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CHALLENGES FOR BIO-BASED PRODUCTS IN SUSTAINABLE VALUE CHAINS

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Abstract

This work concerns studies related to strategic development of products in which bio-based plastics are or will be applied, referred to as bio-based products. The studies cover (1) current and potential benefits of bio-based products in extended value chains including activities after end-of-life of products, (2) value communication between stakeholders in extended value chains, and (3) creating an integrated development approach for optimized bio-based products. Most existing models for value chains were found to be one-way single-flow models to which iterations and interactions have been added to obtain realistic representations of best practices. Interviews of thirteen professionals clarified some barriers between the current implementation of bio-based plastics and the ideal sustainable value chain fulfilment. The most noticeable barriers included trustful information sharing, information and knowledge gaps, sub-optimum application of bio-based plastics, and the need for facilitating product design. The main designers' needs are increased integrated literacy related to bio-based materials, eco-effectiveness and a more effective communication competence in value chains. Based on all findings, six approaches of design tasks integration into value chains have been proposed. These approaches encourage designers to think and act widely across value chains and particularly help implement life cycle thinking to achieve profitable sustainability.

Key words: bio-based plastics, cyclic material flows, end-of-life, integrative product design, sustainability

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1. Introduction

A major sustainability objective is to achieve fully cyclic flows of all materials in societies. In the ideal situation there would be (1) no depletion of resources, at least not in time frames within human imagination, and (2) no creation of useless materials or material combinations, currently called waste. Achieving such a set of cyclic flows will be challenging for some materials and material types. Maintaining cyclic flows for several materials based on non-renewable resources is technically feasible; energy requirements and costs, however, may be prohibitive in many situations.

Bio-based plastics are an emerging group of materials enabling a unique combination of opportunities. The basic characteristic of bio-based materials is that they are based on resources that are renewable within time frames matching material needs and consumption. This characteristic does not apply to any fully synthetic or inorganic material. A sustainable balance between growth and consumption of resources requires responsible practices avoiding, for example, depletion of soil nutrients and interference with food production or food prices. Such interferences, according to available documents, do not occur at present for bio-based plastics (Carus and Piotrowsky, 2009), partly because of the low

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volume of current markets. The use of non-food resources not requiring agricultural land is being addressed (Bioplastics Magazine, 2008a, 2008b; Fernyhough, 2008; Verbeek and Van den Berg, 2008). Such activities should result in sufficient alternative resources for large volumes of bio-based plastics so as not to disturb food availability and prices. Renewable resources can be used for unique plastics unavailable through oil-based routes, as well as for currently known plastics (Ball, 2006; Baumann, 2007; Van Haveren and Schennink, 2007; Rosato, 2007; Thielen, 2008; Urethanes Technology, 2007) and a broad material variety as for oil-based plastics is achievable. The current application potential of available bio-based plastics - still having less variety than oil-based plastics – is not fully utilized yet. The latter issue is among our research topics and results have been and will be published elsewhere (Koster et al., 2008).

Another issue that have been started to address is the set of strategic challenges associated with rapid and considerable growth of bio-based plastics applications in the future, requiring economically competitive achievement of sustainability goals in the full value chains. Historically, new plastics have required almost 10 years average from commercialization to adoption according to McKinsey studies (Weihe, 2009). This was because value chain barriers and technical deficiencies needed to be resolved. These were generally overcome by learning to work with new materials' properties, and by improving materials, respectively. These studies refer to short-term developments needed before value chains themselves can be addressed with more strategic approaches. A basic advantage of bio-based plastics over oil-based ones is that the materials themselves, not considering energy consumption, do not contribute to additional greenhouse gas creation in the Earth's atmosphere. End-of-life issues for products are major strategic challenges, as is obvious for the current oil-based plastics. They will be no less challenging for bio-based plastics. Several principles are technically feasible to give bio-based as well as oil-based plastics a useful destination after the end of a product life. These end-of-life scenarios are not always financially attractive as compared with the costs of generating waste in current societal contexts.

