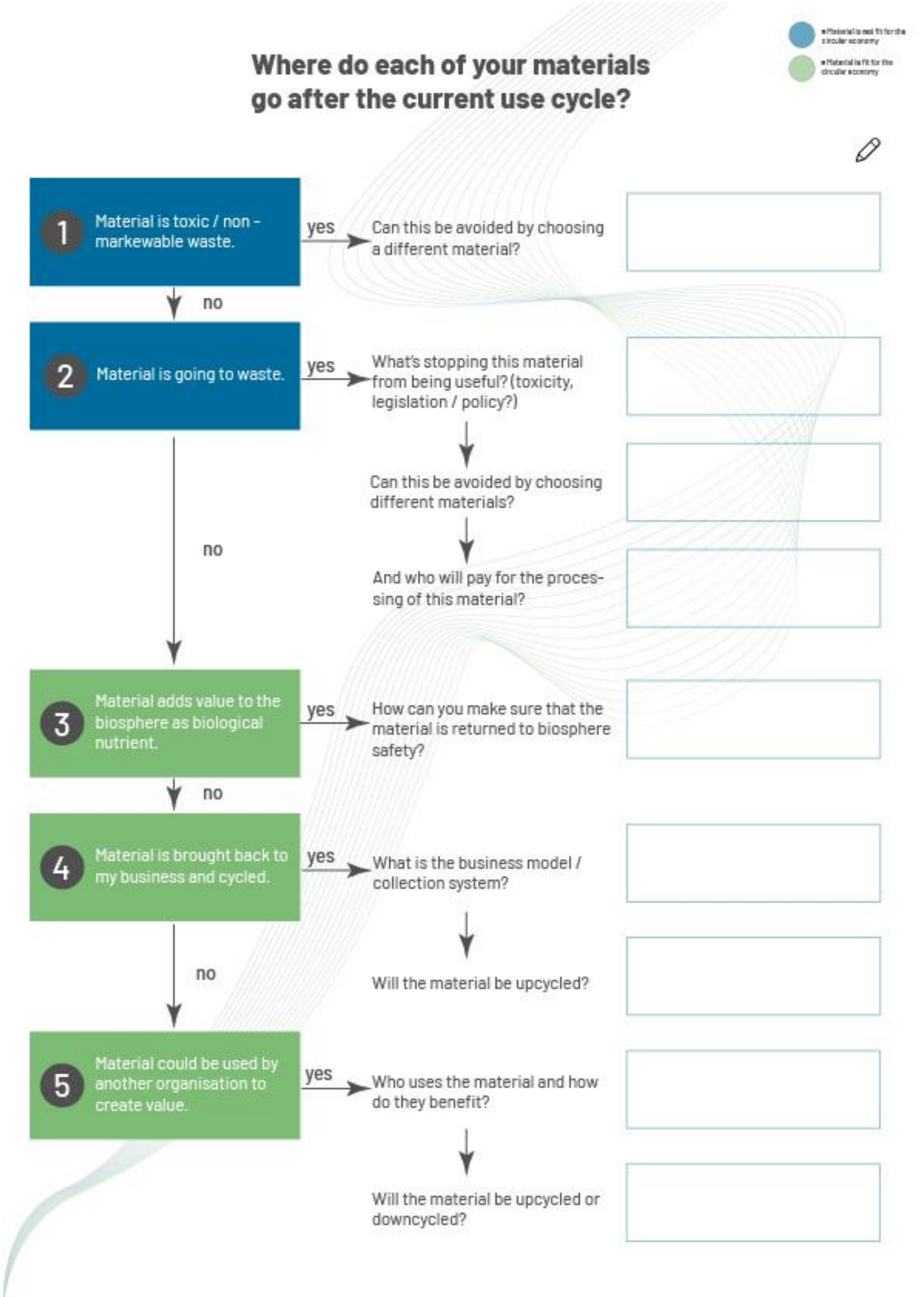
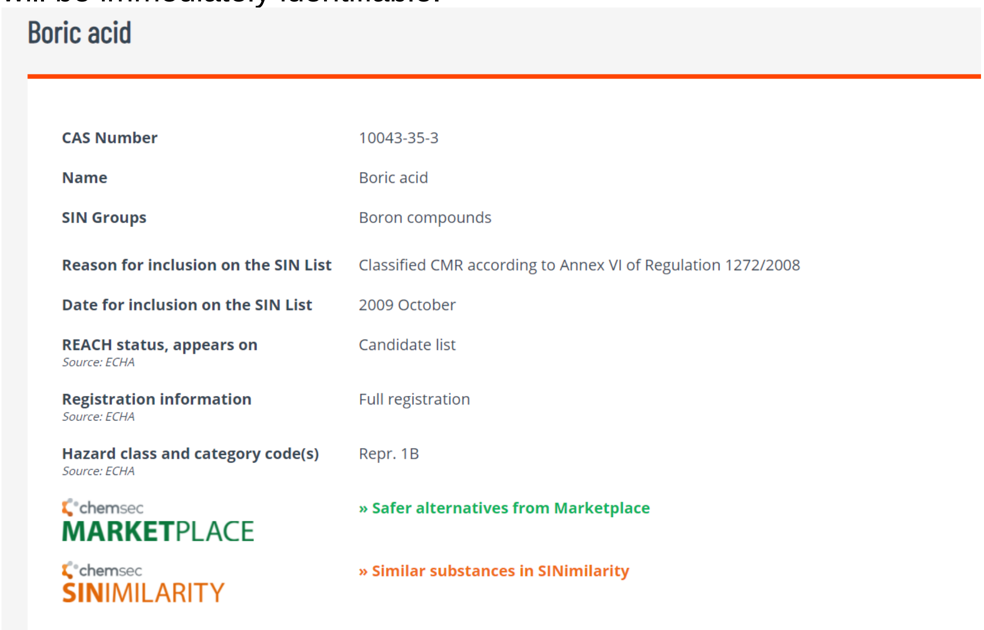


Figure 4: Steps to consider for a product design according to the Cradle to Cradle® Principle (adapted by EPEA based on the Ellen McArthur Foundation)

2.4 Dig deeper – material assessment

At this point, Inputs and most likely some commercial products have been chosen. Now it is appropriate to look at the materials themselves in depth. To do so, the follow steps can be followed:

a) List raw materials and suppliers.
b) Start collecting information for each potential material with the supplier (MSDS, TDS), using the Cradle to Cradle Certified Restricted Substances List (RSL) or CMR substance list as a first filter for healthy materials. Ask suppliers to verify and sign the Restricted Substances List and a CMR declaration.
c) Revise the MSDS and pre-screen the components on a chemicals screening site via CAS number, for example, ChemForward, ChemSec, or Pharos. With this, possible hazards in the composition of the raw materials will be immediately identifiable.



Boric acid

CAS Number	10043-35-3
Name	Boric acid
SIN Groups	Boron compounds
Reason for inclusion on the SIN List	Classified CMR according to Annex VI of Regulation 1272/2008
Date for inclusion on the SIN List	2009 October
REACH status, appears on Source: ECHA	Candidate list
Registration information Source: ECHA	Full registration
Hazard class and category code(s) Source: ECHA	Repr. 1B
chemsec MARKETPLACE	» Safer alternatives from Marketplace
chemsec SINIMILARITY	» Similar substances in SINimilarity

Figure 5: Exemplary chemical profile on a chemicals screening site (ChemSec in this case).

d) As this process can be very challenging if there is a lack of toxicology expertise, it is recommendable to include the help of an external consultant at this point.
e) In addition, the positive list of used substances and materials can be built up and integrated into any available database in collaboration with in-house purchasing and R&D teams.
f) Create a 'Environmental & Health Specification' for each material category. By checking the 'Environmental & Health Specification', an existing database of good raw materials used within your company can be found, which helps both the company and the purchaser find suitable materials.
g) An additional check list with questions for the selection of recycled feedstock helps the company avoid harmful materials for future utilization:

  - Does the recycled material contain contaminants of concern for human health or the environment?
  - Does the recycled material processor screen for and/or eliminate contaminants of concern?
  - Do process-recycled materials for building products require the use of chemicals or technologies that are potentially hazardous to ecosystems, workers, and / or surrounding residents?

To address any potential hurdles identified above, the follow steps are recommended, where possible:

- Some feedstocks contain hazardous substances in quantities that exceed allowable limits for virgin feedstocks. Where thresholds exist for substances of concern in virgin materials, use those same thresholds for recycled content materials as well.
- In the absence of regulatory action on toxic content in feedstocks or final products, develop unified voluntary thresholds and methodologies for screening and testing. Alternatively, use available third partied certification guidelines as a sourcing standard or preferable source of recycled feedstock, both guidelines Recycled content materials assessment methodology and Recycled content material analyte list are published and available at C2CPII homepage.
- Finally, the last step is a risk assessment. The chemicals need to be evaluated as used in a certain context. This evaluation considers the hazard (previously checked in step c) with the expected exposure. Therefore there is a need for full transparency of the Bill of Materials from each supplier. As acquiring this information may be challenging due to confidentiality, a third party may be included in the process to serve as a “material trustee”. This “material trustee” collects supplier information under a non-disclosure agreement and informs the manufacturer if there is a risk within the input or not, without compromising the confidentiality of the supplier. Usually, this is the only way a complete assessment can be achieved.

