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Publication date:
2011

Citation (APA):
Bjørn, A., & Strandesen, M. (2011). The Cradle to Cradle concept - is it always sustainable?. Poster session presented at The Life Cycle Management (LCM) conference : Towards Life Cycle Sustainability Management, Berlin, 28-31 August, .

The Cradle to Cradle concept - is it always sustainable?

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Abstract The Cradle to Cradle (C2C) concept has gained wide interest among especially designers over the past few years. This paper aims to investigate whether C2C products are in fact always sustainable and to explore whether an ideal C2C society is so too. An LCA comparing the C2C certified mineral paper TerraSkin with a cellulose based reference paper was conducted. From this, energy systems and recycling infrastructure was found to be decisive parameters for the sustainability of C2C products. They are therefore not always sustainable. Moreover a literature study identified inherent sustainability conflicts of the C2C concept relating to: 1) 100% closed loop recycling is not thermodynamically practical 2) addition of biological nutrients to the environment may result in loss of biodiversity and 3) even an ideal C2C society will experience resource scarcity and loss of biodiversity as a result of continuous economical growth.

1 Introduction

As a new approach to sustainable product and system design, Cradle to Cradle (C2C), has gained wide popularity, especially in the non-academic environment. It has attracted new companies and revitalized some of the dormant actors. It is however regarded with a high degree of scepticism in the academic environment. LCA practitioners have claimed that it does not include all life cycle stages and therefore cannot be considered a serious concept for sustainable design. This attitude gap is problematic because it inhibits communication between the two groups. This communication is crucial if C2C is to grow from being buzz to a concept that leaves a solid, positive and constructive impact in the world of sustainable design.

Few in-depth studies have so far been conducted to identify where the conflicts arise between C2C and eco-efficiency, with LCA as a measuring tool, and how these conflicts may be solved.

This paper presents the findings of an LCA comparing a C2C product with an eco-efficient reference product. This will serve as a basis for identifying the most important parameters for the sustainability of C2C products. Additionally a number of inherently critical points of the C2C concept will be identified and discussed.

2 Background

The C2C concept is based on three fundamental principles: Waste Equals Food, Use Current Solar Income and Celebrate Diversity [1].

2.1 Waste Equals Food

The first principle calls for the elimination of the very concept of waste and encourages to be inspired by nature's endless nutrient cycles. Instead of the eco-efficient approach of trying to reduce the amount of waste, the focus should be to design systems with outputs that can be taken up as nutrient by other processes. This goes both for emissions during the production stage of a product and for the product itself once it reaches the disposal stage. To ensure that such emissions can undergo 100% closed loop recycling materials should either be defined as technical or biological nutrients. Technical nutrients should be designed for industrial recycling whereas biological nutrients should be designed to return to the soil and feed environmental processes. Biological and technical nutrients should not be mixed beyond easy separability. Otherwise a product is created which neither fits into the biological nor the technical ‘metabolism’. Such a product can never be truly recycled, but merely downcycled into a product of lower quality and value [1].

2.2 Use Current Solar Income

The second principle dictates that the energy required for fuelling a closed loop Cradle to Cradle society must all come from what is termed ”current solar income”, defined as photovoltaic, geothermal, wind, hydro and biomass. These sources correspond with the general understanding of renewable energy sources. Due to the vision of being entirely supplied by energy from the sun, Cradle to Cradle design is not limited by any constraints on the energy use during the life cycle of a product. As long as the energy quality meets the requirements (current solar income) the energy quantity is irrelevant [1].

2.3 Celebrate diversity

The main point of this last principle is to avoid one-size-fits-all solutions and instead design products and systems with local environments, economies and cultures in mind. Also it is encouraged to “become native” and realize ones role as a species among other species. Therefore the aim should not be to reduce negative impacts on the environment as suggested by the eco-efficiency concept as this would result in isolation from other species [1].

