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A Holistic Approach to Design Support for Bio-polymer Based Packaging

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Abstract The growing interest in bio-polymers as a packaging material, particularly from companies looking to reduce their environmental footprint, has resulted in wider adoption. Traditionally the selection and specification of packaging materials was based on aesthetic, technical and financial factors, for which established metrics exist. However with bio-polymers, where the primary rationale for their use is environmental, alternative metrics are required. Furthermore, there is a significant strategic element to the decision process that requires a broader range of horizontal and vertical inputs, both within the business and the wider supply chain. It is therefore essential that a holistic approach is taken to the bio-polymer based packaging design process to ensure that the final packaging meets the original strategic intent and overall requirements of the business. Current eco-packaging design tools are generally limited to professional users, such as designers or packaging engineers, and generally provide tactical rather than strategic support. This disconnect, between the need for inclusivity and greater strategic support in holistic design, and the exclusivity and largely tactical support of current eco-design support tools, indicates a clear need for a new decision support tool for sustainable pack design using bio-polymers. This paper proposes a framework for an eco-design decision support tool for bio-polymer based packaging that has been developed using a predominantly qualitative research approach based on reviews, interviews and industrial packaging design experience and is an extension of previously published work. This research investigates further how existing eco-design methods, such as the 'Balanced Score Card', can be applied within the tool and how the shortcomings associated with incorporating social and environmental aspects can be partly resolved, through a simplified set of metrics tailored specifically for bio-polymer packaging decisions. The results of this research is a framework for the development of a three tier eco-design tool for bio-polymer packaging that provides decision support at the three critical stages of the design process: strategic fit, Feasibility assessment and concept/pack development.

Keywords Biopolymers · Sustainable design · Packaging · Decision support tool · Multi criteria decision making · Life cycle assessment

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Introduction

The development of bio-polymers has been driven largely in response to the growing concerns regarding the sustainability of conventional polymers and the environmental pollution caused by plastic packaging waste [21, 25]. The majority of plastics in use today are manufactured from fossil fuels such as crude oil, natural gas and coal [2]. These non-renewable resources are being rapidly depleted by a range of human demands of which fuel for energy production, heating and transport is the largest user: fossil fuels currently provide approximately 80 % of the world's primary energy needs [15]. Plastics production meanwhile accounts for around 4–5 % of global crude oil consumption compared to the 87 % that is incinerated [22, 23]. Resource depletion is only part of the problem. Carbon dioxide, produced when fossil fuels are burnt, is believed to be a major contributor to global warming and could have

potentially devastating social, economic and environmental consequences in the future if not addressed. As demand for fossil fuels increases, so the pressure to find new reserves pushes exploration into increasingly challenging and environmentally sensitive locations multiplying the environmental impact of extraction and use [4, 16].

Bio-polymers offer a potential solution to both of these dilemmas. Firstly, in terms of production feedstock, synthetic polymers derived from fossil fuels such as crude oil, are replaced by polymers derived from renewable resources such as plants and algae [3]. Secondly, many of the bio-derived polymers retain the biodegradable properties of the original feedstock enabling them to be composted and to breakdown completely in the environment, so reducing the problem of litter contamination [8]. Thus as the technical performance and affordability of these materials has improved, so the adoption of bio-polymers has grown from niche synergetic applications to mainstream, high volume global brands, particularly as leading companies look to capitalize on their consumers'/customers' demands for more eco-friendly products [7]. This observed trend is likely to continue as the pressure on companies to reduce their carbon emissions increases.

Whilst the manufacture of bio-polymers from renewable feedstock is a strong indicator as to their sustainability, fossil fuels are still expended at various stages during their life cycle. When other factors such as water and land use are considered the sustainability benefits of these materials becomes less obvious [3]. This observation is supported by the fact that despite numerous life cycle assessments and other environmental impact studies in this area, the overall environmental benefits of these materials in packaging applications remains contentious and contradictory [7]. This is particularly significant as, in contrast to conventional polymers, the rationale to adopt bio-polymers in packaging is justified primarily on a perceived environmental benefit often at an additional cost. The significance of environmental and sustainable factors in the initial strategic decision to adopt bio-polymers raises the importance of ensuring that these factors are integrated fully into the subsequent design and development stages [1]. Whilst this has been achieved to some degree with environmental considerations, with sustainability, integrating social impacts has proved more problematic [9, 17, 20]. This paper builds on existing published research in the area of eco-design and sustainability extending the initial research by the author on bio-polymer packaging eco-design support [6].

Pack Design Processes

The processes discussed in this paper are based on the design of primary packaging for consumer and retail markets. Primary packaging is usually in direct contact with the product and forms the primary sales unit as retailed to the consumer. In addition to the creation of a new pack from first principles, the re-design and re-engineering of packaging is particularly applicable to bio-polymers, as material substitution may be effected without any noticeable change to the pack structure or appearance.

The Traditional 'Conventional Polymer' Packaging Design Process

The traditional design process of a primary pack has been developed from practical experience over 50 design projects across a range of industry and product sectors and from published academic literature [29]. The key tasks involved have been grouped into five main stages; Preparation, Feasibility, Design, Development and Implementation (Fig. 1a). The preparation stage is a data gathering, sorting and communication exercise. The two key milestones in this stage are the initial preparation of a design brief and the subsequent development of a design specification. Next is the feasibility stage which involves the identification of suitable materials, formats, and processes that meet the technical and commercial essential requirements for the design. If no material can be identified then either the design specification or brief needs to be modified, or in exceptional circumstances the company may develop a new material usually in partnership with third parties. This material development is shown in Fig. 1a as an alternative process stage parallel to the feasibility stage indicating that wider material searches would continue.