Technical principles and processes will need improvements and new ones may need to be developed. Such technical developments will make most sense if they will become part of integrative value chain improvement, which may be an evolutionary development. A related future-oriented vision is that product design should evolve into life cycle design, to contribute to more sustainable value chains. In an exploratory study (Koster, 2009), in which ten professionals were interviewed, it was found that bio-based plastics are expected to keep growing rapidly in the near future while remaining a niche market and primarily replacing oil-based plastics in existing products. It was also noted that market development has not kept up with material developments for bio-based plastics. These findings are obviously applicable to the time period in the quoted McKinsey studies in which short-term value chain barriers and technical deficiencies need to be resolved. The strategic challenges facing designers for a more long-term scenario beyond mere material replacement are the focus of the studies reported below.

2. Method

The key research questions within this work were:

- what is or could be the value of bio-based plastics (in qualitative terms)?
- what would be key requirements for value chains to best achieve the benefits of bio-based plastics?
- How can designers best integrate their contribution into value chains for maximum value creation?

The research questions were expanded into six categories of interview questions related to stakeholders' activities, forecasts and perception:

1. current and future involvement in applications of bio-based plastics;
2. business drivers for applying bio-based plastics;
3. implementation of bio-based plastics applications in value chains;
4. upstream and downstream relationship management within value chains;
5. market communication approaches;
6. near-future market opportunities.

In-depth interviews based on these research questions were held with thirteen relevant stakeholders in The Netherlands, Belgium, Germany and Taiwan. These professionals are involved or consider getting involved in one of the following: (1) bio-based plastics production or other biotechnological activity, (2) bio-based plastics application, (3) studies or consultancy related to bio-based plastics or biotechnological activities. Some of the applicators among them are also involved in the production or application of oil-based plastics. The core activities of the respondents' companies or institutes are:

- bio-based plastics production or supply: 2;
- product manufacturing: 3;
- design and development: 4;
- network platform (NGO): 1;
- innovation and creativity consultancy: 2;
- academic research: 1.

3. Results and discussions

3.1. Current and future involvement in application of bio-based plastics

The current professional involvement of the respondents in bio-based plastics or their application varies between very little (one of many activities) to fulltime. Bio-based plastics were considered by all as having good future potential, although many did not consider themselves sufficiently up-to-date yet to imagine more than material replacement. Regarding their future involvement in bio-based plastics or their application, most of the respondents who do not currently work on it full-time considered it difficult to make a prediction other than stating that they will remain interested in finding application opportunities.

3.2. Business drivers for applying bio-based plastics

All respondents are obviously capable in their professional activities and explained them clearly. Nevertheless it turned out to be challenging to objectively assess their business drivers for applying bio-based plastics. In a generic sense the reasons for adopting these materials are mainly market-driven or innovation-driven or both, innovation being considered a necessity by all. "Green" positioning in the market was perceived as an important company attribute expected by the market. Application of bio-based plastics, no matter how limited yet, was reported as one of the responses to market expectations.

3.3. Implementation of bio-based plastics applications in value chains

The respondents reported several challenges for implementation of bio-based plastics in value chains. The need was seen to further optimize product manufacturing with these partially new materials, as well as to conduct other experiments to expand the materials' application potential. The need for more creative application of bio-based plastics as well as unique designs was also mentioned. It was perceived that Society needs understanding and acceptance of the materials' qualitative values. The respondents assumed that ongoing material improvements will lessen barriers for application. Resolving all these challenges was expected to facilitate a clearer value creation by bio-based plastics, an issue also relevant for relationship management within value chains.

