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Trends in Development and Markets of Biodegradable Materials

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Products made from biodegradable materials (BMs) are slowly but surely gaining a foothold in the market. While packaging made from BMs can already be found on the shelves of major supermarket chains in England, the Netherlands, Italy and Switzerland, in Germany they are still awaiting the results of a pilot project on biodegradable packaging. These new polymers are also establishing themselves in other applications.

In terms of processing and applications, BMs are totally "average" polymers: they are quintessentially thermoplastics that can be converted into a wide range of products on standard plastics processing equipment. However, the concept underlying these innovative materials is different from that of conventional polymers in that the goal is to emulate Nature's cycle. Every year, photosynthesis generates over 60 billion t of organic material worldwide, most of which is degraded by micro-organisms into CO_2, water and biomass. Development work on BMs is therefore focused on renewable resources as well as on the property of biodegradability and its waste-management alternative, compostability (Fig. 1).

The cycle shown here is basically a design goal, but it has already been implemented in a number of different variants. The feedstocks for manufacturing BMs are grown in fields. Composting as a means of recycling the products represents a variant that closes the cycle after consumer use. Energy recovery or fermentative gas extraction would be also conceivable. However, this cannot really be considered a completely closed CO_2 cycle until the feedstock for the production of the BMs is renewable and the energy expended in consuming them is also covered by renewable sources of energy.

Material Developments Help the Market

Whether a polymer is "biodegradable" or "compostable" depends substantially on the type of chemical bond in the polymer and on the properties of the monomer. Renewable resources are not the only feedstocks for BMs. There are BMs produced from mineral oil that also degrade biologically extremely well. Petrochemical constituents – additives and polymers – are often needed anyway for satisfying the technical requirements of the intended application. The underlying concept of the BM cycle and the use of micro-organisms suggest that renewable resources should be employed. This has not so much to do with recycling per se as it has with the aims of sustainable development, climate protection, conservation of resources and regional closed substance-loop waste management. BMs today can be made totally from renewable resources; examples include polyesters, such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA).

But BMs also have technical properties which distinguish them from conventional polymers and which can be particularly beneficial in certain applications. This is illustrated by the following two examples. The barrier properties of PLA are not just desirable in breathable sportswear – they also keep baker's wares fresh and crisp for longer. And incorporation of starch blends into tyres lowers the rolling resistance and hence the fuel consumption while simultaneously yielding good driving properties. If BMs were considered only for their waste management characteristics, they would be restricted to special products, such as collection bags for domestic organic waste, and mulching film. For this reason, the term "biodegradable materials" is increasingly being considered an unfortunate one by manufacturers – and the search is on for a more comprehensive name.

Given the dominance of petroleum-based polymers, a strategy that combines the use of renewable resources with the know-how of the classic polymers industry has greater chances of success in the fiercely contested polymers market (Table 1). Many BM manufacturers are looking to the synergies unleashed by fossil resources and renewable resources. For instance, starch blends – mixtures of degradable synthetic polyesters and pure plant starch – have now advanced to the stage where they are marketable. That this is the right approach from an environmental point of view is confirmed by the first comparative life cycle analysis. So in many ways fossil BMs help the market to develop, and BM technology needs the market so that it can evolve further.

The proportion of renewable resources used in the production of BMs will continue to grow in the medium-to-long term.

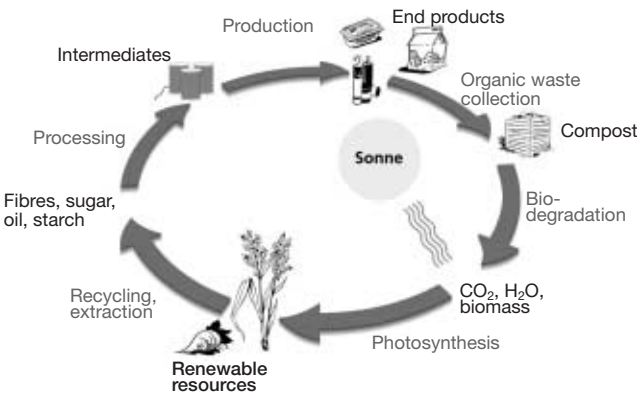

Fig. 1. Idealised closed substance-loop waste management for biodegradable materials