3 LCA results

An LCA was carried out comparing a mineral based C2C silver certified paper (TerraSkin [2]) with a reference cellulose based paper with comparable properties (Lightweight Coated, LWC). TerraSkin is composed of approximately 75% $CaCO_3$ and 25% HDPE. It should be noted that TerraSkin is not completely in agreement with the C2C principles, since it is only Silver certified. However some of its characteristics are shared by all C2C products and the results of the LCA can therefore be partly extrapolated to cover C2C products as a whole. Details on goal and scope can be obtained from [3]. For the purpose of this paper characterized results are illustrated in Fig. 1 for a number of disposal options under present and near future conditions (not representing an ideal C2C future)

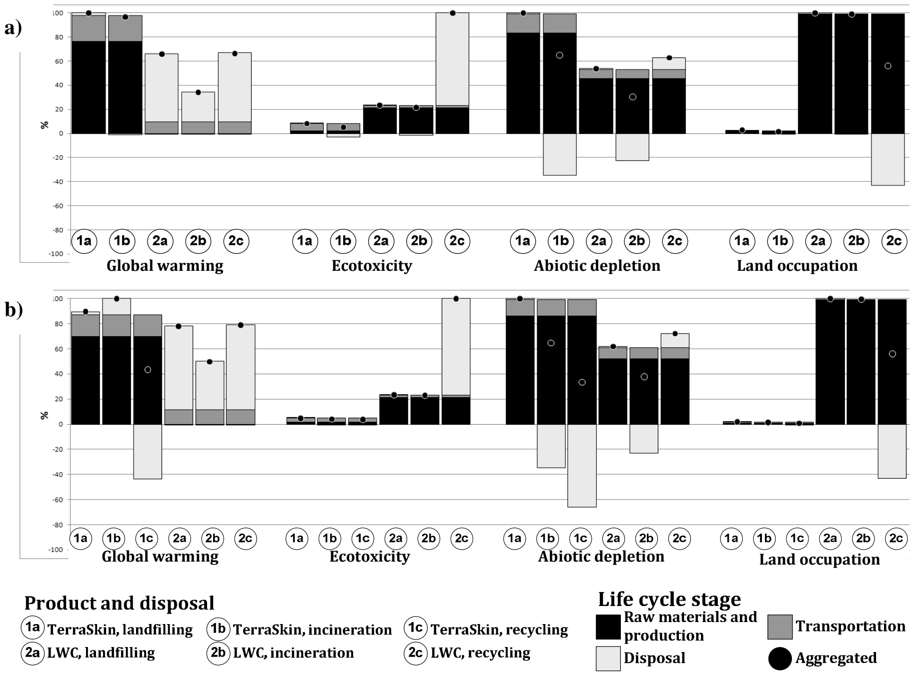

Fig.1: **Characterized LCA results for four impact categories in: a) present conditions and b) near future conditions. For each impact category, the scenario with the highest impact have been assigned a score of 100%. The other scenarios have been assigned scores relative to this for each impact category.**

Fig. 1a shows that under present conditions the TerraSkin incineration scenario has the lowest environmental impact in Eco-toxicity and Land occupation. However the LWC incineration scenario has the lowest impact in Global warming and Abiotic depletion[1]. The fact that the TerraSkin scenarios have significantly higher life cycle net energy consumption means that it generally has a higher impact in categories that are highly correlated with energy consumption from fossil sources (in addition to Global warming and Abiotic depletion shown in Fig. 1). This is because oil and coal are defined as marginal sources for heat and electricity production respectively (Even though the C2C concept states that energy supply should be "current solar income" there is no direct requirement of

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[1] Note that recycling of LWC has a higher impact in most categories since alternative use of saved wood had not been considered due to the scope of the study.

actually applying current solar income at the Silver certification level) [4]. Due to this outcome the normalized results show that TerraSkin has an overall higher environmental impact than LWC paper.