3.4. Upstream and downstream relationship management within value chains

Regarding relations within value chains, developing profitable applications require intense communication with knowledge sharing, according to most respondents. A materials-related knowledge gap between material suppliers and downstream product manufacturers was mentioned. Because of uncertainties and the current limited scale of bio-based plastics application, it was expected that process innovation across the value chain will increase. All respondents have observed a basic willingness to share knowledge. Hesitance to share technological and market-related information, however, is commonly encountered, which was attributed to incompletely developed value chains. Regarding trust building as well as information sharing, personal meetings and contacts were identified as much more valuable than electronic and written communication. Well-known complex issues, as confirmed by the respondents, are life cycle analyses or other environmental characterizations. Working with these is time-consuming and learning experience is clearly needed. Simplified programs exist but are not broadly applied either, partly because additional knowledge is still needed before such a program can be usefully applied. A challenge in the current situation is that different stakeholders have different perspectives on economical, environmental, social and technical factors.

3.5. Market communication approaches

The respondents, except the materials suppliers, did not have market communication specific for applications of bio-based plastics. Specific green marketing would not make sense for them yet because of many uncertainties across value chains. These uncertainties were also considered challenges to be resolved before bio-based plastics application can extend beyond packaging, the currently dominating field. Environmental aspects are generally not the most important factors in market communication, or may not even be included in it. The challenge is to convey appropriate environmental information and other benefits for bio-based plastics, while assuring product quality and proper pricing.

3.6. Near-future market opportunities

Regarding future market opportunities, the respondents forecasted higher profits by increased production volumes, better material quality and more variety. Better intangible material and product qualities were considered important factors for consumer satisfaction and brand loyalty, all of which would be beneficial for bio-based plastics applications if environmental advantages will be achieved. More generally, process innovation across value chains was considered essential for enhancing environmental, social and economical sustainability.

Involvement of customers would increase even more by having them participate in new product development activities. All respondents agreed that a larger role of the current design sector would facilitate development of bio-based plastics applications by increased response to all requirements of different stakeholders and customers simultaneously.

4. Conclusions

Regarding the sustainability objective of cyclic material flows, it is interesting to analyze value chain models in literature. The benefits of such models are their systematic description, reflecting proven best practices or proposing desired situations. The value chain by Porter (Lehmann and Winer, 2005) is clearly a one-way single-flow model, not intended to include cyclic material flows. The enviropreneurial value chain model (Hartman and Stafford, 1998) is represented as a cyclic model with a gap between post-use processing and the start of product development-related activities, making it essentially a linear single-flow model because it contains not even a proposal for the most challenging part of the value chain, i.e., end-of-life scenarios, and related professional involvement.

The supply chain oriented model of materials flow (Tsoulfas and Pappis, 2006) goes a step further in including useful destinations for materials after end of product life. This model, however, is still represented in a one-way fashion. These analyses of value chain models combined with our results make us conclude that an integrative approach to achieve cyclic material flows and other life cycle optimization still need further development and broad adoption.

Most respondents, which have been interviewed in the research at hand, stated that life cycle optimization requires involvement of all stakeholders in a value chain. Most stakeholders need to become more familiar with such close cooperation. Building more trust is an obvious requirement noted by many respondents, similar to findings from previous work on design support for applying innovative nano-structured materials and associated technologies (Koster et al., 2007). These combined findings make us conclude that trust-based close cooperation is a major requirement in creatively finding appropriate applications for new materials and technologies beyond mere material replacement.

Based on these conclusions, it is proposed six approaches of relevant design tasks:

1. Create a shared platform whose content will continually be kept up-to-date by users and experts, so it will serve as an inspirational knowledge base as well as contribute to avoiding knowledge gaps;
2. Initiate or broaden cooperation between all relevant experts and involved non-experts, to broaden everyone's view and facilitate stretching design limits;
3. Involve stakeholders and consumers as co-designers, to maximize creative ideas and cultivate benefits of serendipity;
4. Promote or reward sustainable life styles and product uses by objective and subjective product attributes;
5. Emphasize all aspects of life cycle thinking continuously across value chains and among consumers;
6. Emphasize value creation and re-creation continuously and broadly, and develop an idiom to communicate effectively about non-quantifiable value creation. Such approaches should contribute to optimized life cycle design across value chains, for which we aim to provide proof of principle in future work.

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