Translated from Kunststoffe 92 (2002) 9, pp. 34–40

Basis	Manufacturer (Brand name)
Petroleum Polyester	BASF (Ecoflex) DuPont (Biomax) Eastman (Eastar Bio) Showa Denko (Bionolle) Solvay (Polycaprolacton)
Plant Starch	Earthshell Novamont (MaterBi grades) Rodenburg Biopolymers (Solanyl)
Polyhydroxyalkanoates	Biomer (Biomer) PHB Industries (Biocycle)
Polylactic acid (PLA)	Cargill Dow (NatureWorks) Mitsui (Lacea)
Cellulose (acetate)	Mazzucchelli (Bioceta) UCB (Natureflex)
Mixtures Starch blends	Biotec (Bioplast) Novamont (MaterBi grades)

Table 1. Selection of established BM packaging grades (excluding specialty medical polymers)

The many reasons for this include the more vocal demands for sustainable development and the foreseeable long-term increases in feedstock prices. The pursuit of this goal, however, must not be allowed to lead to a situation in which the development of BMs is overburdened or overtaxed with environmentally motivated specifications. We first need to show that the products are technologically and economically viable today, i.e. at the very outset, before we set about making improvements for the benefit of the environment. There is sufficient scope for accomplishing this. Not only is the proportion of renewable resources for producing BMs on the increase, but scrap and waste materials from the agricultural and food industry could also serve as feedstocks for BMs in the future. In the Netherlands, potato skins produced by the French fries industry are already being converted into a thermoplastic material. The plant concerned, which is just being commissioned, has a production capacity of 40 000 t/a and the manufacturer, Rodenburg Biopolymers, is preparing for product launch, and seeking to target the horticultural sector in particular. As another example, polylactic acid (PLA) could be reclaimed from a variety of wastes that contain sugar, e. g. molasses. The world's largest manufacturer, Cargill Dow, has already declared this to be a development goal.

Biotechnology is also generally held to play a key role in the development of BMs. The genetic engineering company Metabolix announced last autumn that in the USA trials to generate polyhydroxyalkanoates in plants were going well – they expect the first commercial samples to be available within a few years. In 1998, one of the reasons given by Monsanto for ceasing its Biopol activities was that fermentative manufacture was too expensive and production in plants was not likely for a long time to come. The generation of high-quality materials within plants themselves would open up a whole new vista for the polymers industry. This area is being studied by numerous research groups around the world.

Production Capacity is Growing Dynamically

By the end of this year, and at the latest in 2003, when the Cargill Dow and Rodenburg Biopolymers production plants come on stream, global production capacity for BMs will be approximately a quarter of a million tons. The pilot-plant phase of the early 1990s and the following scale-up phase are now making way for industrial-scale production. Although the first products have been known for 10 years now, only now are they going on general release (Fig. 2). If the focus so far has been on developing the materials and specifying base properties, the latest phase is to optimise them for use. It is worth pointing out that BMs are in the early stages of development. Consequently, there is need for further improvements in technical and economic aspects. Global production capacity is showing dynamic growth (Fig. 3).

Some companies, such as BASF and Cargill Dow, have already announced expansions to their production capacity – another half a million tons of BM capacity can therefore be expected within three to five years. Provided that developments overall remain positive, capacity by the year 2010 will be approx. 1 million t. The overall market for BMs is estimated at 5 to 10 % of the total polymers market, but the upper limit is potentially higher. The proportion of polymers derived from renewable resources is likely to be much higher in the very distant future. Even now, by far the most BMs are comprised of renewable resources.

The Market for BMs is Developing

Annual consumption of BM products in the European Union in 2001 is estimated at 25 000 to 30 000 t, which corresponds to a sales volume of about EUR 100 million. No statistics are available for the German market, where loose fill (starch foam) and organic-waste sacks have managed to establish themselves. Market leader is Novamont SpA – an Italian manufacturer – whose sales of starch blends have enjoyed high growth rates for years (Fig. 4). Cargill Dow became the world's largest manufacturer of BMs when its PLA production line went on stream in Blair, Nebraska, in spring of this year (Fig. 5). The new relationship between renewable resources and the polymers industry is manifested by the independent joint ven-

Type of product	Benelux	Germany	UK	France	Italy	Austria	Switzerland	Scandinavia	Spain
Packaging									
Food	+	KS	+		+		+		
Loose fill	+	+	+	+	+	+	+	+	+
Carrier bags	+	KS/(+)	+	+	++	+	+	+	+
Fruit & vegetables	+	KS/(+)	+		+		+	+	
Catering	+	+	+		+	+	+		
Others									
Organic waste sacks	++	+		+	+	+	+	+	
Agricultural film	+	+		+	+		+		++
Toys		+				+			