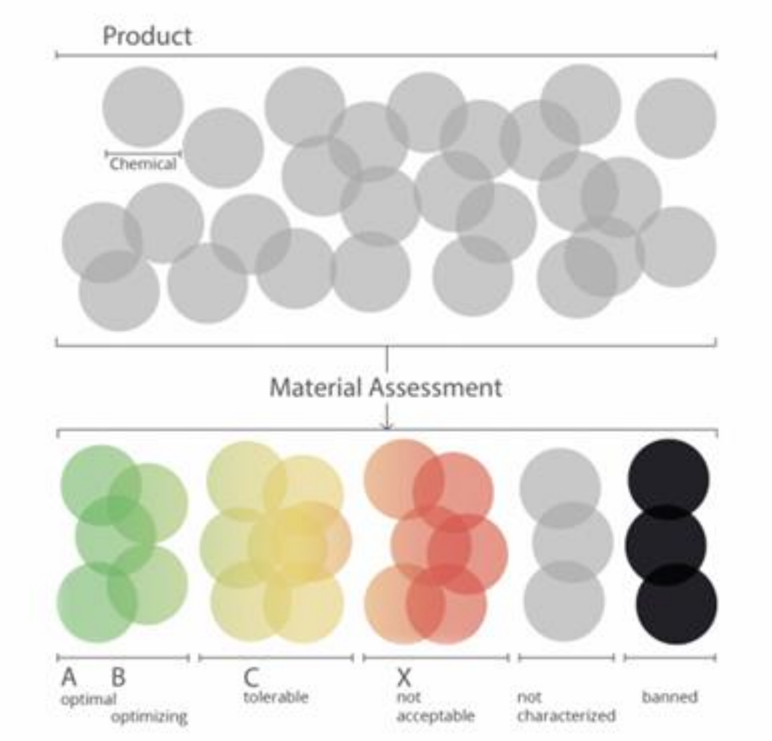


Figure 6: Material assessment methodology (according to the Cradle to Cradle® framework)

2.5 After use – Phase

In this step, a more thorough reflection on what will happen to the product after its use phase must be conducted and a plan must be created on how to implement a safe flow of the materials in the products towards a new usage either in the technical or biological cycle.

For biological nutrients:

- Can the material be used again in the same product or another application? Here it must be kept in mind, that the maximum value of the material must be retained before it is returned to the biosphere.
  - If it can be used in the same product:
    - What is the business model / take-back system with customers?
  - If it can not be used in the same product:
    - Identify concrete solutions describing where this material can flow, while exploring potential partnerships.
- If the material can not be reused:
  - Is the material designed so it can bio-degrade safely?
  - Is the material gasifiable / burns non-toxic and its ashes can be used as fertilizers (parquet product for example)?
  - Does the material need a specific process (composting or water treatment), technology, or infrastructure before it can return to the biological cycle?
    - If yes, does the company have access to it?

- If not, who does have access? Explore potential partnerships.

Technical nutrients:

- Where will the materials be used again? Can it be used in the same or another application/product? Keep in mind to retain the maximum value of the materials.
  - If in the same product or alike (i.e. within the same company):
    - Can the product be disassembled in in-house facilities?
      - If not, where?
    - Can the product be recycled in in-house facilities?
      - If not, where?
  - If in another application/product:
    - Find a safe flow towards a new usage for the materials which are not able to be recycled in the installations. Explore potential partnerships or clients that could be interested in the material.

Always keep in mind:

Attention to regrettable substitutions, research alternatives properly before making changes.

3 Analysis of ICEBERG solutions

In the following chapters the innovation products are analyzed in depth, using the methods described in chapter 1.2. The sub-chapters entail products belonging to the same material group.It is important to know, that most of the projects currently work on prototypes and the adjustments of the formulation, as well as the testing of collected recycling material. Thus, the following analysis and recommendations are applicable for this current stage of product development, and can change quickly.

3.1 Cement and concrete based products

3.1.1 Eco-hybrid cement

The first product to be analyzed is a special kind of cement called "Eco-hybrid cement" which is being developed by CIMSA.

The production of cement involves the consumption of large quantities of raw materials, energy, and heat. Cement production also results in the release of a significant amount of solid waste materials and gaseous emissions.

The objective of this innovation project within the frame of the ICEBERG project is to optimize the formulation and industrial upscaling of novel Eco-Hybrid Cement. Eco-Hybrid Cement is produced through the combination of CSA cement and Blended Cement with 30 wt% of diverse RBM (brick, concrete, glass, and gypsum). Calcium sulfoaluminate cements (CSA) are a promising low CO_2 alternative to ordinary Portland cements. They are produced by burning CSA clinker from limestone, bauxite, and calcium sulfate at about 1250°C and blending the clinker with 15 – 25 % gypsum and/or anhydrite. Blended cement is a mix of OPC 42,5 with 30 wt% of diverse RBM (brick, concrete, glass, and gypsum). The smart combination of CSA and blended cement incorporating high amounts of RBM (>30 wt%) would contribute to creating synergistic effects and minimize the environmental impact by reducing CO_2 emissions (35 %) and raw material consumption (30 %).

3.1.1.1 Product composition and properties

Portland cement is manufactured by crushing, milling, and proportioning the following materials:

- Lime or calcium oxide, CaO: from limestone, chalk, shells, shale, or calcareous rock
- Silica, SiO2: from sand, old bottles, clay, or argillaceous rock
- Alumina, Al2O3: from bauxite, recycled aluminum, clay
- Iron, Fe2O3: from clay, iron ore, scrap iron, and fly ash
- Gypsum, CaSO4.2H20: found together with limestone

The materials, without the gypsum, are proportioned to produce a mixture with the desired chemical composition and then ground and blended by one of two processes - dry process, or wet process. The materials are then fed through a kiln at 4,712ºC to produce grayish-black pellets known as clinker. The alumina and iron act as fluxing agents which lower the melting point of silica from 5,432 to 4,712ºC. After this stage, the clinker is cooled, pulverized and gypsum added to regulate setting time. It is then ground extremely fine to produce cement.[2]

In the ICEBERG project, three prototypes where developed and tested with a varying percentage of recycling aggregate. The composition of these prototypes is well known on a generic material level. The composition disclosed at the defined threshold is available to the customer under a secrecy agreement.

According to the answered questionnaire, the novel Eco-Hybrid Cement has the following circular properties:

Material identification / Health:

- SVHC-free – Yes
- CMR-free – Yes
- Free of Annex XVII chemicals – Yes
- Free of Prop. 65 chemicals – No data to complete the statement

Material origin:

- Pre-consumer recycled content: >25 – 50 %
- Post-consumer recycled content: 0 %
- Renewable content: 0 %

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – No
- Is the product designed for dismounting? – No
- Can the product be disassembled and dismantled into its single materials? - No
- Design for re-use? – No
- Which cycling scenario is the product designed for? – None
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? – No

3.1.1.2 Update on the product in March 2023

- Because of the physical nature of geological materials, it is recommended to ensure, that these substances are below levels likely to impact human or environmental health. The Producers found out through ICP analyzation that low proportions of heavy metal occur in the product.
- It is also recommended when using industrial by-products defined as geological materials (e.g., coal fly ash, phosphogypsum), to be evaluated

[2] PennState – College of Engineering.

for the presence of radioactive elements.[5] The Producers did not consider the recommendation to the unlikely effect on health, but they could consider it, if they had to.

- It is recommended to evaluate concrete adhesives after checking their material health criteria. The Producers are working on checking them
- The evaluation process is repeated by replacing the problematic raw material with not problematic material, which leads to a final healthy and complete recipe of product for the future. This recommendation could not be considered as the producer has been using the same raw material for many years.
- A focus on the re-use potential in the next design steps is highly recommended. The Producer of the Product instead likes to focus on the RCA and Re-use

3.1.1.3 Analysis of the optimization potential and recommendations in August 2021

Material identification / health:

Cement is mainly made of geological materials which makes it hard to name the composition exactly. Geological materials have a variable chemical composition and may contain toxic metals, radioactive substances, or other compounds. Toxic metals are defined as antimony, arsenic, cadmium, chromium VI, cobalt, lead, mercury, nickel, thallium, tin, uranium, and vanadium in the C2C geological material methodology.

Because of the physical nature of geological materials, toxicological data for all hazard endpoints is frequently unavailable. To help ensure that these substances, if present, are below levels likely to impact human or environmental health, geological materials must be analyzed, for example, according to the C2C geological material[8] methodology as outlined in section 2.

The banned list limits for geological materials are shown below. The limits refer to the amount of metal or metalloid (in mg) that leaches or migrates from a sample of material (in kg) via an extraction methodology. For this assessment methodology, the limits may also be applied to the total amount of each listed metal within the homogeneous material.

Banned List Metal	Banned if total concentration OR migration exceeds this limit:
Arsenic	47 ppm or mg/kg
Cadmium	17 ppm or mg/kg
Chromium VI (not total Chrommium)	0,2 ppm or mg/kg
Lead	160 ppm or mg/kg
Mercury	94 ppm or mg/kg

Table 1: Banned List Limits for Geological Materials[3]

[3] Cradle to Cradle Products Innovation Institute (b).