During the design stage, the pack concepts are conceived, created, evaluated and selected. This may involve a number of iterations from initial brainstorming of ideas, to visuals and finally three dimensional models or working prototypes. Usually one concept is selected for the development phase which will involve testing and trials. At the end of development the final specification for the pack will be produced, which contains all the information required for its manufacture. The final stage is implementation, which begins with approval of the pack across the business and continues through its introduction with monitoring and feedback of its performance.

The Alternative Sustainable 'Bio-polymer' Packaging Design Process

The alternative sustainable design process for bio-polymer packaging, as depicted in Fig. 1b, has six key process stages; Strategy, Preparation, Feasibility, Design, Development and Implementation, as well as an alternative Material Research and Development stage that runs in parallel with the Feasibility stage. The key differences in

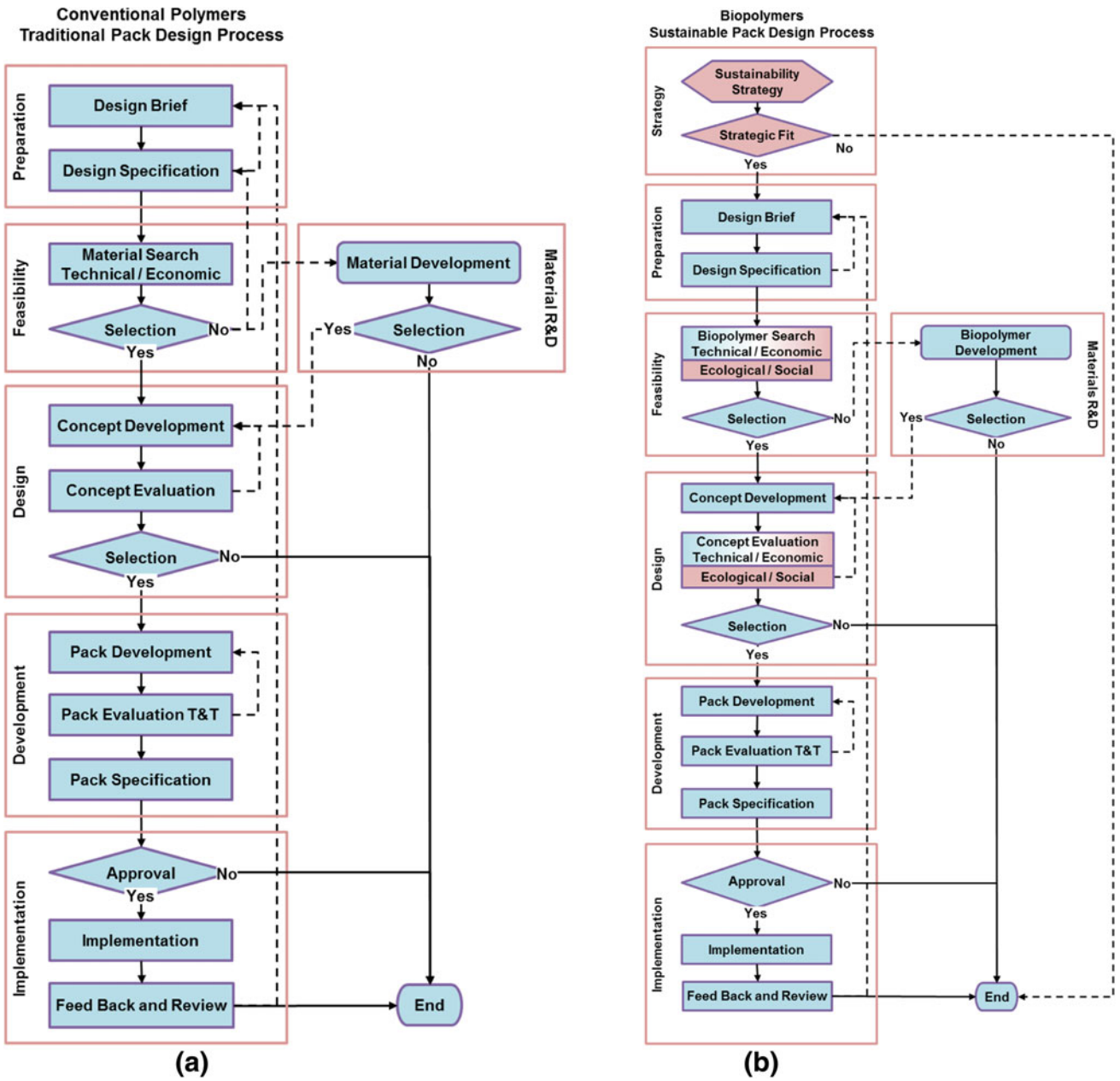

Fig. 1 Key stages in a traditional and sustainable primary packaging design process

this process, when compared to the conventional polymer packaging design process, are the addition of the Initial Strategy stage and modifications to the Feasibility and Design stages. The other stages in this process are consistent with the traditional pack design process.

The addition of the Strategy stage is required to ensure that the potential benefits achievable through the adoption of bio-polymers are in line with the company's strategic goals and expectations. With a traditional pack design activity, the strategic goals are well understood by the business and may include, cost reduction, increased margins/sales and profit improvement. With the sustainable design process, the strategy driving the interest in biopolymers is more complex involving social and environmental factors. It is essential that before embarking on an expensive packaging development exercise and product launch, realistic expectations are established based on the strategic goals which can be easily communicated and translated into design actions which in turn can be included in the design Brief and Design Specification produced during the Preparation stage.

The Feasibility and Design stages have been modified from the traditional design process through the inclusion of sustainability considerations, metrics and assessment

criteria in the material database fields and in the concept assessment/selection criteria. It should also be noted that due to the immaturity of bio-polymer discovery, it is much more likely that companies will have to take an active role in bio-polymer Research and Development (R&D) than with conventional materials.