KS = Kassel (Modelprojekt)

Fig. 2. State of market introduction of BMs in Western Europe in the year 2001

Segment	Examples		Argumentation/Driver
Packaging	Loose fill foil, film Hollow bodies, bottles, trays, blisterpacks Nets, sacks, bags	➢ ➢ ➢	Food packaging biologically contaminated Recycling is therefore difficult Plethora of materials hampers conventional recycling Short-lived applications
Fast Food Catering Stand	Crockery Cutlery Straws Beakers	➢ ➢	Returnable is not always possible or cheaper Products often biologically contaminated through food contact
Fibres/Textiles	Clothing Technical textiles Fabric	➢ ➢ ➢	Breathable Haptic properties Gloss
Toys	Craft materials Bricks and blocks Golf tees	 ➢ ➢	 Paedagogic advantages Environmental safety/education
Convenience	Organic-waste sacks Personal hygiene products e. g. nappy film, cotton buds	➢ ➢ ➢	Short-lived articles Recycling difficult (see above) "Natural contact"
Horticulture	Plant pots Underlays Peat sacks Seed/fertilizer tape Binding material	 ➢ ➢ ➢	 "Natural contact" – Composting advisable Recycling very difficult due to contamination Lower manual costs
Agriculture	Covering film Mulching film Tying yarn	➢	As for horticulture
Medicine	Implants Operation materials Oral hygiene Gloves	 ➢ ➢	 Safe absorption and degradation in the body Short lifetime, disposable
Other	Functional supports Mounting technology Grave lights Writing implements	➢ ➢ ➢ ➢	Specific application advantages Lower manual/waste-management costs Compostability required Advertising effects, etc.

Table 2. Overview of possible applications for BMs

ture formed by one of the world's largest agrarian companies, Cargill, and the chemicals and plastics group, Dow.

BM products are particularly suitable for applications with a short service life (Table 2). Their compostability predestines them for such applications as agricultural film, cemetery articles and organic-waste sacks (Figs. 6 and 7). BMs often bring waste-management benefits for these applications. Once the sacks have served their primary function and passed out of use, they are recycled efficiently, in both the environmental and the economic sense, by micro-organisms. This degradation may either take the form of composting or occur in the ground, as in the case of agricultural films and horticultural articles.

BMs are increasingly being used for applications that do not require their special waste management properties. In textiles and tyres, for instance, they are used solely for their functional properties. BM packaging is starting to become established in England and Italy, where composting plays a miniscule role as a means of recycling. This contrasts with Germany and the Netherlands, for example, which have the national composting infrastructure in place that would enable BM packaging to be recycled. The advantage is that scraps of food do not disrupt "organic recycling" and the costs are considerably lower than those of conventional recycling. The practicality of this is currently being tested in a pilot project in Kassel/Germany, the only one of its kind in the world.

Environmental Packaging Motivates Consumers

Up to now, the packaging market has been prevented from developing by high product costs and, in some cases, limited suitability for the application. While this is essentially the case, progress is being made nonetheless. Consumers in Great Britain, the Netherlands and Italy are already encountering BM packaging in their supermarkets. It has been recognized there that such innovations constitute a need which has to be satisfied, especially with environmentally conscious consumers. Roused by the BSE crisis, English supermarket chains, such as Sainsbury's and Tesco, are pursuing this strategy. Their supermarket shelves contain a wide range of BM packaging for "Organic Food" (Fig. 8).

Apart from "service packaging", such as carrier bags, the packaging making its way onto the shelves is mainly for fruit, vegetables and other fresh products (Fig. 9). Primary film packaging, e. g., for personal hygiene products and high-quality magazines, is also to be found. Extruded and woven nets, as well as weldable bags, have now reached technological maturity. Transparent dishes for fresh products – fruit, pasta and delicacies – are available in different sizes. Added to which, there is cling film and film overlay for hot-seal applications. Like cellophane, which also comes in degradable variants, PLA has a high twisting strength for twist-off packaging, which is of central importance for the confectionery industry. Vertical and horizontal flow-pack packaging is completely new. Deep-freeze packaging film has come to the front of the development pipeline at BASF.

