



Biopolymers as a Sustainable Alternative?

Packaging Materials. As natural materials biopolymers are expected to solve the disposal problems of current plastic packaging. But can they really do this with no ifs and buts? What about competition with the food chain? Do they deliver the ecological, service and disposal advantages expected of them to their full extent? The following article attempts to answer these questions.

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In the current debate about sustainability and environmental awareness in the food industry conventional plastic packaging is time and again the focus of attention. Its very good service properties, such as good chemical resistance, optimized processing and high level of design freedom are offset by disposal disadvantages, such as large volumes of waste, high persistence or the complexities of single polymer recycling. On top of this they are predominantly based on limited petrochemical raw materials and

therefore have a negative CO₂ balance when incinerated.

For this reason the interest of the packaging industry in biopolymers has grown strongly and there are already special legal provisions for them. For example since the beginning of this year the sale of plas-

tic carrier bags made from petrochemical raw material has been banned in Italy. As a result of the revision of the German packaging directive in May 2005 biopolymer packaging with certified compostability was freed from disposal fees, such as the levy for the “Green Dot” (Grüner Punkt), until 2012 (Fig. 1).

With continuously growing quantities of biopolymers in the marketplace it is, however, increasingly necessary and sensible also to consider all other alternative disposal options for biopolymer packaging alongside composting. Through intelligent disposal in many cases additional (cascade) utilization can be achieved, meaning that alongside composting other disposal routes are often feasible, for example recycling, in similar ways to con-

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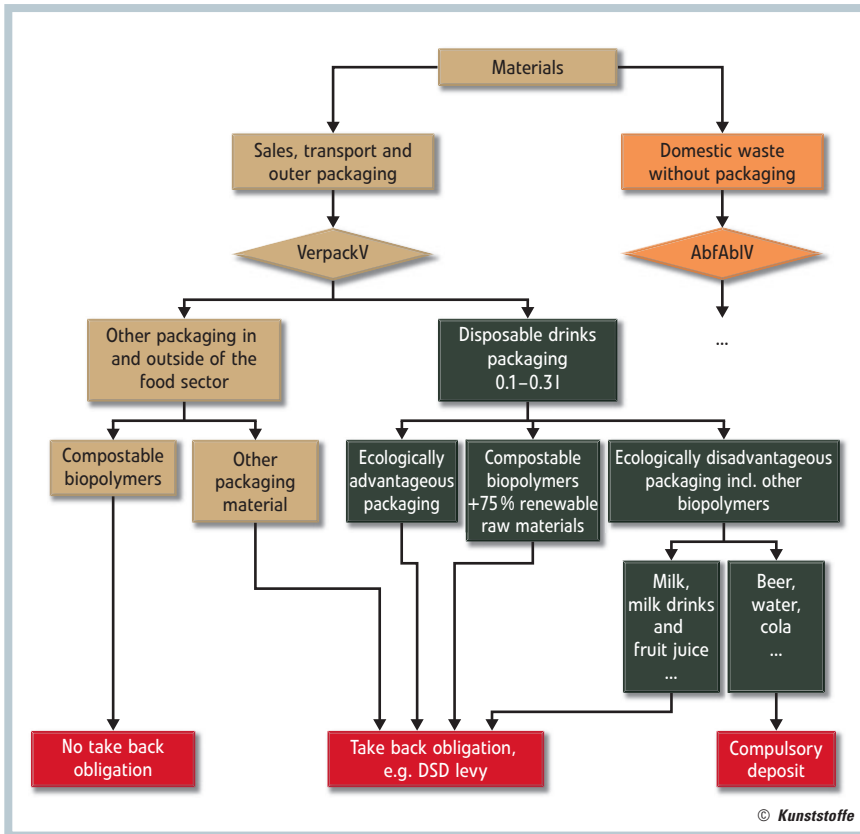


Fig. 1. Waste groups as defined by the 5th edition of the German "Verpackungsverordnung" (Packaging Directive) [1]

ventional plastics, their use as substrates or co-substrates in biogas production, or as replacement fuels in energy production. In all these cases energy can be recovered without setting additional CO₂ free (Fig. 2).

Biopolymer Film and Packaging

In manufacturing and processing biopolymers fundamentally the same technology can be used as for conventional plastics. Since most biopolymer films are based on polylactide (PLA or polylactic acid) and starch blends (Fig. 3), thermo-plastic manufacturing techniques are dominant. An additional large group is formed by regenerated cellulose and various polyvinyl alcohol (PVAL) films. Film casting techniques are overwhelmingly used for the manufacture of films from these [4].