Comparison Between the Two Processes

By comparing the two processes illustrated in Fig. 1, clear differences can be seen between the two approaches. These differences are summarised in Table 1. Firstly the question of, whether bio-polymers can form part of a company's packaging strategy and contribute towards their overall business sustainability goals, needs to be addressed. This is a high level decision, most likely taken at board level or by senior management, and would primarily be concerned with the broad commercial, financial, environmental, social and technical implications of using bio-polymer packaging. These strategic goals for the business, which include sustainability, must be accurately and simply communicated to the packaging design stage. The traditional method of a design brief is used to achieve this but with additional 'sustainability' goals included.

This design brief is then expanded into a design specification, which includes all the economic, technical, brand, product, manufacturing, logistics and sustainability requirements, prioritized as essential or desirable. This process is achieved through consultation within and across the business areas that are impacted by the proposed changes at every stage of the pack's lifecycle and would usually be carried out at middle management level within the business. This is an iterative process as, in order to develop a realistically achievable design specification, changes may be required to the original brief.

This design specification would then be used to carry out a material search for commercially available bio-polymers that meet the essential and, where possible, desirable requirements of the specification. Once all the potentially suitable materials have been identified, an initial selection process based on the most promising and potentially beneficial bio-polymers would be made. If no suitable material can be found, then material research and development can be explored. If successful the material(s) would then be selected for use in the concept development.

The development of packaging concepts is largely the same for both processes, although support may be required by the designer on the bio-polymer material properties. However the assessment of concepts will require, in addition to traditional criteria of economic, technical, aesthetics etc., social and environmental impacts to be addressed. These along with the economic impacts are assessed throughout the whole pack life cycle for each pack concept. These are then compared against each other and conventional polymer counterparts. The concept evaluation can be an iterative process, informing the design process, as well as being used for final selection.

The remaining steps of both processes involving the development, testing, trialing and implementation of the final pack design are largely the same, with the exception of the bio-polymer packaging evaluation and approval activities requiring the inclusion of additional sustainability data. Before outlining the framework for a holistic and integrated approach to the sustainable design of bio-

Table 1 Comparison of key process stages between traditional and sustainable packaging design

Process stage	Traditional design for conventional polymer packaging	Sustainable design for bio-polymers packaging
Strategic	*Not required* Strategic goals already communicated and understood within the business	The decision to use bio-polymer packaging is primarily a strategic one and so should be relevant and contribute to these corporate sustainability objectives
Preparation	Essential and desirable design requirements identified and then specified	Essential and desirable design requirements identified and then specified
Feasibility	Identifies technical and commercial feasibility of design objectives	Identifies technical and commercial feasibility of design objectives, as well as *sustainability goals*
Development (alternative process)	Less likely	More likely
Design	Design decisions informed by basic commercial and technical criteria	*Uses sustainability criteria to direct design in addition* to basic commercial and technical criteria.
Development	Standard company testing and trialing procedures followed	Standard company testing and trialing procedures followed
Implementation	Standard company procedures followed	Standard company procedures followed

Italic cells indicate a significant change in the process

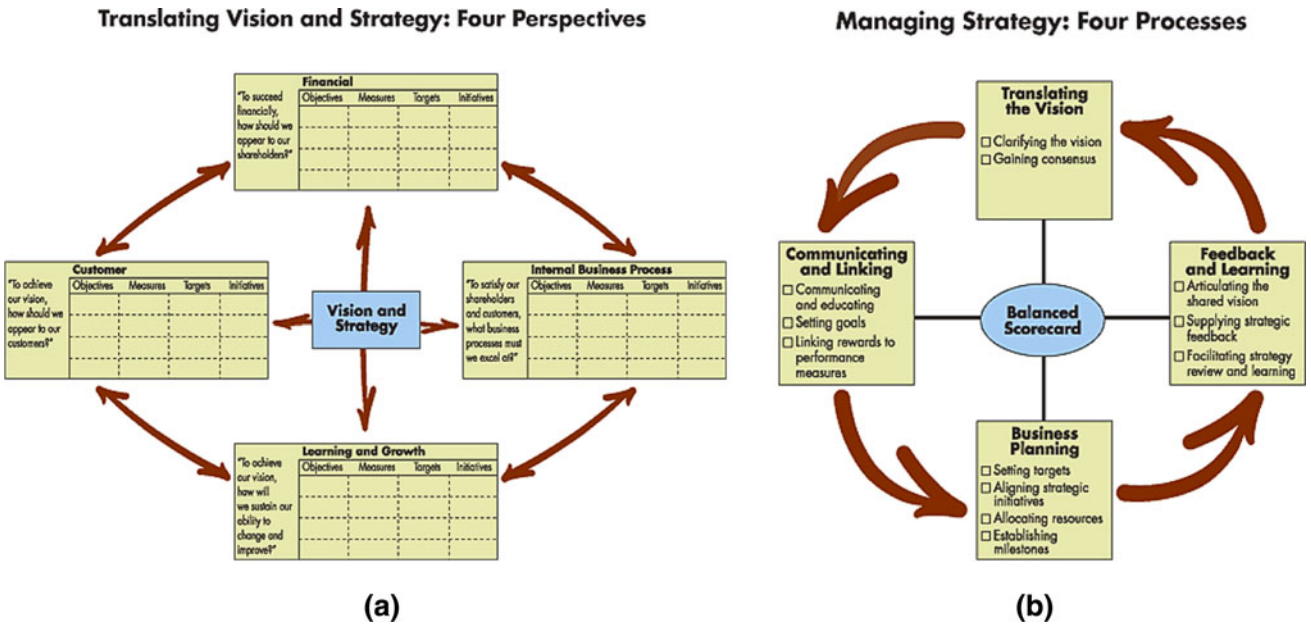

Fig. 2 The four perspectives and four processes of the balanced scorecard. *Source* Robert S. Kaplan and David P. Norton, "using the balanced scorecard as a strategic management system," Harvard business review (January–February 1996): reprinted with permission. Copyright (c) 1996 by Harvard Business Publishing; all rights reserved

polymer packaging, based on the key differences identified and discussed in this section, it is worth considering other approaches that have been used to address the issues of incorporating sustainability issues into the strategic decision making and design process.