It is also recommended for indoor to use products that contain rock or stone-based material (e.g., granite, etc.) or industrial by-products defined as geological materials (e.g., coal fly ash, phosphogypsum), to be evaluated for the presence of radioactive elements.[5]

Furthermore, it is recommended to evaluate the concrete additives by collecting MSDS and TDS to check the material health criteria before using them. Some useful suggestions can be found under Cap 3 generic design guideline.

The evaluation process is repeated by replacing the problematic raw material and actively searching for a new replacement, eventually finding the right raw material, and leading to a final healthy and complete recipe of product for the future.

Considering the design for re-use the producer replied to all questions with “No”. The objective of this report/interview is to support producers to design/develop multi-life circular products with an improved health perspective and explore the feasibility of setting up their own take-back system by facilities or cross-industry cooperation with other industries for take-back and recycling of this designed product. Therefore, a focus on the re-use potential in the next design steps is highly recommended.

3.1.1.4 Conclusion and future recommendations

After the feedback of the producer it is not clear whether actual design changes have been made or are planned for the future. Therefore the recommendations are still applicable today.

3.1.2 Structural precast recycled concrete elements

The second product is a “Structural precast recycled concrete element”, developed by TEPE Betopan.

Recovered concrete from CDW can be crushed and used as aggregate, mainly for road bases and sub-bases, but new concrete can also be made using a percentage of recovered crushed concrete. The hardened cement fraction from recovered concrete provides a good opportunity for recycling into the cement clinker process. For larger amounts, however, more efficient separation and treatment techniques would be required to produce a raw material with sufficient purity and homogeneity.[4]

TEPE Betopan A.Ş., a company of Bilkent Holding, set up its factory in 1984 in Ankara Beytepe, marking the start of the first Cement Bonded Particleboard production in Turkey with the registered trademark of TEPE Betopan. They are the only company that produces both cement-bonded particleboards and fiber-cement boards in Turkey. The main objective is to develop structural concrete elements incorporating >75 wt% of recycled concrete aggregates and Eco-hybrid cement.

3.1.2.1 Product composition and properties

The common materials that are normally used in precast concrete construction for precast concrete are cement, ordinary Portland Cements [OPC], 43 grade [IS:8112], 53 [IS:12269], aggregates, water and pigments [Oxides].[5]

TEPE Betopan on the other hand, uses the Eco-hybrid cement by CIMSA, described above, along with chemical additives.

Multiple prototypes were developed, using three different cement dosages, that lead to the compression strengths C30 C40 C50, with recycling aggregate proportions from 0% to 100%.

In this report, the 100 percentile recycling concrete is portrayed in detail. The composition of this concrete element is 16% eco-hybrid cement supplied by CIMSA, no natural aggregate and 74% recycled concrete aggregate, 10% water inclusive 0.3% super plasticizers.

According to the answered questionnaire, the “Structural precast recycled concrete element with 100% recycling aggregate” has the following circular properties:

[4] CEMBUREAU- The European Cement Association.

[5] Blocks PreCast – build smarter, build quicker.

Material identification / Health: (requirements do not meet all requirements asked in the PCDS due to design at a very early stage)

- SVHC-free – Yes
- CMR-free– no answer is given
- Free of Annex XVII chemicals– Yes
- Free of Prop. 65 chemicals– Yes

Material origin:

- Pre-consumer recycled content: >0 – 10 %
- Post-consumer recycled content: 75 – 95 %
- Renewable content: 0 %. Renewable Materials are materials that have been produced from a source, that can be renewed by short- to medium-term regeneration.

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? - Yes
- Is the product designed for dismounting? - Yes
- Can the product be disassembled and dismantled into its single materials? – Above 95 % are designed to be dismantled to the level of materials that can be reused or recycled for other products
- Design for re-use – Yes
- Which cycling scenario is the product designed for:
    - The product is designed for remanufacturing
- Which cycling scenario is the product designed for:
    - 25 – 50 % of the product is designed for recycling at the same level of quality
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling – Yes

3.1.2.2 Update on the product in March 2023

The chemical additives, whose compositions were recommended, used in the product have been composed. Only the acrylic based polycarboxylic type superplasticizers have been used for the production of related structural elements.
An assessment was recommended for the eco-hybrid cement supplied by CIMSA and for the aggregate. TEPE Betopan does not see this as their responsibility at this stage, and therefore does not provide information on the assessments.

At this stage, R&D studies of products produced by recycling CDW are carried out. As a result of these studies, it is planned to create additional documents to understand and explain the re-use scenario, wherein recycling CDW is presented as the best scenario and recycled products are used.

3.1.2.3 Analysis of the optimization potential and recommendations in August 2021

The chemical additives used in this product are unknown. For recycling aggregate percentages above 90%, super plasticizers are used. As a next step, the verification of the chemical composition of these additives is recommended.

For the assessment of eco-hybrid cement supplied by CIMSA and aggregate, based on the scope and definition of geological materials, the geological assessment methodology is recommended, as detailed in 3.1.1.3.

The circular flow of materials is an important part of circular design. The product is not only a response to future human needs but also a response to the question of how to maximize the use of limited resources. It indicates in the template that the manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling. As there is no additional documentation provided to explain this particular after-use scenario nor details on the re-use of recycled innovative products in the future are provided. Thus it is recommended that these mechanisms are thoroughly planned and assessed at a later stage.

3.1.2.4 Conclusion and future recommendations

The recommendation under D3.2 is still applicable to this product, as there was no significant change in the formulation.

3.1.3 Ultra-lightweight non-structural wall elements

The third type of product is “Ultra-lightweight non-structural wall elements” as developed by TEPE Betopan.

Lightweight concrete (LWC) has a maximum density of 2000 kg/m^3 and is achieved by using low-density aggregates. Intermediate-density concretes, where parts or all of the normal-density coarse aggregates are replaced with structural-grade low-density aggregates, have densities of 1450 kg/m^3. The main advantage LWC can offer is a reduced dead load of a concrete structure, which then allows the structural designer to reduce the size of column, footings, and other load-bearing elements. LWC mixtures can be designed in a similar strength as normal-weight concrete.[6]

The objective is to develop ultra-lightweight non-structural wall elements containing eco hybrid cement, 100 wt% recycled concrete and other aggregats.

3.1.3.1 Product composition and properties

Based on the literature research,[7] in terms of the mix design, ultra-lightweight concrete is very similar to conventional concrete with the only significant difference being that the aggregate fractions are very light.

TEPE Betopan also uses the Eco-hybrid cement, developed and supplied by CIMSA for their panels. A few different materials were added as lightweight aggregate prototypes. The company experimented with pumice, perlite, foam agent as well as with silica aerogel. The main goal of adding the low density aggregates is to achieve better thermal insulation while maintaining structural stability.

This is also reflected in the BOM. The prototype consists of 51% eco-hybrid cement supplied by CIMSA, 15% post-consumer recycled aggregate, 1% silica aerogel, 33% water and 0,2% foaming agent. This indicates that multiple light aggregates can be included simultaneously.

According to the answered questionnaire, the “Ultra-lightweight non-structural wall elements” have the following circular properties:

- SVHC-free – Yes
- CMR-free– not applicable
- Free of Annex XVII chemicals– Yes
- Free of Prop. 65 chemicals– Yes

Material origin:

- Pre-consumer recycled content: >0 – 10 %

[6] LightCoce.

[7] Hunger / Spiesz.

- Post-consumer recycled content: 50 – 75 %
- Renewable content: 0 %

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – Yes
- Is the product designed for dismounting? – No
- Can the product be disassembled and dismantled into its single materials? – 0 % of the product is designed to be clearly removed from the product. 0 % of the product is designed to be dismantled.
- Design for re-use? – Yes
- Which cycling scenario is the product designed for:
  - >10 – 25 % of the product is designed for recycling at the same level of quality.
  - The product is designed for remanufacturing.
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? – Yes

3.1.3.2 Update on the product in March 2023

- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling. It is recommended, that a better understanding of the mechanisms behind this take-back system and the future re-use of recycled innovative products is developed. The update of the producer states, that Research and Development studies of products containing CDW are being carried out. As a result of these studies, it is planned to create additional documents to understand and explain the re-use scenario, wherein recycling CDWs is the best scenario and the first recycled products are used.
- For the assessment of the eco-hybrid cement and aggregate supplied by CIMSA and based on the scope and definition of geological materials, the geological assessment methodology is recommended. The producers state, that this would be the responsibility of their supply chain. Therefore no recommendations have been implemented by the producer. It is unknown which chemical additives are used in this product, thus verifying the composition of these additives is recommended as the next step. Due to the lack of feedback from the producer's side, it is likely that no implementation of the former recommendations has happened.

3.1.3.3 Analysis of the optimization potential and recommendations in August 2021

For the assessment of eco-hybrid cement supplied by CIMSA and aggregate, a geological assessment methodology is recommended to be followed, as detailed in 3.1.1.3.

3.1.3.4 Conclusion and future recommendations

It is recommend to consider the Geological material guideline for the testing of perlice and pumice in the future development stage.

As the producer mentioned in D3.3, MasterRoc® SLF 30 as a foam agent is used in this product. No further information regarding its formulation has been delivered by TEPE nor is it readily available online. This makes it impossible to give any further recommendation at this stage.

The recommendations from 3.1.3.3 still remain valid for the chemical additives.