BM packaging offers specific technical advantages in this application. For example, the high vapour permeability of starch blend films used for packaging damp fruit and vegetables keeps the contents fresher for longer. Virtually no condensation occurs either in non-perforated packaging. The result is a lower reject rate. Furthermore, packaging and food can be composted together without any further manual treatment once the shelf life has expired.

The strongest argument for using organic packaging is provided by consumers. They are very heavily in favour of such a sustainable product. This was demonstrated, for example, by market research that accompanied the compostable-packaging project in Kassel. The idea of having "Potatoes Package Potatoes" fascinated many shoppers and even less educated consumers appreciated that it represented progress. It should be a simple task for marketing experts in the packaging industry to address and satisfy this need. In addition, there is an opening here for effective differentiation from competitors in product marketing. BM packaging is increasingly moving into the market's field of vision in Germany as well, thanks in no small part to the pilot project in Kassel.

Pilot Project in Kassel Tests the Consumer

The pilot project in Kassel is jointly supported and financed by industry, the Fed-

Profile and Aims of the IBAW
The International Biodegradable Polymers Association & Working Group IBAW is an association of the manufacturers and processors of biodegradable plastics, and service providers. Key focus is on performing public relations exercises for experts in the field as well as creating framework conditions, especially in the European Union. A central aim is the promotion of closed substance-loop waste management through innovative and environmentally friendly products made from BMs. This also entails the use of renewable resources as well as quality assured recycling of BM products by processes close to nature, such as composting.

compostable

eral Ministry for Consumer Protection, Nutrition and Agriculture and the agency Nachwachsende Rohstoffe FNR e.V. It is essentially addressing two questions:

- Consumer acceptance: How do consumers react to the new packaging – can they see the benefit? Information on this is being collected by accompanying market research.
- Recycling via organic-waste bins: Specially labelled BM packaging in Kassel is recycled by composting. Are consumers able to deliberately dispose of this packaging in the organic-waste bin without increasing the quantity of extraneous materials (due to "incorrect disposal") that disrupt the system? The project is being scientifically monitored by the Chair of Waste Management at the University of Bauhaus-Weimar.

Since May 2001, more than 80 retail shops, including Edeka, REWE, tegut and dm Drogeriemarkt, have been selling about a dozen products in compostable packaging that is identifiable by a hexagon. A campaign is being run under the motto "The 6th Sense" to inform consumers about the new packaging material and to encourage them to place it in the organic-waste bin. The waste-collection company Interseroh is operating a new type of dual system in Kassel in which

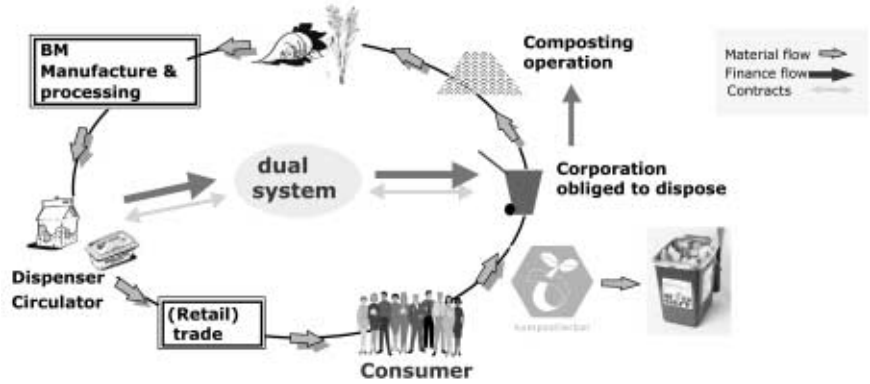

Fig. 10. Schematic diagram of the dual system for BM packaging in Kassel (operator: Interseroh)

packaging is recycled by composting (Fig. 10).

Unique in the world, this pilot project is enjoying a high level of acceptance with consumers and the retail trade in Kassel: 61 % of the consumers in the test market were already aware of the high-tech BMs in September and 80 % of Kassel inhabitants who have bought the new products (one in five) rated them as good or very good. Some 87 % would buy them again. About 90 % of the 600 Kassel respondents deemed the idea of replacing conventional plastic packaging by compostable packaging to be good or very good. These findings came from an interim project report compiled in autumn of last year and were based on 600 interviews.