In the last three to four years the production capacity for biopolymer packaging has increased after a fairly hesitant start. The most important reasons cited for this delay were the requirements for food grade approval, important barrier properties and the need for optimization in industrial processability. For example changes in the composition and/or organoleptic properties of the packaged

material due to migration of gases, aromas and moisture have to be excluded for biopolymers as well [4].

Barrier Properties of Biopolymer Films

Barrier properties are one area where biopolymers with their polar structure show a significant difference when compared to conventional polymers such as polyethylene (PE), polypropylene (PP) or polyethylene terephthalate (PET).

Amongst the biodegradable biopolymers only PLA, the biopolymer that has been furthest developed as a packaging

material up until now, and polyhydroxyalkanoates (PHAs) show a certain degree of barrier functionality for water vapor (Fig. 4). Compared to PET, PE or PP however, water vapor permeability is still clearly higher.

The most promising possibility to improve the barrier properties of biopolymers is said to be coating. This is especially true for PLA bottles and PLA films where there are a number of approaches to coating. However, additional coating also means additional effort. On top of that these coatings are often not as durable as the base material and are also more scratch and crease sensitive [4]. As an alternative, work is being carried out on the manufacture of multi-layer films, that is the combination of biopolymers and (petrochemical) barrier materials.

Novel material developments, such as the bio-PET that is partially manufactured from renewable raw materials (bioethanol) for Coca-Cola and Danone Waters or the entirely bio-based Bio-PE from Braskem S.A., São Paulo, Brazil, make such coatings superfluous. In the meantime they offer a like for like replacement of conventional polymers and are already partially replacing these. As so called "drop in solutions" they have the same chemical structure as their petrochemical cousins and therefore represent with first biopolymers with high water vapor barrier properties. With these novel third generation biopolymers the focus is no longer on biodegradability as a disposal option, but rather on the preferred use of bio-based raw materials as a feedstock for the synthesis of durable polymeric materials.

Sustainable Disposal of Biopolymer Packaging

If a decision is taken to use packaging made from renewable raw materials for

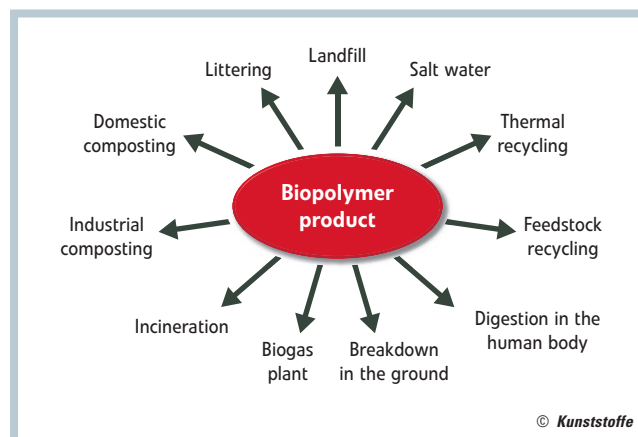


Fig. 2. Disposal options for biopolymers [2, 3]

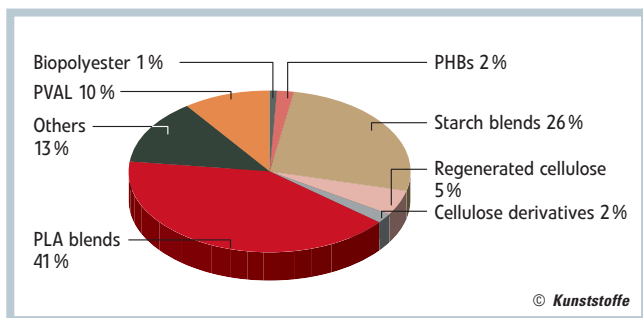


Fig. 3. Overview of the biopolymer film materials used by the currently known film manufacturers in Europe (approx. 60 companies) [4]