Approaches to Sustainable Strategy and Design

A financially based strategy, such as described for conventional polymers, is simple to communicate and can be easily translated into direct operational activities. Likewise the results of these activities can then be measured and reported back within the existing financial and auditing structures, so enabling the effectiveness of the strategy to be determined. However, with bio-polymers, many of the drivers for change are not easily translatable into economic measures. This issue is not just limited to bio-polymers, studies carried out by Kaplan and Norton [19] concluded that increasingly, long term strategic objectives were becoming more difficult to translate into simple financial measures and targets. These findings led them to develop the balanced scorecard (BSC) which later evolved to incorporate sustainability issues.

The Balanced Score Card and Sustainability

The Balanced Scorecard (BSC) was initially developed as a mechanism for assessing a company's performance beyond its traditional financial measures. Kaplan and Norton's initial assertion was that the long term success of a company was no longer limited to financial capital, but that soft factors, such as customer focus, knowledge base and intellectual property, were also important. These key factors were captured in the BSC as four perspectives; financial, customer, learning and growth, and internal business process (Fig. 2a). From this diagram it can be seen that these four perspectives are all inter-connected, forming an integrated set of objectives and measures. This is achieved by defining goals, supported by appropriate long-term strategic objectives (lagging indicators) and identifying the specific competitive advantages of the business that can be used to achieve these objectives (leading indicators). Thus for each specific strategy, key performance drivers will be identified for each of the four perspectives. However, since a loose set of indicators and measures would be ambiguous and ineffective, these must be prioritized in terms of their strategic relevance. By creating a hierarchical cause and effect network, through causal linking of the leading and lagging indicators towards the long term financial goals, the resources of the business can be prioritized to those activities that will best promote the conversion and communication of the strategy.

This original concept of the BSC quickly evolved during its use in industry into a much broader strategic management system, linking long term strategy with short term operational actions. Whilst the initial concept of the BSC applied a primarily top down approach, three additional processes were added that linked these long term objectives with the short term actions. These four key processes, as

shown in Fig. 2b are: Translation of the strategic vision; its communication and linking to performance measures; business planning; and feedback and learning. The diagram highlights the cyclic relationship of these processes, showing how the feedback and learning phase has the potential to influence and inform the strategy providing a continuous mechanism for improvement, refinement and re-evaluation of strategic goals.

This functionality of the balanced scorecard, to allow non-financial success factors to be considered and incorporated within the business strategy, made it an obvious starting point for bringing corporate social responsibility (CSR) and sustainability management into the heart of business; through the inclusion of social and environmental factors into the core 'economic' management system. The need to reconcile these three factors or 'pillars' of sustainability (Social, Economic and Environmental) was noted at the 2005 World Summit [28]. These terminologies evolved to reflect a more corporate perspective, becoming known as the 3Ps: People, Profit and Planet, also referred to as the triple bottom line [10].

A number of approaches have been proposed on how a 'sustainability balanced scorecard' (SBSC) could be achieved [5, 11–13, 18, 24, 14, 26]. Figge et al. suggest two alternative approaches to achieving this, either by integrating the environmental and social sustainability factors into the existing four perspectives of the BSC, or introducing a fifth 'non-market' perspective. Furthermore, both of these two approaches can be extended with an additional second step incorporating the results from the higher level BSC of the strategic business unit into a 'derived social and environmental scorecard' [13].

Applying the SBSC to the Bio-polymer Eco-design Tool

The BSC is a tool to implement strategies, translating vision into action; it does not create the strategy. Likewise the Sustainability BSC (SBSC) provides a mechanism and method for incorporating and communicating sustainability within the core business strategy and, whilst it does not itself create the strategy, its use "may help to detect important strategic environmental and/or social objectives of the company" [5]. However, the time and effort involved in developing an SBSC is considerable and usually involves significant learning, due to an initial lack of knowledge of business leaders on the sustainability issues and strategies.

Bieker identifies a number of difficulties with implementing SBSC in practice: Firstly the enormous amount of patience, power and persistence required over long periods of time by top 'powerful' management; secondly the lack of will of the incumbent 'sustainability' managers to relinquish their sphere of influence by integrating sustainability into traditional management structures; and thirdly a lack of sustainability policy and/or strategies within the business at the start of the process.

The rationale for having an SBSC, and the difficulties encountered by Bieker when implementing it, are indicative of the problems faced by an organization when considering the use of bio-polymer packaging. Firstly, the motivation for this change would almost certainly be based on environmental or sustainability improvement and so would lie outside the traditional financial decision making. Secondly, whilst the feasibility of using bio-polymer packaging is largely an operational decision, the motivation to do so is predominantly a strategic and tactical one. Ensuring that the original motivation (strategy) for using bio-polymer packaging is not lost during the realization and feasibility process (action), requires that the strategy can be clearly communicated based on a realistic expectation of what bio-polymer packaging can achieve and also requires a degree of knowledge and understanding by senior management on the issues surrounding packaging, sustainability and bio-polymers.

The first requirement of a bio-polymer eco-design tool should be to overcome those difficulties as identified by Bieker in [5], by providing guidance through a supported step by step process that helps the management establish the role that bio-polymers could play in achieving the company's strategic sustainability goals. The results of this process would then communicated down through the business in a similar way to that achieved by the SBSC. In our research, by focusing the scope of the tool solely on bio-polymers and their comparison with their conventional polymer counterparts the complexity of tasks are managed at each stage thus keeping the time and effort required to a minimum, regardless of the level of knowledge of bio-polymers or existing sustainability strategy.