3.1.4 Demountable pre-cast carbonated blocks

At VITO and Orbix, a technology was developed to convert the sand fraction of recycled concrete aggregates into building blocks. This is done by adding carbon dioxide (CO_2) and Carbinox, a calcium-rich by-product from stainless steel production, as binders. The Carbinox reacts with the CO_2 to form $CaCO_3$, a process called carbonation.[8]

For this carbonation process, calcium-rich slag from stainless steel production is dried into an ultra-fine powder. The powder is mixed with the concrete aggregates (<4 mm) and water to form a homogeneous mixture. This mixture is pressed into blocks, placed in a CO_2 curing room and treated with carbon dioxide. Carbon dioxide is absorbed by the Carbinox and converted into calcium carbonate, which acts as a strong binder that replaces cement. The use of CO_2 as a binder instead of cement is not only cheaper and more sustainable, but also this Carbstone-technology captures CO_2, contributing to global climate goals.

The objective of this project under the collaboration of Orbix and VITO is to investigate the sand fraction of recycled concrete aggregates as raw material for carbonated blocks to close the raw material carbon cycle of cement.

3.1.4.1 Product composition and properties

According to the current BOM that was provided by the manufacturer, the product consists of 72% carbonated recycled concrete aggregate, that is used for aggregate purposes, as well as 24% of the product Carbinox from Orbix as a binding agent with additional aggregate purposes. There is also 4% CO_2 chemically bounded in the carbonates, also used for binding.

According to the answered questionnaire, the “Precast hollow-core blocks” have the following circular properties:

- SVHC-free – Yes
- CMR-free– Yes
- Free of Annex XVII chemicals– Yes
- Free of Prop. 65 chemicals– Yes

Material origin:

- Pre-consumer recycled content: 0 %
- Post-consumer recycled content: >95 %
- Renewable content: 0 %

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – Yes

[8] VITO NV.

- Is the product designed for dismounting? – Yes
- Can the product be disassembled and dismantled into its single materials? – 0 % of the product is designed to be clearly removed from the product. Above 95 % of the product is designed to be dismantled.
- Design for re-use? – Yes
- Which cycling scenario is the product designed for? – The product is designed for refurbishment
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? – No

3.1.4.2 Update on the product in March 2023

In the recent project phase, the main components changed from just the high calcium CDW with the binding agent $CO_2$to including an additional binder Carbinox as a 24 percentile component. This is due to the low binding activity of the sand fraction of recycled concrete aggregates. The Carbinox has been tested for radioactive contamination and shows very low radioactivity in comparison to natural stones.

3.1.4.3 Analysis of the optimization potential and recommendations in August 2023

Recycled concrete aggregate is considered as a geological material, therefore, the geological assessment methodology is recommended (all detailed information can be found under 4.1.4.).

An additional radioactivity test might be required. However, since it is unknown what specific tests the manufacturer performs on this innovative product, it must be confirmed with the manufacturer whether the suggestion is useful.

In addition, it is indicated that the manufacturer/industry association does not have a dedicated collection system in place to gather and deliver products for recycling. However, based on the feedback from VITO, many concrete recycling plants that produce concrete aggregates are situated in Flanders. So the manufacturer can use material that is currently already produced for other applications (e.g. use in concrete, use in road layers). The carbonated blocks can also be recycled by the same recycling plants.

3.1.4.4 Conclusion and future recommendations

As further recommendations, the final product should be tested for leaching and radioactivity. For the development of possible changes or additives, the circular design guideline has to be kept in mind.

3.2 Circular ceramic-based tiles

Ceramic tiles are one of the most widely used materials in both commercial and residential buildings.

The manufacturing process of tiles consists mostly of mineral compounds and clay, which are usually fired at 1050 to 1230°C[9]. In the European Union, the greatest energy source for that is natural gas.

The main raw materials are clay, feldspar, and kaolin. Other materials used for production are limestone, sand, glass for the glaze of the tile, color pigments and other specific raw materials. Ceramic tiles are usually installed using tile adhesives or cement based mortars[10].

Due to the high temperature of firing and fuel emission during the production process, the search for solutions to reduce fuel emissions and alternative energy resources is an ongoing topic since two decades.

In addition, some of the specific raw materials used for ceramic production such as high-grade magnesia, bauxite, silicon carbide, and graphite are not readily available in Europe. For parts of the industry, the main minerals must be imported[11], therefore the circular use of limited resource raw materials becomes more important.

The objectives of this innovation project within the frame of the ICEBERG project are to research possible wall-covering ceramic materials made from either sintered construction materials or wall-covering ceramic materials with 10% of non-ceramic materials in the formula. Also, the sintering temperature should be reduced by up to 120 ºC following only the convectional thermal treatment, giving the following results:

- Low CO_2 emissions and energy saving are expected.
- Resource efficiency might be improved by using recycled materials in new products with positive results.

Another remarkable feature of the tile is the imprinted QR code on the surface of the tile that is only visible under UV light. This means that information about the product and its components, as well as disassembling instructions or other useful post-consumer advice can be accessed immediately.

3.2.1 Product composition and properties

The main raw materials used in the production of ceramic products are natural clays, sand, feldspar as a fluxing agent, fireclay and quartz sand as a leavening agent, colorants, and other mineral additives. The composition of the UV-visible QR code is unknown.

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[9] Case Studies in Thermal Engineering.

[10] European Commission (b).

[11] Cerame-Unie.

Compared with commercial ceramic tiles, in this innovation project, recycled ceramic material (mentioned as post-consumer recycled source), mortal, drywall, concrete, clay as an additive, and STP (Sodium triphosphate), an additive in the wet milling process, are declared as generic materials in the BOM. The final composition constitutes of 77 % recycled ceramic material as well as 8 % mineral CDW.

According to the answered questionnaire, the "ceramic tiles" have the following circular properties:

Material identification / Health: (requirements are not met due to design at a very early stage)

- SVHC-free – Yes
- CMR-free – Yes
- Free of Annex XVII chemicals – Yes
- Free of Prop. 65 chemicals – Yes

Material origin:

- Pre-consumer recycled content and
- Post-consumer recycled content: up to 70 %
- Renewable content: 0 %

In the innovative products, the producer confirmed the product contains >25 – 50 % post-consumer recycled content by weight, higher than commercial one with 0 – 10 %. It's impossible to confirm that post-consumer recycled content in each batch of material does not contain any hazardous substances in a concentration above 0.1% by wt. The analysis test is pending but the presence of any hazardous material is not expected as only products compliant with regulations will be brought to the market, as fundamentally required of all products.

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? - Yes
- Is the product designed for dismounting? - No
- Can the product be disassembled and dismantled into its single materials? - > 95 % of the product is designed to be cleanly removed from the product and be dismantled to the level of materials that can be reused or recycled for other products.
- Design for re-use**:** 99-100 % of the product is designed for recycling at the same level of quality. The remainder of the materials is foreseen by the manufacturer to be recycled at a lower quality than the original content.
- Which cycling scenario is the product designed for? - The product is designed for remanufacturing
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? – No

3.2.2 Update on the product in March 2023

The main strategy was not changed in the last project phase. There is a focus on the manufacturing process in terms of process optimization and the input materials.

There is no interest in working with a glue which can be reversible, because the current approach is to include the mortar, used to apply the tile to its underlying surface, into the composition of the recycling tile. Detachable glues on the basis of polymers could negatively impact the recycling of the mineral tile on its mineral underground

- According to Karaben Gruup, the composition information of raw materials is tested regularly with samples and the final product is analyzed to a certain extent with different tools at the current stage of the project
- The definition and composition of recycled materials can be fulfilled by certifying the chemical composition of the final product for each batch of the product, produced with the same raw material. A case-by-case solution can be implemented using the QR-code on the surface of every tile, to provide information about its composition and post-consumer advice.
- It was recommended to take the guideline for geological materials into consideration under Cap 4.1 to avoid harmful content. This was not considered as there are no harmful materials expected in the CDW.
- As the recycling material is received by another company and their input material varies between mostly pre-consumer recycling material to mostly post-consumer recycling material, no statement could be made concerning the percentage of pre-consumer-recycling material.

3.2.3 Analysis of the optimization potential and recommendations in August 2021

- With proven formulations, it is recommended that composition information on raw materials is obtained and a deeper material assessment of compositions is carried out following the circular design guideline before the product is put into use.
- It is recommended to take the guideline for geological materials[12] into consideration to avoid harmful content, for both virgin and recycled content. The Table 1: Banned List Limits for Geological Materials can be found in chapter 3.1.1.3
- If the product contains 25-50 % pre-consumer recycled content, it should be further displayed whether the recycled material comes from production or after installation.
- Planning a take-back system for post-installation and post-consumer is recommended.

[12] Cradle to Cradle Product Innovation Institute (b).

- Ready for re-use and leasing as a service with reversible adhesive can be attractive options, as the benefits of reversible adhesives include easy access for repair and replacement of single pieces of ceramic tile.
- For clean post-consumer recycling, a detachable connection is a prerequisite. It is highly recommended to assess solutions for a reversible attachment system.

3.2.4 Conclusion and future recommendations

During and after the extraction of clay and other minerals, quarries and riverbanks are restored and returned to their natural state, recreating habitats, and promoting biodiversity. In the holistic Cradle to Cradle approach, aspects like biodiversity must also be taken into consideration. The goal is to make a positive impact instead of mitigating the negative impacts these processes have on society. By restoring clay extraction sites and protecting biodiversity, the ceramic industry can play a role in maintaining recreational areas for sustainable local communities. However, the extraction of minerals and biodiversity of local sites are not the focus of the research in the ICEBERG project.[13]

[13] Cerame-Unie.