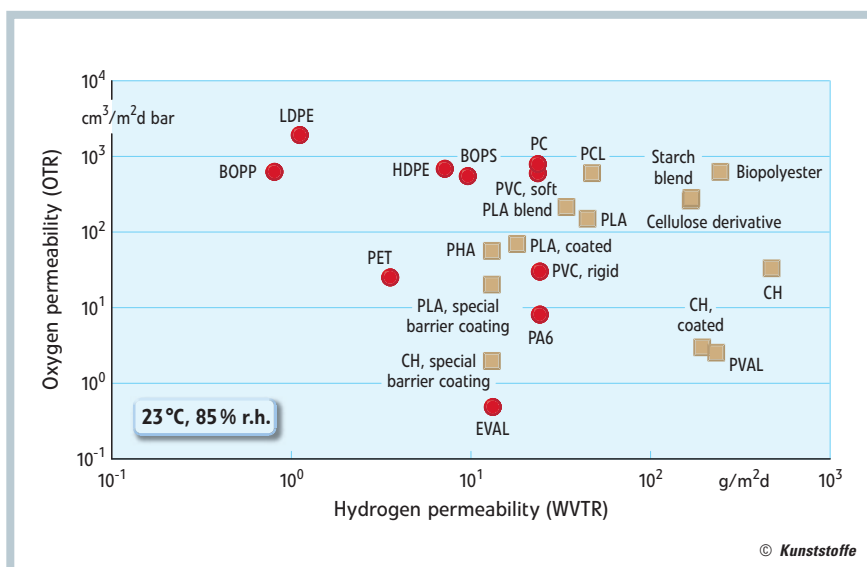


Fig. 4. Comparison between the barrier properties of biopolymers with various conventional packaging plastics (0 to 5% rel. humidity; BO = biaxially stretched/orientated, coated regenerated cellulose = metalized, coated PLA = SiO_x-vapor deposition; CH = regenerated cellulose) [4]

sustainability reasons, it is not sufficient in terms of an objective assessment of the sustainability of biopolymers only to consider the supply of the biogenic raw materials and the energy required during manufacture (“cradle to gate”). It is also necessary – in the sense of “cradle to grave” – to assess the disposal properties. Through additional utilization during disposal an even higher degree of sustainability can be achieved (Fig. 5).

Composting: Up until now composting was the center of attention for biopolymer packaging. In general it can be said for biopolymers that have been certified as compostable that they can be broken down effectively in industrial composting plants and digested to products such as CO₂, H₂O or biomass/humus [5 to 7]. Fundamentally this means that the system of composting certified biopolymers works from a technical standpoint. However, in respect of the composting logistics there is still a need for some optimization. For example the requirement for separate collection and transport represents a logistical, economic and in particular ecological problem

since this is often associated with additional overheads [2, 4].

In most cases the compostability certificate also only confirms that an existing product (a specific material with a defined wall thickness) is biodegradable within a certain period of time under industrial conditions (e.g. defined quantities of oxygen and moisture, regular turning of the pile, temperature profile and the presence of suitable micro-organisms). This can,

however, not be equated to a full decomposition in domestic compost [4].

At present the disposal logistics of compostable packaging including the related legislation (e.g. the German composting directive) have not been acceptably and coherently solved. For example biopolymer packaging in Germany despite appropriate marking of compostability certification and the dispensation under the disposal regulations, i.e. the waiver of disposal levies of for example the German DSD (Green Dot) is regarded as erroneous throw-in for the yellow and brown bins.

If composting, as in many cases, is simply a part of the disposal process it is not one of the most sustainable disposal options. Composting is sensible if the decomposition provides an additional functional advantage at the same time. Examples of this are biodegradable flower pots or agricultural film that after use can be simply plowed in and do not have to be collected and disposed of, laundry bags that dissolve in the washing machine or medical implants whose breakdown in the body matches the healing process [4].

On top of this the quantity of CO₂ produced via the “cold burning” processes of composting is exactly the same quantity that would also be produced during direct incineration of the biopolymers or combustion of the biogas produced from the biopolymers which have additional energetic utilization [1, 4].

Recycling: Alongside composting, in a differentiated view of the disposal options attention must be given to classic recycling. However, there is hardly any experience in the area of thermoplastic biopolymers. It is likely that similar problems will be found to those found while recycling conventional polymers. For example it is assumed that their generally lower thermal and chemical stability will

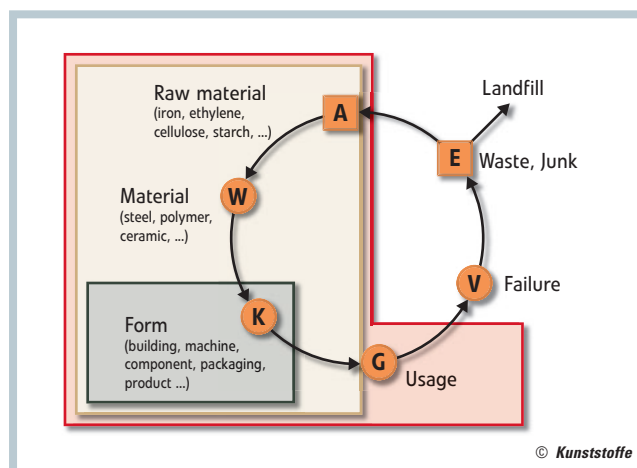


Fig. 5. Various system boundaries in ecological balancing (gray = “gate to gate” (processor), beige = “cradle to gate”, red = “cradle to waste”, black = “cradle to grave”) [4]