A Holistic Approach

The Design Council [27] lists the roles of packaging as threefold: to sell the product; to protect the product; and to facilitate the use of the product. In order to be able to fulfill these roles the packaging must meet many varied and sometimes conflicting demands and requirements. These include legislative, financial, manufacturing, technical, logistical, marketing, branding, promotional, environmental, and disposal. In fact it is often the case that packaging will have to meet multiple departmental requirements arising from a business and its supply chain, which are in direct conflict with each other, such as pack security versus ease of opening, differentiation versus standardization, and cost versus performance.

Vertical and Horizontal Integration

It is therefore unsurprising that the packaging design process requires input from key internal departments as well as suppliers and customers within the supply chain. To fully appreciate the complexity of the design process it is helpful to have a basic understanding of how packaging change is managed within the typical consumer goods manufacturer. How companies incorporate the various packaging functions, such as packaging design, within the corporate structure will vary according to its size, sector and culture.

An illustration of a simple corporate structure is given in Fig. 3, based typical consumer products brand owner/manufacturer. The packaging roles are divided into three key functional areas: Operational Support (Short Term View), Design and Development (Medium Term View) and Research and Development (Long Term View) and the departments/directors that are most likely to control each of these functions, have been assigned. Thus strategic packaging research will most usually report to the director of R&D whilst operational support would probably report to the purchasing or operations director.

Finally Fig. 3 indicates which key actors in the supply chain are most likely to have interaction with these packaging and departmental functions. Packaging suppliers for example would predominantly be engaging at the operational level but through their R&D and product development may also have tactical and strategic relationships with the company in the development of new packaging or materials. In this arrangement a new packaging material, such as bio-polymers, might be identified by the strategic packaging function during its early development phase. The key focus, at this stage, would be to establish the potential commercial advantage delivered by this new material to the business, the associated costs and the probable timescale for change.

If a business case can be made then, at the appropriate time, it would be taken forward by the packaging development group. Here the material would be tested and trialed and a full cost benefit analysis undertaken. If approved, this would then be passed to packaging management/operations to implement, involving extensive production and market trials and a rolling implementation across the range of products. During and after implementation, the performance of the pack would be monitored in the marketplace. It is also worth noting that the cost of changing a pack at the end of the design process is much more costly than at the beginning. As strategy is determined at board or senior management level, whilst tactical and functional decisions are made in the later stages by middle management and skilled employees, any disconnect between these two extremes in the process could have severe consequences on the effectiveness and impact of the design change.

Figure 4 illustrates how these key packaging functions relate to the business areas in the context of horizontal and vertical integration. An effective decision support tool must take into account the need for inclusivity both within the business and across the wider supply chain as the decision to adopt bio-polymers for packaging within an organization

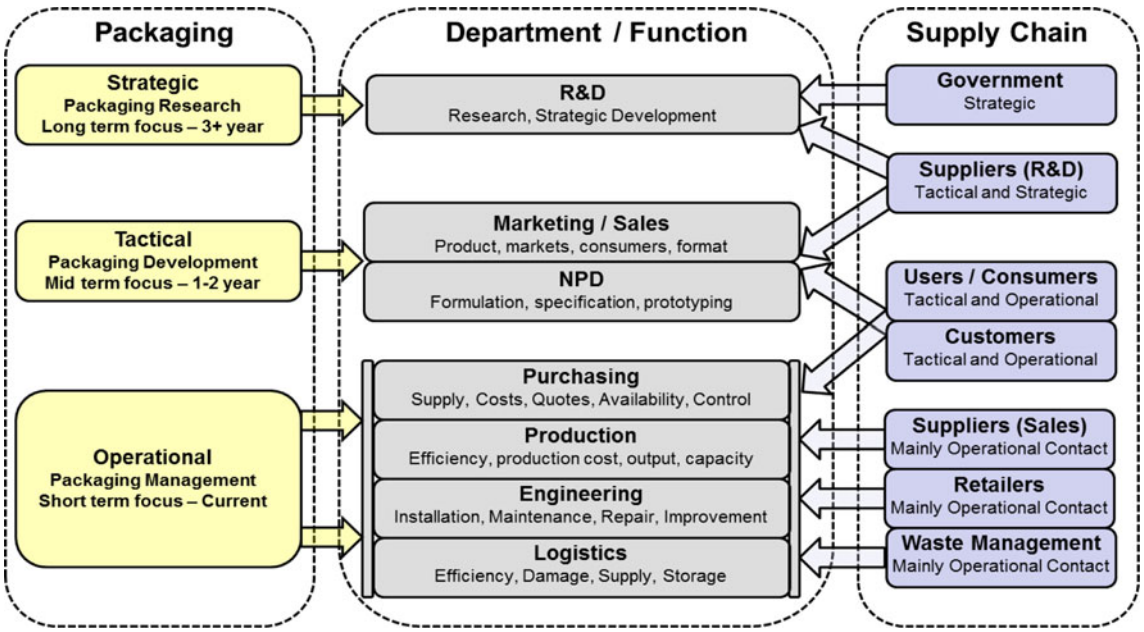

Fig. 3 Illustration of a common organizational structure and reporting hierarchy of packaging functions within a typical brand owner manufacturer and its relation to the wider supply-chain