3.3 Wood based products

3.3.1 Circular wooden fiber insulation panels

The analyzed product is a wooden-based panel as developed by Pavaflex.

Two prototypes of the board are developed under this project: One with 35% recycling fiber from construction and demolition waste wood and another one with which substitutes 100% the softwood pin chips used in regular production.

VTT is the supplier for construction and demolition waste wood (pin chips).

This is an innovation for wood panel production as it has never been done before on an industrial scale.

3.3.1.1 Product composition and properties

The BOM indicates that the innovative product is made with softwood pin chips, CDW pin chips, flame retardant (Ecochem INH 540 needed to get Euroclass E), and Bicomponent Polyester fiber as fiber binder.

To produce a flexible wood-fiber board insulation, an industrial line is planned next year, as well as a frame of pre serial prototype production. The future raw material could include the integration of at least 35 % CDW. The aim is to incorporate as much CDW as possible while still fulfilling product properties and ensuring good perceptible quality. Therefore, for the moment, the mentioned 35% CDW is a supposition.

Based on the current situation, the producer filled out the BOM based on its available information. However, there is no feedback regarding the PCDS since it will be done in the later development stage.

According to the answered questionnaire, the “circular wood fiber insulation panels” have the following circular properties:

Material identification / Health:

- SVHC-free – Yes
- CMR-free– not applicable
- Free of Annex XVII chemicals– Yes
- Free of Prop. 65 chemicals– Yes
- PEFC is a plus for a good source of wood

Material origin:

- Pre-consumer recycled content: 0 - 10 %
- Post-consumer recycled content: 0 % (means only for technical nutrient)
- Renewable content: 75 - 95 % (fresh and recycled wood)

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – No
- Is the product designed for dismounting? – Yes
- Can the product be disassembled and dismantled into its single materials? – More than 95 % of the product is designed to be clearly removed from the product. >75 - 95 % of the product is designed to be dismantled.
- Design for re-use? – Yes
- Which cycling scenario is the product designed for:
  - >75 – 95 % of the product is designed for recycling at the same level of quality.
  - The product is designed for remanufacturing.

The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? – No

3.3.1.2 Update on the product in March 2023

- 70% of the fresh wood chips are sourced from PEFC certified sources.
- VOC testing has been done for the standard product Pavaflex and should be done for the innovation product as well due to the change of recipe.
- Recycled Content Materials List of Analytes[14] is recommended to use for recycled CDW.
- Pavaflex states that abrasion of the product in the use phase is something that would not concern the user, because of little exposure for the user. As the product is encapsulated in wall or roof constructions, direct exposure for user can be ruled out.
- Flame retardant, glues, and other additives are not checked for the compliance with the optimal end of life scenario, as explained in chapter 2.2 Safe and circular material choices. This is especially important for ingredients that are not from a secondary or renewable source.

Based on available information from BOM, a bicomponent polyester / Co-polyester fiber is used as fiber binder in this innovation product and a polymerization process is explained in D3.3, P210.

Concerning the after use scenario, Pavaflex states that the finished product is in the current stage not suited for recycling in the company’s plant. The production facility is not equipped for this material at the moment.

[14] Cradle to Cradle Product Innovation Institute (c).

3.3.1.3 Analysis of the optimization potential and recommendations in August 2021

As Pavaflex is mainly made with wood, this product based on C2C criteria can most likely be considered as a biological nutrient. However, some points may be reviewed before it is safely returned into the next biological cycle.

Regarding fresh wood fiber, the following points should be considered in terms of wood sourcing:

- Wood species
- Source of the wood (geographic location)
- Policy for avoiding the processing of wood from illegal felling
- Certificates like FSC, PEFC, or similar for the case applying. The producer already takes this into consideration.

Regarding CDW, all contaminates are possible due to the universal sources of recycled waste. Therefore an analysis of this recycled content is necessary to ensure the quality of the final product. It is expected that the producer will have some kind of a regular testing system in house to ensure the products are compliant with the regulations.

The interaction paths of Pavaflex during its use shall also encompass off-gassing, leaching/abrasion from the panels. As an indoor product if applicable, VOC emission testing should comply with off-gassing standards for the construction sector, like the German AgBB. It is expected that the producer has already done some kinds of analysis for its products. It is recommended to consider the VOC emission requirements in the Cradle to Cradle Standard as a supportive tool.[17] Secondly, abrasion products (dust) may be formed during the use period. Exposure to abrasion dust is minor but existent. The formed amount depends on the use pattern of the panels. In the further process, it needs to be discussed with the producer if this is already considered.

In addition, the used flame retardant, glues, and other additives if any, should be checked if they comply with the envisaged cascade scenarios before an in-depth assessment of interactions with biological systems is justifiable.

To maximize the productivity of renewable material in the product, potential cascading options at the end of the product's useful life should be considered. Cascading is the efficient utilization of resources by using residues and recycled materials for material used to extend total biomass availability within a given system.[15] If cascading was already considered, a detailed interview is necessary on how and where the product can be used in its next cycle.

Topics that should be considered in terms of material sourcing are “resources and biodiversity”, “water”, “production risks”, “social conditions”, and “energy”. Most of these criteria may be covered by PEFC, however, it makes sense to do a more thorough check of their fulfillment (encompassing a deeper analysis of FSC/PEFC criteria, their weak points, and recommendations resulting from it) at a later stage.

[15] European Commission(a).

Biological Materials Assessment Methodology and circular design guidelines can be recommended as supportive tools for a deeper assessment.

Conclusion and future recommendations

Producing flexible wood-fiber board insulation on an industrial line is planned for next year, also in a frame of pre serial prototype production. The future raw material could contain 35 % CDW.

The design of a future cradle of this innovation product is unclear since there're few information available. As current stand on march 2023, old panels are not refurbished, because the production plant is not equipped for this material. But it already works with some equipment for managing the wastes band coming from sawing and sizing. Technology exists and could be extended for the future for recycling some old Panel.

Chapter 2.3 *Testing material choices* is recommended for the design of future recycling paths. A positive definition of this product and a detailed material assessment of this product is relevant and a necessary step for the future intended material path (re-use) of this innovation product.

Once flame retardant, glues, and other additives are fully defined, they could be checked according to chapter 3.3.1.3.

3.3.2 Circular green wood chip concrete panels

Green wood chip concrete panels as developed by TEPE Betopan are used to produce interior wall elements and roof slab. They are the only company that produces both cement-bonded particleboards and fiber-cement boards in Turkey. While producing cement-bonded particleboards, they manufacture the panels by chipping and treating the specially grown pine tree and adding cement to the mortar mixture.

The objective of the project is to develop ultra-lightweight non-structural wall elements and green wood chip concrete panels containing Eco hybrid cement, 100 % recycled concrete aggregate and alkali-treated recycled wood fibers.

The concrete panels with wood fibers are easy to install and lightweight with increased flexibility.

3.3.2.1 Product composition and properties

The composition of the circular green wood chip elements is similar to the lightweight panels from TEPE Betopan, including the eco-hybrid cement as well as aggregate and chemical admixtures. The difference is in the aggregates, which consist of recycled concrete aggregate and wood chippings.

This is also reflected in the BOM. The innovation product consists of 32% eco-hybrid cement, 8% recycled aggregate, 40% recycled wood chippings, 8% water and 12% chemical additives. The recycling components exist of 100% post-consumer recycling content from CDW.

Some chemical admixtures were used in wood-chip concrete panels. First, there is an aluminum sulphate ($Al_2(SO4)_3$) solution that accelerates cement hydration. Another chemical admixture is a sodium silicate (Na_2SiO_3) solution which acts as glue between cement and chip[16].

According to the answered questionnaire, the “circular wood chip concrete panels” have the following circular properties:

- SVHC-free – Yes
- CMR-free– Yes
- Free of Annex XVII chemicals– Yes
- Free of Prop. 65 chemicals– Yes

Material origin:

- Pre-consumer recycled content: >0 – 10 %
- Post-consumer recycled content: 50 – 75 %
- Renewable content: 0 %

[16] ICEBERG circular economy of building materials (Page 168).

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – Yes
- Is the product designed for dismounting? – No
- Can the product be disassembled and dismantled into its single materials? – 0 % of the product is designed to be clearly removed from the product. 0 % of the product is designed to be dismantled.
- Design for re-use? – Yes
- Which cycling scenario is the product designed for:
    - >10 – 25 % of the product is designed for recycling at the same level of quality.
    - The product is designed for remanufacturing.
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? – Yes

3.3.2.2 Update on the product in March 2023

- It is unknown which chemical additives are used in this product, thus verifying the composition of these additives is recommended as the next step. Due to the lack of feedback from the producer's side, it is likely that no implementation of the former recommendations has happened.
- Regarding *fresh* wood chips, a list of requirements for wood sourcing in chapter 3.3.2.3 should be considered. The producers instead apply the Alkali treatment, as the aim of this project is using *waste* wood for recycling and then integrating it into panels.
- For the assessment of the eco-hybrid cement and aggregate supplied by CIMSA and based on the scope and definition of geological materials, the geological assessment methodology is recommended. The producers state, that this would be the responsibility of their supply chain. Therefore no recommendations have been implemented by the producer.
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling. It is recommended, that a better understanding of the mechanisms behind this take-back system and the future re-use of recycled innovative products is developed. The update of the producer states, that Research and Development studies of products containing CDW are being carried out. As a result of these studies, it is planned to create additional documents to understand and explain the re-use scenario, wherein recycling CDWs is the best scenario and the first recycled products are used.