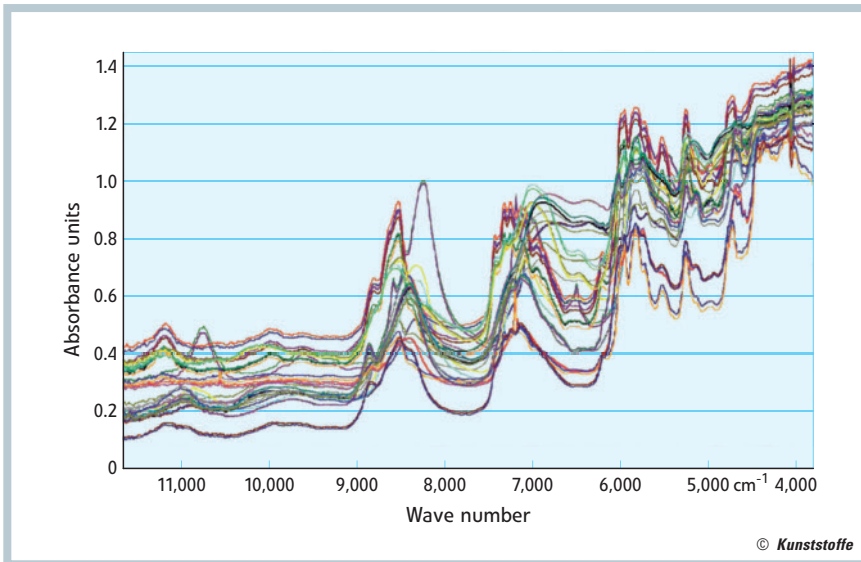


Fig. 6. NIR spectra of various biopolymers [4]

lead to an even more pronounced down-cycling effect. In this respect experience gained from pre-consumer (recycling of production waste) and post-consumer recycling (recycling of mixed and soiled waste) including sorting and possible stabilization from conventional plastics can and should be used.

In addition there is poor compatibility between various biopolymer material classes as well as combinations with conventional plastics. Thus here as well with respect to high quality secondary raw materials there is a desire for the best possible polymer type separation of waste streams [2, 4].

At present, however, there is very little information on how biopolymers affect the overall waste stream. On the one hand a possible contamination of secondary raw materials through small quantities of biopolymers should be avoided, on the other hand separate treatment of individual materials is only economic above a certain proportion of the waste stream, which is in practice around 10,000 t/a of waste. As the first trials performed on the possible separation from the waste stream have shown biopolymers can, fundamentally, be for example identified in the waste stream from their characteristic NIR (near infrared) spectrum (Fig. 6).

Incineration: A significantly higher additional utilization during disposal can also be achieved with a direct (co-) incineration of biopolymers. An additional separation from the conventional plastic stream is not absolutely necessary for this.

The higher the proportion of bio-based material the more CO₂ neutral is the combustion energy that is made available [1].

Figure 7 shows the bio-based carbon content as a share of total carbon content for various specimen biopolymer materials. With this information about the bio-based carbon and the associated share of renewable raw materials in the biopolymer it is possible to calculate the bio-based and therefore neutral CO₂ produced during incineration.

In a similar way to petrochemical plastics or generally for all energy sources the calorific values are almost entirely dependent on the individual elementary composition (and the water content) of the material being burnt. The source of the carbon (petrochemical or bio-based) plays no part in respect of the resulting heating or combustion values. Only the ratio of oxidizable to non-oxidizable components is important here. In the case of the materials investigated this is the ratio of carbon and hydrogen to oxygen and water in particular. Therefore it is not sur-