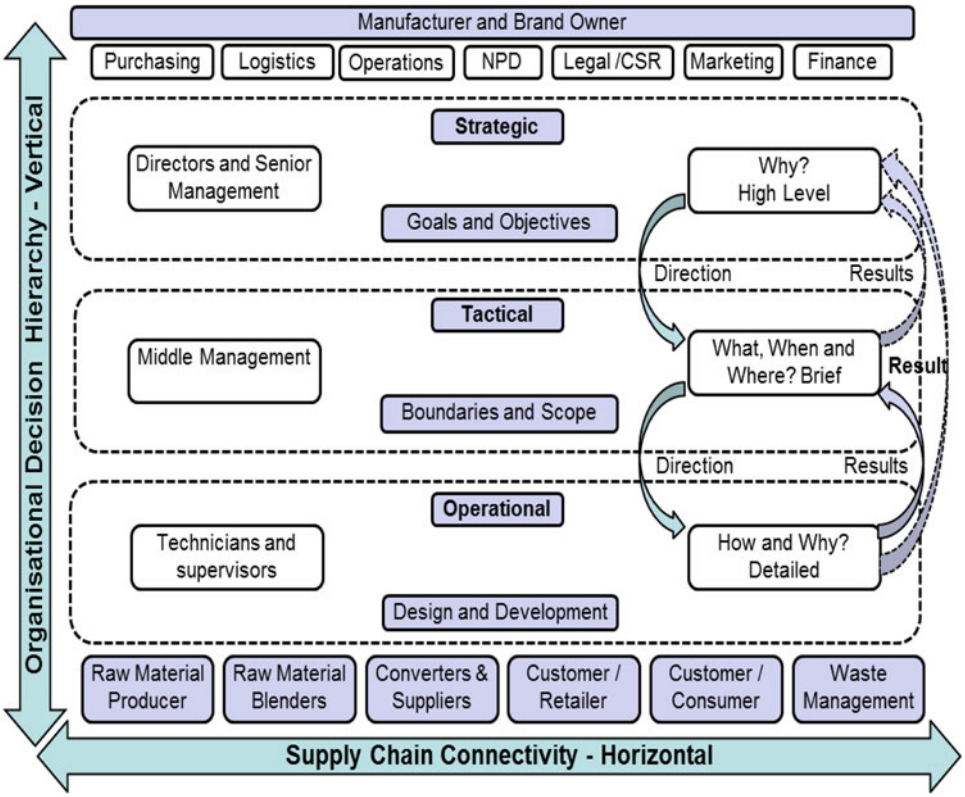

Fig. 4 Key packaging functions and their relationships within a business

will not be restricted to any one group, function or skill set. For a tool to be fully inclusive it needs to engage actors at all levels and stages by matching their abilities and meeting their needs.

The Framework

The Holistic Integrated Sustainable Design (HISD) framework for bio-polymer packaging proposed in this research is concerned solely with bio-polymers in packaging applications and the conventional polymers being replaced. Whilst there are many factors that might affect the selection of materials and design of a pack, for this framework, only those factors relevant to the comparison of a bio-polymer pack with a conventional polymer pack need be considered. The framework is not intended as an alternative to the existing pack design process or for the wider comparison of non-polymer materials or pack formats. To achieve this goal a systematic approach is proposed to review, select and assess the use of bio-polymer packaging in terms of its potential for reducing the environmental, social and economic impacts of conventional polymer packaging. The HISD framework for bio-polymer packaging consists of the following three stages and is illustrated in Fig. 5.

The HISD framework firstly establishes the potential of bio-polymers to contribute to the company's Business, CSR and/or Packaging strategies, and then translates these into communicable business actions. These actions then inform the development of a technical, commercial, social and environmental requirements specification, which will be used to evaluate and select the most appropriate bio-polymer(s). Finally, a robust life cycle assessment of the selected bio-polymer(s) and the incumbent conventional polymer alternative(s) must be undertaken for each proposed pack concept.

This evaluation stage should assess the environmental, social and economic impacts across the whole life cycle and provide a mechanism by which the results for alternative pack options can be compared against each other, and against the original specification and strategic objectives. The complexities involved in integrating this sustainable thinking into the current pack design process are two-fold. Firstly there is the unresolved problem of integrating the three pillars of sustainability into a single assessment process, and secondly there is the difficulty of integrating these additional design considerations and activities into the existing pack design processes and requirements. The tasks involved in each stage of the framework are described in more detail in the following sections.

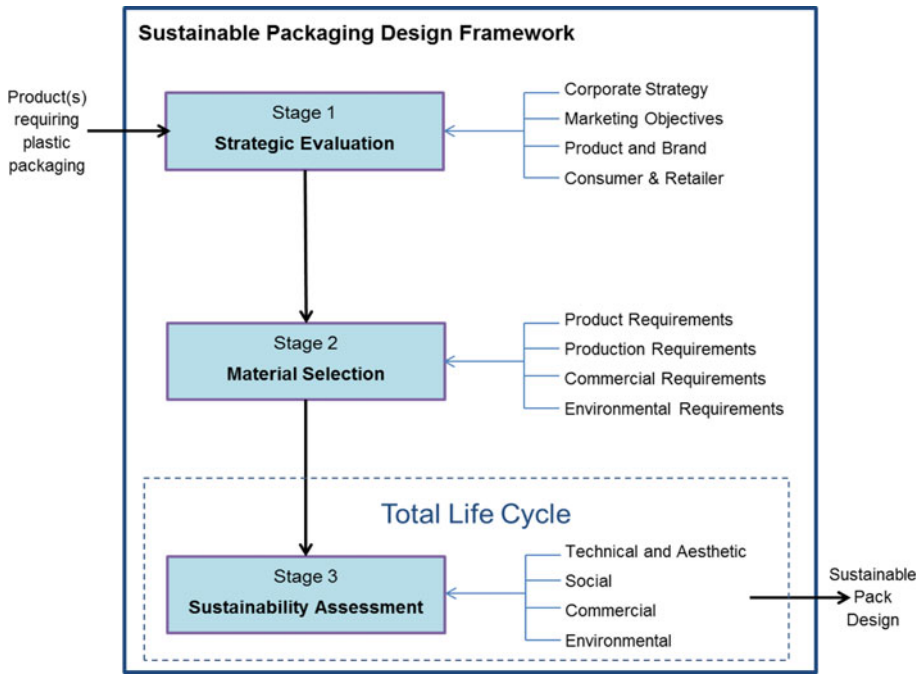

Fig. 5 The holistic integrated sustainable design framework for bio-polymer packaging

Framework for Bio-polymer Packaging Functional Stages

The three stages or tiers of the proposed HISD framework, as shown in Fig. 5, are:

1. Strategic Evaluation
2. Material Specification
3. Sustainability Assessment.

These three tiers are framework forms the basis for a computer aided Eco-Packaging Design Support tool as illustrated in Fig. 6. Each of these.