The results also show that one third of consumers are willing to pay a surcharge. They would be willing to pay 15 cents for a carrier bag, instead of the current 10 cents, provided it were compostable. For a compostable yoghurt cup, they would willingly pay 5 cents more. However, further higher price hikes would hamper sales of the new materials. Similar, very positive results were obtained just prior to that by the dm Drogerie chain of chemists' shops, which had offered its customers compostable carrier bags in Dortmund and then asked them for their opinions.

The provisional results of analyses of the waste may be summarised as follows. So far, there has been no significant change in the proportion of "incorrect disposals" into the organic-waste bins relative to the zero analysis prior to the start of the project. In fact, there appears to be a slight drop in the level of extraneous substances. The available BM products were mostly disposed of in the organic-waste bin. BM compost – and this is another outcome of the studies – is just as suited to cultivating field fruits as is quality-assured, non-BM compost.

Generally, however, the availability of the products was low and it was not always easy for consumers in Kassel to find them. It is therefore planned to prolong and expand the project. This will then make it possible for new companies to join in with their BM packaging at any time. The nappy manufacturer, Moltex, decided back in April to launch its new environmental nappy in compostable packaging, which is based on maize starch, on a nationwide basis (Fig. 11).

Significance of the Kassel Pilot Project

The Kassel pilot project is crucial to the development of the BM packaging market. It shows that theoretical closed substance-loop waste management can actually work in practice. The overall popularity of BMs is growing. Thanks to the Kassel project, a

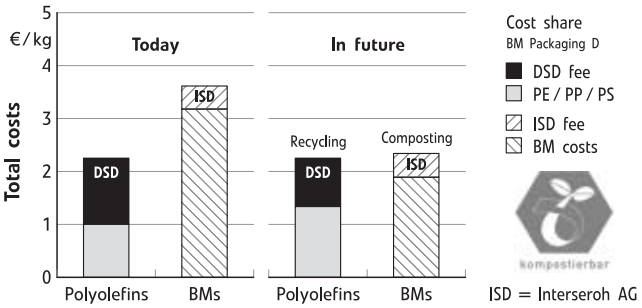

Fig. 12. Analysis of the total cost of BM sales packaging in Germany: today and in future

number of new packaging developments have already been initiated. The topic of "organic packaging" is picking up momentum. The positive results gained from the accompanying waste management studies should also instil confidence in waste management.

The dual system operated in Kassel by Interseroh AG has major economic significance for the development of the BM packaging market. If it proves possible to establish the system everywhere in Germany, the competitive drawbacks of BMs compared with those of mass-produced conventional packaging polymers will decrease considerably (Fig. 12).

Compostable plastic packaging licensed from Interseroh would cost EUR 330 to 450/t. The DSD GmbH system, which treats BM products as conventional plastic packaging, charges approx. EUR 1350/t. In view of the expected scale-up effects of BM production and general price tendencies in the feedstocks sector, the long-term outlook is that the competitive positions are comparable.

Outlook

Biodegradable materials are now on the brink of industrialization. The first products are already set to conquer mass markets, such as the packaging sector. The plastics processing sector is showing increasing interest. Well-known companies, such as Autobar, RPC and Trespaphan, are now studying this topic intensively.

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Fig. 3. Increase in production capacity for BMs derived from mineral oil and plants up to the year 2007

Produktionskapaziät = Production capacity; davon auf Basis Erdöl = Of which based on mineral oil; davon auf Basis Pflanze = Of which based on plants

Fig. 4. Writing implements made from starch blends have been on sale for years, mostly as advertising materials (photo: Novamont)

Fig. 5. Cargill Dow delivers polylactic acid to the Japanese market for packaging minidiscs (photo: Cargill Dow)

Fig. 6. In Spain, France, Italy and Germany, more than 5000 hectares of BM agricultural film has been used; when all costs are considered, the products are fully competitive (photo: BASF)

Fig. 7. Highly transparent films from polylactic acid are used in flower shops in Kassel – they can also be recognized by their sound (photo: Trespaphan)

Fig. 8. The British supermarket chain Sainsbury's uses degradable cellophane flow-pack packaging for fruit (photo: UCB)

Fig. 9. Tested at Aldi in Germany and used by Albert Hein in the Netherlands: compostable film bag for potatoes from the company natura (photo: BASF)

Fig. 11. Available since April 2002 in many German supermarkets: primary packaging for nappies from the company Moltex, made from starch blends produced by Novamont; this is the first BM packaging to be launched nationwide in Germany (photo: Moltex)