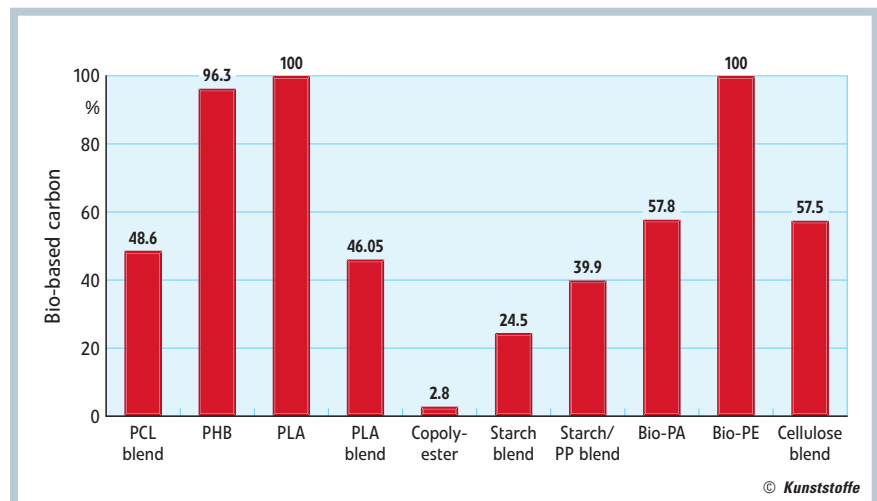


Fig. 7. Bio-derived carbon as a proportion of the total carbon content for various biopolymers

prising that the calorific value of bio-based PE is the same as that of conventional petrochemical based PE. As is also the case for conventional plastics like PA or PET hetero-atoms such as nitrogen or oxygen reduce the mass specific calorific value of biopolymers (Fig. 8).

In respect of combustion emissions initial investigations have shown that in a similar way to the calorific values for a particular material the emissions are dependent only on the chemical composition, including any additives, and the combustion temperature. For biopolymers the toxic potential of emissions was found to be similar to that of wood combustion. Thus, as was expected, no modifications of conventional incineration equipment are required for the incineration of biopolymers [8].

More on this Topic

Book Tip
Engineering Biopolymers
Markets, Manufacturing, Properties
and Applications

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Biogas: A further disposal option for biopolymers up until now hardly considered by scientists or in practice is digestion to biogas. Since a biogas plant produces biogas, with its principle component methane (CH₄), in multiple steps from organic substrates under anaerobic conditions in contrast to the CO₂ pro-

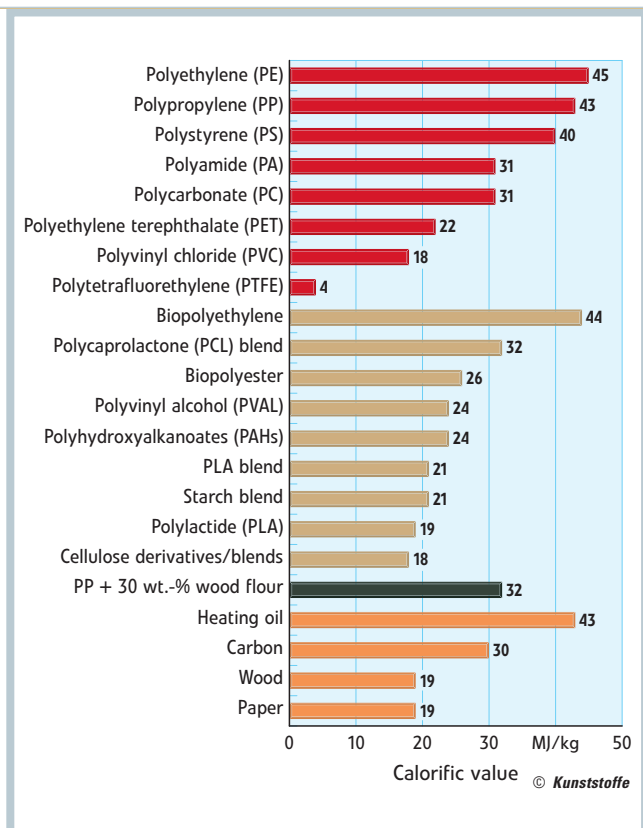


Fig. 8. Calorific values of various biopolymers in comparison to conventional polymers and petrochemical energy sources [4, 8]

duced in aerobic composting, production of biogas from biodegradable polymers seems to be fundamentally possible [4].