Strategic Evaluation

The aim of the strategic evaluation is to establish the potential for bio-polymer packaging to contribute to the relevant strategic goals of the business and if appropriate, support the translation and communication of these strategic goals into business actions.

Traditionally strategic goals have been relatively easy to communicate in financial terms to the rest of the business. However, when trying to communicate less traditional strategic objectives such as sustainability, responsibility, and knowledge etc., as would be the case with bio-polymers, the traditional financial model proves inadequate.

Early studies carried out by Kaplan and Norton in the 1960's concluded that long term strategic objectives were becoming increasingly difficult to translate into simple financial measures and targets [19]. As discussed in section "The Balanced Score Card and Sustainability", these findings led to the development of the balanced scorecard (BSC), which was further adapted to include sustainability measures, becoming the sustainability balanced scorecard (SBSC). As highlighted in section "Applying the SBSC to the Bio-polymer Eco-design Tool", there are problems associated with implementing an SBSC, which in the case of bio-polymers, would include insufficient existing knowledge and lack of senior management time. The proposed framework attempts to address these issues via the strategic review stage which eliminates the need for specialist knowledge and minimizes the senior management time required to get to an actionable result. This is achieved through the following four tasks.

(a) Definition of current business sustainability strategy
(b) Categorization of business
(c) Identification of the strategic goals relevant to bio-polymer packaging
(d) Prioritization and communication of strategic goals

Definition of Current Business Strategy The strategic review begins with the definition of the existing business sustainability strategy according to the three 'pillars' of sustainability—Economic, Environmental and Social. The information entered at this stage provides a reference point for subsequent developments. This task comprises of both free text as well as multiple choice inputs which are used in the subsequent tasks of this stage.

Categorization of Business The second task is to identify and allocate a category to the business. This will be used to

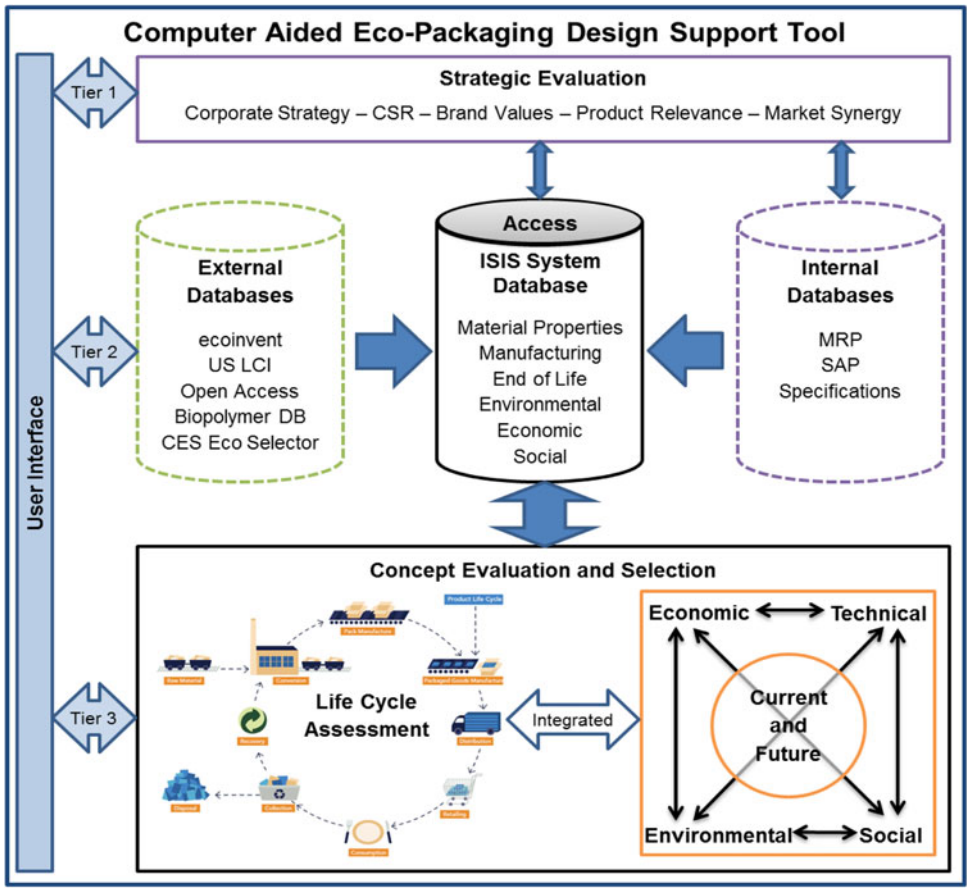

Fig. 6 An overview of the EPD framework implementation through the ISIS (EPD) tool

inform the identification of strategic goals by allowing the questions to be tailored to the business, thus reducing the time and complexity. Again a multiple choice question format is used, with questions regarding the company size, sector, scope and spend. These are combined with the initial'strategy' inputs and analyzed. The results are then used to allocate a particular category to the company, with the objective being to reduce the senior management time required by creating a more tailored and streamlined process in the final two tasks of this stage.