3.3.2.3 Analysis of the optimization potential and recommendations in August 2021

Based on generic circular design guidelines, this innovative product contains a mixture of biological and technical nutrients. Considering the future reutilization of this product, it is possible that the recycled wood contained within this product may only be thermally used.. It should be thoroughly analyzed whether the wood contaminants compromise the recycling of the concrete, as a separation of the individual materials will most probably be infeasible.

Waste wood from construction and demolition is one of the biggest post-consumer wood material flows. Although large amounts of the wood entering buildings are of a natural or generally harmless state, contaminations may occur via different paths at different points throughout the usage phase. This could result in the wood released from buildings entering a material flow of high uncertainty, in terms of both quantity and quality.
Again, it should be thoroughly analyzed whether the wood contaminants compromise the recycling of the concrete, as a separation of the individual materials will most probably not be feasible.

In the guideline, the base wood material must be identified in terms of species and genus of the organism of origin. Given the complex composition of waste wood and the necessity of enhancing cascading use[17], it might be a big challenge to find clear sources of waste wood and assess them to fulfill these criteria.

Regarding fresh wood chips, the following additional points should be considered in terms of wood sourcing:

- Wood species
- Source of the wood (geographic location)
- Policy for avoiding the processing of wood from illegal felling
- Certificates like FSC, PEFC, or similar for the case applying

It is unknown which chemical additives are used in this product , thus verifying the composition of these additives is recommended as the next step.

For the eco hybrid cement, the same recommendations apply as to TEPE Betopan as for the ultra-lightweight nonstructural wall elements.

It indicates in the template that the manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling.

As there are is no additional documentation provided to explain this particular after-use scenario nor to provide details on the re-use of recycled innovative products in the future, it is recommended that these mechanisms are thoroughly planned and assessed at a later stage.

3.3.2.4 Conclusion and future recommendations

Please consider the recommendation under 3.3.2.2 in the future development stage since it is a general recommendation for this kind of product.

Please consider the information under 2.3 Testing material choices into development of future cradle (next life time after use).

[17] Cradle to Cradle Product Innovation Institute (a).

3.4 Silica Aerogel and Silica solution

An aerogel is an aero mesoporous, solid foam consisting of a network of interconnected nanostructures. The term aerogel does not refer to a specific material composition but to a geometric arrangement in which a substance can be present. The manufacturing process for silica aerogel generally includes low temperature supercritical drying of CO_2 which operate under low temperature and high pressure conditions., different from the process for mineral wool. Primary material for other silica aerogels is sand. A resource that does not have infinite capacity[18].
Insulation materials with aerogel are new developments. There is still a lack of experience regarding the deconstruction and recycling of these materials.

The objective of this innovation is to reuse and recycle the waste from buildings to produce low-cost aerogel products which are the most promising materials for thermal insulation applications due to their nano porous with a fine, open-pore structure.

Silica solution is mostly made from CDW. It serves as the main component for silica aerogel. The solution cannot be treated as building material, but rather as an intermediate product for one.

As aerogels are used for thermal insulation of buildings, both energy consumption / CO_2 emission reductions and production waste valorization can be achieved with this innovation.

3.4.1 Product composition and properties

There are three types of products to supply to their project partners to make a final product. The two products are silica solution and silica aerogel from construction waste.

- Silica aerogel is made of 90 % silica and 75 wt.% of silica is from pre-consumer recycled source. The other 10% consist of Silane, a silylating agent. In the RSL v. 4 declarations, the manufacturer confirmed that there is no RSL substance intentionally added into this product.
- Silica solution is made of 50 % Sodium silicate solution. The Silica solution is made of sodium silicate which is 40% from pre-consumer recycled source and diluted with water. The rest is expected only water (50 %). In the RSL v. 4 declarations, the manufacturer confirmed that there is no RSL substance intentionally added into this product.

[18] Wecobis - Ökologisches Baustoffinformationssystem

According to the answered questionnaire, the products have the following circular properties:

Material identification / Health:

- SVHC-free – Yes
- CMR-free – Yes
- Free of Annex XVII chemicals – Yes
- Free of Prop. 65 chemicals – Yes

Material origin:

- Silica aerogel
  - Pre-consumer recycled content: 75 – 95 %
  - Post-consumer recycled content: 0 %
  - Renewable content: 0 %
- Silica solution
  - Pre-consumer recycled content: about 10-25 %
  - Post-consumer recycled content: 50-75 %
  - Renewable content: 0 %

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – Yes
- Is the product designed for dismounting? – No
- Can the product be disassembled and dismantled into its single materials?
  - 0 – 10 % of silica solution is designed to be cleanly removed from the product and be dismantled to the level of materials that can be reused or recycled for other products.
  - 0 % for silica aerogel
- Design for re-use: wt.% of the product is designed for recycling at the same level of quality. The remainder of the materials is foreseen by the manufacturer to be recycled at a lower quality than the original content:
  - Silica aerogel: 75 – 95 %
  - Silica solution: 0 %
- Which cycling scenario is the product designed for?
  - The product is designed for re-use as-is or with minimal modification: Silica solution
  - The product is designed for re-use as-is or with minimal modification and for remanufacturing: Silica aerogel
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? - No, but the necessity of a separate collection system is worth thinking about.

3.4.2 Analysis of the optimization potential and recommendations in August 2021

A separate take-back system for aerogel is not expected. It will be recycled in an existing recycling stream. A similar situation is also expected for silica solution.

3.4.3 Conclusion and future recommendations

The recommendations have been well implemented. There are no further recommendations. For the development of possible changes or additives the circular design guideline has to be kept in mind.

3.5 Circular plasterboards

Gypsum plasterboards are building boards for interior construction. Together with gypsum fiber boards, they form the basis of dry construction, with lightweight stud walls and suspended ceilings. Gypsum fiberboards are also used as prefabricated screed.
The production of FGD (Flue gas desulphurization**)** gypsum using waste gases from flue gas desulphurization plants, often at coal plants, will lose importance in the long-term concerning global climate targets. Furthermore, the mining of natural gypsum is becoming increasingly problematic due to environmental regulations, land conflicts, and citizens' initiatives in, for example, Germany as well as in countries such as Brazil.
Nowadays, the industry must therefore increasingly address the qualitative recycling of gypsum and look for alternative solutions.

At an early stage of the project, British Gypsum and the Loughborough University developed a new hydrocyclone treatment combined with acid purification to achieve recycled gypsum from post- consumer plasterboard waste. In the following stages, the process for recycling gypsum was adapted to reach the highest levels of purity possible, with initial results measuring about 96-97% in the laboratory at Loughborough University.
The objective later on was to develop a production process with high amounts of recycling gypsum from refurbishment and demolition plasterboard wastes. That technically demonstrates the feasibility of producing multi-life plasterboards with 35 wt% of recycled gypsum from refurbishment or demolition plasterboard wastes, instead of the usual 10 wt% in Gyproc wallboard standard plasterboard, as well as 100 wt% recycled paper.

3.5.1 Product composition and properties

Plasterboards are produced on large belt lines in continuous operation as a 1.25m wide endless belt. The gypsum is mixed with water and additives such as starch and thus constitutes the binder for the gypsum boards. The gypsum slurry is applied and distributed on the conveyor belt between two layers of cardboard. It quickly solidifies here, forming a stable plaster structure. Gypsum fiberboards are made with 15 - 20% reinforcement of cellulose fibers.

For impregnated boards, an additional layer of water-dispersed polysiloxane is applied[19].

While gypsum does indeed comprise the bulk of drywall panels, there are several other ingredients included: cellulose, gypsum plaster, paper and/or fiberglass fibers, plasticizers, starch, finely ground mica crystal as an accelerant, EDTA or other chelating agents, anti-mildew agents, such as boric acid, wax emulsion or silanes to hinder water absorption, and potassium sulfate.[20]

[19] Bundesverband der Gipsindustrie e.V.

[20] SAIMAXX.

The innovative product developed for the ICEBERG Project is plasterboard with a high share of recycled gypsum.

The ICEBERG plasterboard consists of 35 wt% recycled gypsum from refurbishment plasterboard waste, which is above the current maximum of around 10 wt% BAU recycled gypsum,100 wt% recycled paper, which is used as plasterboard covering, and additives such as starch, glass, fiber and fluidizer.