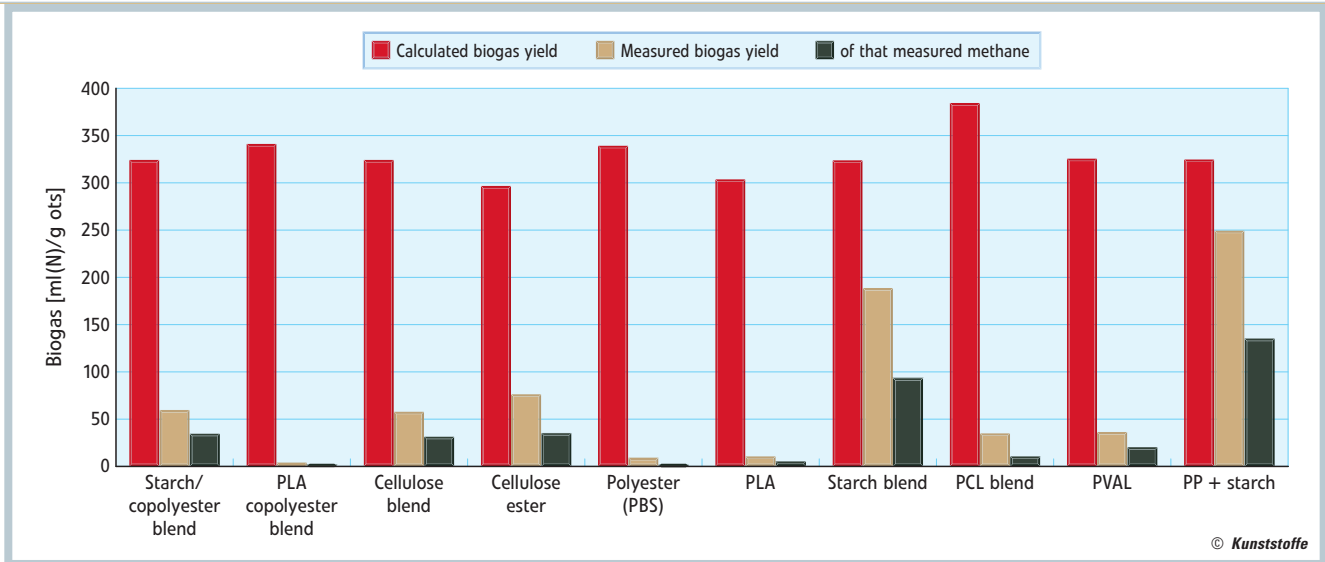
An additional follow-on option would be the treatment of the biogas produced from biopolymers to bring it up to natu-

ral gas quality for feeding into the distribution network.

Alongside energy or fuel production an additional advantage is the co-disposal of packaging and food content. Out of date, surplus production or spoiled food could be – without additional effort, for example through mechanical separation of packaging and content – fed directly into a biogas plant. In cooperation with the University of Rostock, Germany, an initial orientating analysis of the breakdown behavior of biopolymers under anaerobic conditions in a biogas plant has been conducted (Fig. 9).

From the stoichiometric composition the theoretical yield of biogas was calculated in advance assuming a complete conversion. As part of the initial investigations it was, however, found that most biopolymer esters, such as PLA or copolyesters, can only be digested with great difficulty. The highest yield of biogas came in contrast from starch based polymers and starch blends.

In follow-on investigations the relationships between the biopolymers to be digested (e.g. material type, molecular structure and weight, crystallinity and additives) and the biogas plant process pa-



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Fig. 9. Biogas yields for various biopolymers: Comparison between the calculated and measured values

rameters (e.g. residence time, temperature and organic digester loading) in respect of conversion rates as well as methane yield are to be analyzed. In addition it will have to be established whether and if so what effects possible pre-treatments (e.g. thermal pre-treatment, size reduction and microwaves) have on the digestion and the resulting gas quantities and quality.

Conclusion

Biopolymer packaging is in particular application areas a good alternative to conventional plastics. However, use of biopolymer film should not take place without an additional ecological, service or disposal benefit.

In addition to the raw material side bio-based biopolymer materials offer many different advantages on the disposal side, the so called “end of life options” [2, 9].

Alongside composting, through intelligent disposal an additional cascade utilization in the form of a practically CO₂

neutral generation of energy can be achieved. In this case biopolymers are a source of renewable energy that was previously used mechanically, for example as packaging. Thus the use of bioethanol as a polymer raw material with a subsequent mechanical recycling and final incineration of the biopolymer with energy recovery represents a significantly higher utilization than the direct combustion of the bioethanol. The amount of CO₂ generated in each case is the same since from one carbon atom a maximum of just one CO₂ molecule can be produced regardless of whether the biopolymer is composted, directly combusted or takes the alternative route as a fuel such as biogas or bio-fuel. ■

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