Fig. 1b illustrating near future conditions shows that due to the introduction of TerraSkin recycling, an expected decrease in the energy consumption of the production of TerraSkin and the assumption of natural gas as marginal heat and electricity source, the relative outcome between the compared products changes considerably. This change is most notable for Global warming and Abiotic depletion, where Fig. 1b shows that there is no longer any significant difference between TerraSkin and LWC. As a consequence TerraSkin appears to have the overall lowest impacts under future conditions when considering normalized results.

The observations from this case can be partly extrapolated to C2C products as a whole through two general observations: 1) Due to the exclusion of energy efficiency considerations of C2C products they will often be less sustainable than eco-efficient reference products from an LCA point of view. This is because the primarily fossil based energy consumption of today results in adverse environmental impacts across many impacts categories included in LCA methodologies. It could be argued that if all companies producing C2C products were to construct capacity for renewable energy to fulfill their own energy needs, then energy consumption would not be an issue. However this is not currently realistic and the alternative, to buy renewable energy certificates, has lately been criticized of in fact not leading to the construction of more renewable energy capacity [5] 2) C2C products that are technically recyclable may not be practically recyclable due to limited volumes on the market. This further challenges the claim that C2C designed products are inherently sustainable. Both of these issues are expected to decrease in importance in the future as the share of renewable energy is expected to increase and the market is expected to contain large enough volumes of C2C products for feasible recycling systems to be established (Fig. 1b). Therefore while the C2C concept represents an inspiring vision for product design in an ideal future it has been demonstrated that it should presently not be applied without e.g. energy efficiency considerations.

4 Critical points

Three inherently critical points of the C2C concept have been identified: 1) 100% closed loop recycling of technical nutrients, 2) Environmental benefit of biological nutrient addition, 3) Compatibility with continued economical growth.

4.1 100% closed loop recycling of technical nutrients

C2C advocates argue that 100% closed loop technical nutrient cycles is possible when isolating technical nutrients from biological nutrients [1]. In that way downcycling is avoided. However thermodynamically it has been demonstrated that the work required to separate ideal mixtures of two or more substances increases without bounds as the separation process proceeds [6]. Thus the last bit of impurity of one substance diluted in another substance requires infinite amounts of energy to separate. This theoretical evidence is reflected practically from the fact that impurities can only be removed down to a certain level in current recycling processes after which they will persist in low concentrations in the recycled materials. Therefore while it may be useful to separate biological from technical nutrient this alone does not guarantee closed loop recycling. It also does not guarantee the elimination of problematic chemicals needed in the recycling process (e.g. solvents), although this is claimed by the authors [1].

This means that some materials will not be accepted in C2C designs, which is problematic since it may compromise the overall sustainability as well as the functionality of products. This can be illustrated from the case of automobiles. A recent trend within automobile design is to increase the use of composites and specialized metal alloys. This allows for lightweight designs and important features such as heat and corrosion resistance. Composite materials cannot undergo closed loop recycling since they represent a practically inseparable mix of e.g. glass fibers and a polymer matrix [7]. While individual alloys can theoretically undergo closed loop recycling, provided that they are not mixed with other alloys, this is not logistically feasible when considering the hundreds of alloys often applied in one automobile [8]. Therefore when applying the C2C design to cars composites and the large diversity of alloys would most likely not be allowed. However, LCA studies indicate that the environmental benefit of the lightweight components by far outweighs the disadvantage of their non-recyclability [9, 10]. While this conclusion is of course dependent on the automobile fuel, some products depend on composites and alloys for their function (such as strength as well as heat and corrosion resistance). Therefore the need for these materials will not be eliminated, even in an ideal future where fuel consumption is not associated with any significant environmental impacts. However, while it is difficult to predict the future, recyclable substitutes to composites and alloys may be developed, which would eliminate this critical point.

4.2 Environmental benefit of biological nutrient addition

This critical point can divided into two distinct points: 1) Limited nutrient value in biological nutrients and 2) Adverse effects of addition.