According to the answered questionnaire, the "plasterboards" have the following circular properties:

Material identification / Health:

- SVHC-free – Yes
- CMR-free – Yes
- Free of Annex XVII chemicals – Yes
- Free of Prop. 65 chemicals – Yes

Material origin:

- Pre-consumer recycled content: 25 – 50 %
- Post-consumer recycled content: 25 – 50 %
- Renewable content: 0 %

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – Yes
- Is the product designed for dismounting? – No
- Can the product be disassembled and dismantled into its single materials? -> 95 % of the product is designed to be cleanly removed from the product and be dismantled to the level of materials that can be reused or recycled for other products.
- Design for re-use? – > 95 % of the product is designed for recycling at the same level of quality. The remainder of the materials is foreseen by the manufacturer to be recycled at a lower quality than the original content.
    - Which cycling scenario is the product designed for? – The product is designed for remanufacturing
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? – Yes

3.5.2 Update on the product in March 2023

The product developed will no longer include phosphorus gypsum. As phosphorus gypsum tends to contain hazardous waste, the material is no longer used for the innovation product. Instead, British gypsum will focus on advanced technologies for purification and processing of gypsum waste.

British Gypsum stated that there will be circular plasterboards available in May 2023.

3.5.3 Analysis of the optimization potential and recommendations in August 2021

Geological materials include rocks, clays, sands, limestone, and other industrial minerals. Industrial by-products such as coal fly ash, tar, bitumen, and other complex, variable fossil-derived distillation residues, blast furnace slag, and phosphogypsum are also included in this geological assessment guideline since they are used in place of natural geological material due to the similarity in composition.

Given the physical nature of geological materials, toxicological data for all hazard endpoints is frequently unavailable. To help ensure that these substances, if present, are below levels likely to impact human or environmental health, geological materials must be analyzed, for example, according to the C2C geological material guideline, methodology outlined in section 2. An additional radioactivity test is also recommended.

For indoor use, products that are made of homogeneous materials that are or that contain phosphorus gypsum must also be evaluated for the presence of radioactive elements.

Further recommendations are first, the "Beyond Compliance" paper on socially and environmentally responsible gypsum mining internationally and second, to set the focus on occupational health, safety, and social responsibility towards the local population and workers. Finally, enabling quality assurance in production as well as return logistics through positively defined materials, especially positively defined additives, is also recommended.

After optimization of the recycled gypsum, an additional recommendation is to regard the chemical composition of recycled paper and other additives.

Further consideration of a take-back system and closed-loop recycling processes to get a better understanding is recommended as well.

3.5.4 Conclusion and future recommendations

The recommendations in project phase 3.2 for geological materials are still relevant for this innovation product.

In addition, for the recycled gypsum and recycled paper, a recycled material content analysis test is recommended to use in the later developing stage, to ensure this product is compliant with regulations. It is expected that the production will set up a kind of regular analytical test system to ensure the quality of recycled source material before it is used in production.

Another future field of interest should be reversible connections. To enable a reuse scenario for the multiple lifecycle plasterboards, a method of separation without demolition is necessary. Screws under plaster, as commonly used in the drywall industry for example, are not reversible connectors.

Testing of waste water in the gypsum recycling plant is recommended.

3.6 Circular PU based products

3.6.1 PU insulation panels

The next product group analyzed are PU-based insulation boards developed by Soprema.

Improving energy efficiency has been long recognized as the key to tackling climate change. It is also considered to be the fastest, most sustainable, and cheapest way to reduce greenhouse gas emissions and enhance energy security worldwide.

On the one hand, thermal insulation plays an important role in reducing the level of heating and cooling energy required in buildings. On the other hand, the treatment and disposal of construction waste have received increased attention in recent years due to legislations in Europe and other countries and concerns about the limited availability of landfill sites.

In the ICEBERG project, this innovation solves the problem of the industrial PU waste (pre-consumer recycled content). The ICEBERG project aims to recycle the PU insulation foam to produce a polyol and also use 27% polyol from renewable sources and 3% polyol from pre-consumer recycling sources to produce rigid PUR panels.

3.6.1.1 Product composition and properties

The insulation boards are made from insulation foam and the flexible facing.

The insulation foam generally consists of: polyols, blowing agents, catalysts, Surfactant and various additives for properties improving, and isocyanate products (MDI). The multilayer facings of the panels consist of MetPET, kraft paper and PE..

A full list of raw materials with their commercial trade name for commercial products PUR and PIR are very clearly detailed in the BOM on the generical material level.

The composition of the innovation product in this current stage was documented via the BOM. The final composition of the product will be conducted later after the prototype is developed.

According to the answered questionnaire, the PU insulation boards have the following circular properties: (this information is only concerning the recycled polyol)

Material identification / Health:

- SVHC-free – No
- CMR-free – No
- Free of Annex XVII chemicals – Yes
- Free of Prop. 65 chemicals – Yes

Material origin:

- Pre-consumer recycled content: 0 %
- Post-consumer recycled content: 10 - 25 %
- Renewable content: 0 – 10 %

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – No
- Is the product designed for dismounting? – No
- Can the product be disassembled and dismantled into its single materials? – 0 % of the product is designed to be disassembled, above 95 % of the product are designed to be dismantled.
- Design for re-use? – No
    - Which cycling scenario is the product designed for? – None
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? – No

3.6.1.2 Update on the product in March 2023

The full analysis of the primary material is not possible on an industrial scale. However, the final product is can be analyzed completely.

A prototype was made in 2022. All of the supplied secondary material was used, amounting to 10%.

3.6.1.3 Analysis of the optimization potential and recommendations in August 2021

Depending on the applications, PU insulation board will typically stay in place for 30 to 60 years or more.
The products today will become recycled feedstock and then turned into new future products. It is therefore particularly important that the compositions of the products are fully positively defined today, by voluntarily using more stringent assessment criteria than just complying with regulations.

Pre-consumer and post-consumer recycled polyol:

- Since the composition of product waste (pre-consumer recycled polyols) is known and the same as virgin material, the material health recommendations are also the same.
- The long life cycle of polyol may have also a negative impact on the quality of post-consumer recycled polyol, since the recycled product is likely to be contaminated by others in its use phase or substances used in the past, which are no longer admitted today. This will cause more costs but from a Cradle to Cradle® perspective, such recycled material is not recommended if it cannot be guaranteed to be of the same quality as the virgin material.

Once the material health issues with recycled panels are solved, the steps to follow up are explained in the generic circular design guideline. In addition to that, a strategic plan to set up a take-back system is recommended.

3.6.1.4 Conclusion and future recommendations

The earlier recommendations are still relevant for the future of the innovation product. For the development of possible changes or additives the circular design guideline has to be kept in mind.

3.6.2 PU Aerogel

An aerogel is an aero mesoporous, solid foam consisting of a network of interconnected nanostructures. This nanostructure can form from Polyurethan.

3.6.2.1 Product composition and properties

Polyurethane aerogel is made from recycled polyols.

- PU aerogel is made of isocyanate and polyols. About 50 wt.% of polyols are from recycled polyols (pre-consumer). In the RSL v. 4, it states this product contains 4,4' diaminodiphenylmethane < 0.1 wt.%.

According to the answered questionnaire, the PU aerogel has the following circular properties:

Material identification / Health:

- SVHC-free – Yes
- CMR-free – Yes
- Free of Annex XVII chemicals – Yes
- California Proposition 65 – No data available to answer this question.

Material origin:

- Pre-consumer recycled content: 10 - 25 %
- Post-consumer recycled content: 50 – 75 %
- Renewable content: 0 %

Material recovery:

- Is the product designed for maintenance & repair to extend the useful lifetime of the product? – Yes
- Is the product designed for dismounting? – No
- Can the product be disassembled and dismantled into its single materials?
    - 0 %
- Design for re-use: wt.% of the product is designed for recycling at the same level of quality. The remainder of the materials is foreseen by the manufacturer to be recycled at a lower quality than the original content:
    - 0 – 10 %
- Which cycling scenario is the product designed for?
    - The product is designed for re-use as-is or with minimal modification and for remanufacturing
- The manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling? - No, but the necessity of a separate collection system is worth thinking about.

3.6.2.2 Analysis of the optimization potential and recommendations in August 2021

A separate take-back system for PU aerogel is not expected since PU aerogel shall be recycled with PU panel together without an additional separate process.

The compositions of this PU aerogel shall align with the compositions of the PU Panel from Soprema.

In the PCDS template for PU aerogel, it indicates there is a high level of one SVHC substance in the aerogel. The SVHC substance (MDA) is from recycled polyols which is below 0.1wt% so the content of MDA in PU aerogel will be 0.02-0.04 wt.%. Further, the C2C - restricted substances list is recommended as a supportive tool for new product design in the long term.

To have a deeper understanding and evaluation based on the Cradle to Cradle® perspective, full composition disclosure is necessary. Also, further conversation with the producer to have a better understanding of the exposure scenario during production, use phase, and after use is recommended.

3.6.2.3 Conclusion and future recommendations

The recommendations have been well implemented. There are no further recommendations.

4 Conclusions

This report includes a circular design guideline for products as well as an in-depth assessment of the innovation products on the generic level within the ICEBERG project. It shows the benefits of the developed products as well as the potential these products have to become fully circular building materials. This was achieved with the help of the project partners and by applying the circular design guideline to the innovation products.

4.1 Optimization results

In the course of the cooperation with the project partners, the following results were achieved concerning the product composition:

Based on feedback from filled out questionnaires and interviews from all partners, it shows that an in house chemical control system to comply with regulations is in general already set up as the baseline of all product development. It has been confirmed by all project partners that even at the current stage, some products are not tested. It is also confirmed by project partners that the regular analysis of raw materials inclusive the secondary or recycled material will be analyzed, until the regulation requirement are fulfilled and only then will the product be launched on the market.