Identification of the Strategic Goals Relevant to Bio-polymer Packaging This is the central task of this stage and involves mapping the key strategic sustainability and business objectives against the key properties and impacts associated with bio-polymers and bio-polymer packaging. These are grouped to include economic, environmental and social factors, as well as technical and commercial requirements. The outcomes from this stage are threefold: firstly to answer the general question as to whether or not bio-polymers can contribute towards the company's strategic goals on sustainability is provided; secondly, the compatibility, relevance and benefits of bio-polymers with respect to the product and brand is determined; thirdly, a list of the key strategic objectives that are intended to be met in full or part by the adoption of bio-polymer packaging is produced.

Prioritization and Communication of Strategic Goals Having identified the key strategic goals, the next step is to prioritize them, based on the level of importance to the business. This prioritized list then provides the input for the development of a top level 'design brief'. The design brief outlines the key objectives and strategic goals of the business that are expected to be met in full or part through bio-polymer adoption as well as the technical and commercial targets that must be met by the pack design.

Specification and Material Selection

The aim of the specification and material selection is to assist in the identification of potentially suitable materials for the purpose as defined in design brief. However the design brief is a high level document, produced by senior/middle management, which describes the key objectives and strategic goals of the design, but has little detailed guidance on the technical and commercial requirements. In order for the appropriate materials to be selected the detailed pack/material performance requirements must be specified more precisely. Once complete this can be used to

identify and select the appropriate bio-polymer materials for concept development. As shown in Fig. 4, it is anticipated that this is likely to be undertaken by lower/middle management with some degree of technical knowledge. The following three tasks must be completed during this stage:

(a) Development of a detailed design/material specification from the brief.
(b) Prioritisation and approval of specification requirements.
(c) Identification of suitable bio-polymer materials.

Development of a detailed design/material specification from the brief: This document, developed initially from the design brief, considers the requirements of the pack (material), in a more detailed, structured and systematic approach. The first step is to ensure that every relevant part of the business and supply chain is represented. Then through a combination of previous experience and consultation, an inventory for the specification can be developed. A template providing the most common requirements could be provided as a starting point for this process, providing both a document structure and tick list of likely considerations.

Prioritisation and approval of specification requirements: Once the full list of requirements has been produced, these should be prioritized. This could involve the separation into either essential and desirable requirements, or a more detailed division including degrees of desirability. Once complete, this specification document should be approved by the business and can be used later in the business to assess the designs and inform concept/pack selection. However, prior to this the first application would be to identify suitable materials, with the appropriate properties, to meet the specification requirements.

Identification of suitable bio-polymer materials: This would be achieved most efficiently if the attributes of the materials, listed in a database, were directly comparable/searchable with the requirements in the specification. Whilst it is not expected that the database would be able to hold every detail of a material, covering all possible aspects of its performance, it should contain sufficient detail of the most essential attributes. These should be in each of the main performance areas, such as economic, technical, performance, aesthetic, environmental and social impacts to allow material selection to be made at least to the point of short listing. The database would also include contact data for the suppliers of these materials.

Evaluation and Selection

The purpose of the evaluation and selection stage is to support the designer during the pack development process by providing a rapid mechanism for assessing the design concepts and informing design changes using sensitivity analysis. These assessments should adopt a life cycle approach integrating key economic, environmental, and social and impacts with technical and aesthetic requirements. How much weighting is given to each impact will be decided by the user who can use the default settings or adjust individual impact weightings as required. Other factors such as manufacturing and consumer appeal can be assessed using existing tools and processes such line trials, pack testing, focus groups and market research. Furthermore, because the bio-polymer industry is still in its early stages of development compared to conventional polymer which are quite mature and, whilst the impacts from conventional polymers are increasing rapidly as their feedstock reserves are depleted compared to bio-polymers whose impacts are likely to reduce as more efficient production methods are employed, indication as to the future impacts should be considered as well as current. This is particularly important to industry that requires payback over a number of years on investments.

Tool Implementation and Operation

This section describes how the three stages of the framework described in section "Framework for Bio-polymer Packaging Functional Stages" are brought together into a single tool and how this tool will be managed, controlled and promoted. Firstly the tool would be web based, allowing users to create a secure area for storing each project and assign access rights to relevant personnel at the appropriate level (Read/Write Edit). As changes are made to a project, all project personnel would receive automatic notification of the changes/project status. This could be further enhanced by allowing timeframes to be set for the completion of each stage and responsibilities to be assigned, enabling auto prompting as deadlines approach.

Data added in one tier will be retained and available to another, for example, the strategic requirements assigned in the first tier will be available for concept comparison in the third tier allowing each concept to be assessed and scored against the original strategic goals. The database of materials would be updated regularly and suppliers of materials would be able to submit materials to the web manager for inclusion. Eventually this could be updated to allow suppliers to update the database directly, although it will be necessary to have common standards, such as methodology, functional unit, metrics etc., to ensure like for like comparison can be made between materials.

Conclusion and Further Work

Through the application of Sustainable Balanced Scorecard Methodology to the specific requirements of bio-polymer

based packaging design, it is possible to reduce some of the ambiguities of integrating social factors with environmental and economic ones. It has been demonstrated that a holistic and integrated approach is required for the eco-design of plastics packaging if the future challenges of sustainability are to be achieved and that, to this end, better guidance at both the strategic and tactical level of the selection, justification and use of bio-polymers is required to avoid 'green wash' and ensure the greatest environmental, sustainable and ecological return are achieved. The framework outlined in this paper provides the basis for an integrated eco-design support tool for bio-polymer packaging that would provide a significant support towards improving the sustainability of plastics packaging.

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