This first point is related to the fact that many materials that, according to the official definitions, qualify as biological nutrients does in fact not contain any macro- or micronutrients (such as N, P, and K and Zn, Mn, and Se respectively) [11]. An example of this is PLA (polylactic acid) which along with many other biobased polymers is only composed of C, O and H atoms. Therefore when added to the soil through composting as prescribed by the C2C concept it will be more or less completely decomposed into CO_2 and H_2O [4, 12]. Even when assuming that a small fraction of the biopolymer is retained in the soil as humus, resulting in various positive effects (e.g. facilitation of plant nutrient uptake as well as carbon sequestration) other disposal options, such as incineration and anaerobic digestion have been found to be more sustainable [3, 13, 14]. This conclusion is dependent on the environmental impact associated with energy production. It could thus be argued that there is no need for energy utilization through waste incineration or anaerobic digestion in an ideal future with plenty of renewable energy capacity and that composting could therefore become a sustainable disposal option.

The second point relates to the C2C perception that the environment can "benefit" from the addition of nutrients. This is used as an argument to integrate nature into human designs instead of aiming to conserve nature through the separation of human and natural processes [15]. However, it has been demonstrated that individual species will react differently to a certain concentration of a given nutrient. Some will be growth-inhibited and others growth-stimulated [16]. This means that any manipulation of natural systems will result in a changed species composition, a decrease in some species numbers and in worst case a loss of biodiversity [17]. Thus the positive vision of benefiting the environment can in some cases actually lead to a violation of the third principle of the C2C concept of celebrating diversity. An example of this is the design concept of integrating seeds into an ice cream wrapper in order to support plant growth when disposing of the wrapper, as suggested by [1]. This design concept has been highlighted for being problematic, since it may result in the formation of invasive species and destruction of local ecosystems [17].

4.3 Compatibility with continued economical growth

One of the most provocative messages of the C2C concept is that it is compatible with continued economical growth. The argument is that as long as resources are circulated within closed loops then the rate at which they circulate does not need to be restricted. Also, when biological nutrients are beneficial to the environment then more biological nutrients are even more beneficial. There are several flaws with this reasoning. Firstly, the historical development clearly shows that the direct material consumption (DMC) per person is well correlated with the income and thus with economic growth at the societal scale (not considering changes in population numbers) [18]. This means that even though 100% closed loop recycling is to be achieved it does not eliminate the need for virgin resources and thus the problem of resource scarcity. In terms of renewable material resources continued economical growth will necessitate an increase in the conversion of natural productive lands for the growth of biobased materials for the production of food and non-food items (such as bioplastic). As demonstrated above some species will be negatively affected by this impact and it will consequently lead to a loss of biodiversity at a global scale.

5 Conclusion and perspectives

It can be concluded that products designed after the C2C concept are not always sustainable. This is highly influenced by the fact that the sustainability of products greatly depends on external systems such as energy supply and waste management infrastructure. In an ideal C2C society these systems would match the C2C products. Energy consumption would be without adverse environmental effects and sophisticated waste infrastructure would ensure closed loop recycling. However, present eco-efficient considerations should not be ignored and therefore LCA should serve as a reality check on the sustainability of C2C products.

Even in an ideal C2C society inherent critical points of the concept exist. Absolute closed loop recycling is in fact not possible. The addition of biological nutrients to the environment will not result in a benefit unless the specific ecosystem has been degraded by human impacts as a starting point. (When it comes to natural environments, that have low biodiversity and primary production, such as desserts, and interesting question is whether or not they can “benefit” from the addition of nutrients. Can such nutrient additions enhance nature as implied by [1]?) Also an ideal C2C society will experience resource scarcity and loss of biodiversity as a result of continuous economical growth.

These points along with the value of eco-efficiency need to be addressed by the advocates of the C2C concept. If not, the concept may never be accepted in the field of sustainable design.

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