Beyond the regulation requirements, the recommendations from the circular design guideline, regarding radioactive tests and geological material guideline are applicable to most of the innovation products.

Additional C2C recommendations regarding recycled material content and its analysis method are introduced to all project partners. Some partners have agreed to implement recommended tests at the current stage as part of their product development. Some are willing to take the recommendations at a later stage since the development of the product is still ongoing.

In order to emphasize the aspects regarding the circular design, the partners were asked to answer questions that investigate the recycling path after the product's use.

Concerning the question whether the manufacturer/ industry association has a dedicated collection system in place to gather and deliver products for recycling or not, some of the partners answered with Yes, but some answered with No. This shows that future development under this aspect can be still improved in the future.

For different products, the optimal circulation is not always identical especially as the possibility of reuse is more difficult for some products than for others due to undefined or unsuitable binding agents. Therefore the optimisation recommendations were adapted to the expected material stream.

4.2 Constraints

Like most scientific statements, the recommendations and analysis in this report have limitations:

Depending on the development stage, some additives are not possible to define at current stage, which makes it impossible to give detailed recommendations. It is suggested to review this open work in the later development stage, to ensure the developed products have positive defined compositions for a well prepared future cradle of these products.

Due to the current lack of a harmonized classification and rating system for the circularity of buildings, a common understanding of the most relevant topics had to be established. This was done under D3.2 by defining on the one hand all the properties that should be regarded on product level and on the other hand, by establishing a system that can bring those properties into the context of a complete building.

In some products, a renewable source is also considered into product design, but the after use scenario of this product is still unclear. Due to undefined compositions of smaller portions of the product, such as additives, recommendations could not be made at this stage. However, the project partners have the possibility to assess them later, following the generic circular design guidelines once these compositions are defined.

4.3 Linkage to other parties of the construction sector

As mentioned in the introductory chapter, circular design in the construction industry does not only refer to building product manufacturer, but also to other parties as planners or architects. In order to close the circle and allow these evaluated building products to actually be used in real construction projects, knowledge of them is necessary among planners and architects. On the one hand, this knowledge dissemination is possible as a pull system from planners by conducting intensive research on building products that meet sustainable and circular requirements or by being supported by sustainability consultants. Alternatively, the process is also possible as a push system, with building product manufacturers putting a lot of effort into their marketing and ensuring that as many planners as possible include their products in their planning. However, in order to really create scale and allow sustainable building products to be incorporated into the design of circular buildings on a large scale, a combination of a pull and push system is needed. For example the data provided by manufactures could directly be implemented to create a material passport.

One digital example of a software solution, which is able to create such a material passport is BIM & More. The tool allows manufacturers of building products and planners of construction projects to work together in a new way. On the one hand, manufacturers are able to connect their product data management systems directly to the system platform. This allows the provision of daily updated data and makes it available for all services that are connected to the system platform. On the other hand, planners and architects have the possibility to access this specific data of the manufacturers as well as to integrate generic data directly into their construction planning. By manufacturers entering the attributes to sustainability characteristics on the material level of their products, these can be used for later calculations on the construction system level and building level. Thus, the assessment by manufacturers and disclosure of the values can be directly integrated into the planning process of planners. The following images show the material attributes regarding sustainability as well as a possible building project evaluation resulting from the date entered at the beginning of the planning.

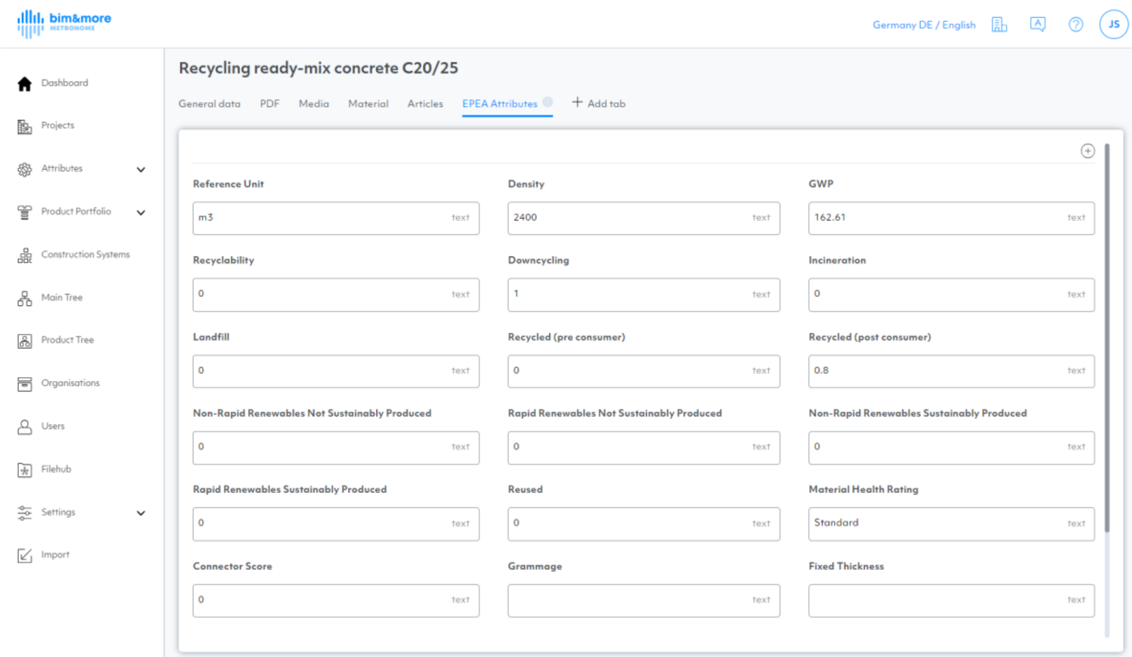

Figure 7: BIM & More - Attributes for Circularity Assessment

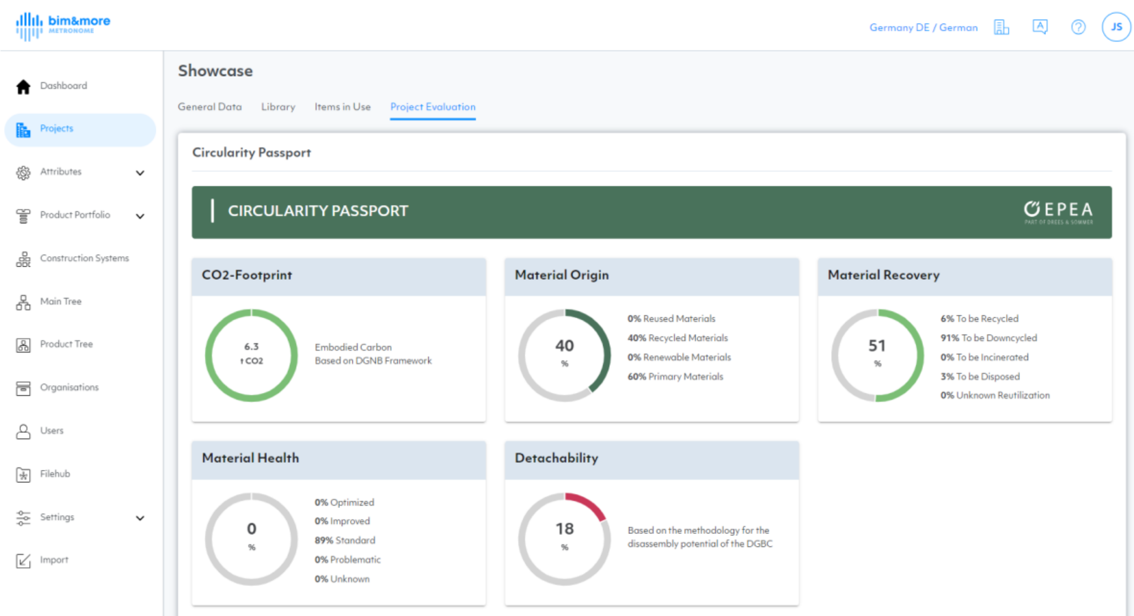

Figure 8: BIM & More - Project Evaluation in BIM & More

4.4 Outlook and future recommendations

The circular design guideline provides an orientation for healthy and circular product development. This guideline should also be kept handy for further development.

Further recommendations concerning product composition are to provide information on components in more detail, at least to a level of 100 ppm, e.g. additives must also be analysed in order to carry out a material health assessment.

Due to rapidly changing product compositions of innovation products, constant adaptation to the current stage of recommendations necessary.Therefore, it is recommended to conduct an assessment also at the end of product development.

Another important topic for further product development and research is future circularity, with the goal to reuse refurbish or recycle the innovation products:

As the report focused on assessment of the material health aspect of Cradle to Cradle®, other aspects like product circularity need to be taken into account as well; for example the building level with the dismountability of products within the building should be considered in detail.

Defining whether the product is part of the biological or technical cycle is crucial to choose the right materials. Knowing where the product goes after its end of life is necessary for development of the product. Furthermore, this decision influences the choice of connector of the innovation product in the building.

Next to product optimization, it is crucial to improve the sorting and collection systems of the innovation products for future recycling or reuse, to create a real circular system.

All of these efforts result in the opportunity to realize material flows. This can be facilitated by documenting the information in digital passports, which provide products and buildings with a digital identity, eventually resulting in buildings as material banks.

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