Potentials and Challenges of Bioplastics – Insights from a German Survey on "Green" Future Markets

Dr. Severin Beucker[1], Dr. Frank Marscheider-Weidemann

[1] Borderstep Institute for Innovation and Sustainability, Clayallee 323, 14169 Berlin, Germany

[2] Fraunhofer Institute for Systems and Innovation Research, Breslauer Strasse 48, 76139 Karlsruhe, Germany

Speaker: Severin Beucker

Corresponding author: Severin Beucker, beucker@borderstep.de

Abstract

Bioplastics based on renewable resources are considered one way to reduce environmental impacts, oil consumption and increase the use of agricultural feedstocks. Some of the newly developed materials based on biotechnology even have properties that make them superior to regular plastics; they can, e.g. be breathable, printable and antistatic. But can bioplastics really make a significant contribution to a less resource-intensive economy based on renewable materials?

The Borderstep Institute and the Fraunhofer Institute for Systems and Innovation Research (ISI) are examining the potentials and challenges of a "future bioplastics market" on behalf of the German Federal Ministry for the Environment. The analysis covers economic potentials as well as possible environmental effects from the intensive use of agricultural raw materials to produce bioplastics. Furthermore, bioplastics represent only one possible application of renewable resources which competes with other utilisations, e.g. as intermediates for the chemical industry, biofuels and, most of all, the production of food and animal feed.

The presentation will give an insight into the results of the analysis of the economic and environmental potentials and the challenges of bioplastics and their future applications. It will also identify the key factors influencing the future application of bioplastics.

Keywords: Bioplastics, Renewable Resources, Resource Consumption, Future Markets

1 Introduction

Each year more than 200 million tonnes of plastics based on petroleum are produced worldwide. 20 % of all plastics are manufactured in Europe and Germany accounts for approx. 9 % of the global production with 18 million tonnes.

Applications of plastics range from simple packaging materials to premium commodities in the electronics and computer as well as automotive industries. Because of their physical properties, low manufacturing costs and broad applicability, plastics have become a very important basic material for many industries and products.

The term plastic stands for a complex group of materials of synthetic or semi-synthetic polymers with organic components that can be subdivided into the three major groups of thermoplastics, thermosetting plastics and elastomeres. Depending on the polymer group or subgroup, plastics can have completely different attributes like plasticity, durability, elasticity or breaking strength. They can be resistant to heat and chemical influences.

Besides their technological and economic importance, plastics also have relevant environmental impacts. Plastic production is responsible for a significant amount of resource consumption, especially of oil. Polymers based on fossil resources are also responsible for a number of environmental effects such as waste problems and bioaccumulation in the food chain. For example, a recent study of Greenpeace shows evidence of the accumulation of flame retardants in marine organisms (Greenpeace 2006).

Rising oil prices and the environmental effects mentioned are drawing more attention to bioplastics. These are a group of plastics manufactured from renewable resources such as sugar, starch, celluloses etc. derived from agriculture or forestry[1]. They can be used as single materials and as compounds by mixing them with fibres or regular plastics. To create specific attributes, additives are included to create, e.g. mechanical or temperature stability. Additives and fibres can either be made of renewable resources or can be the regular additives also used for conventional plastics.

A lot of hope is attached to the biotechnological processing of bioplastics as such processes have significant potential to reduce energy and raw material consumption in the production phase and could make new fractions of biomass such as straw and lignin available for the production of bioplastics.

Bioplastics can have a short or a long lifespan depending on the material or the compound used to produce them. Many bioplastics are partially or completely biodegradable. After their useful life they can be degraded mostly into water and carbon dioxide by micro organisms like fungi, bacteria or enzymes. This makes bioplastics also a candidate for reducing carbon dioxide emissions although energy is needed to produce and harvest the raw materials as well as for the manufacturing processes involved. In the following sections attention will be drawn to the economic and environmental implications of a possible future use of bioplastics.

2 Different Bioplastics and their Applications

Since bioplastics became a field of intensive research and development, a number of biopolymers with specific attributes and fields of application have become available. One of the aims of the research in recent years was to technically and physically adapt biopolymers to a stage where they can be processed like regular oil-based polymers on an industrial scale and using established machines or with the existing technologies of polymer manufacturers (extrusion, injection moulding, etc.) (Karus 2003: 2).

Common forms to classify biopolymers are derived from their application or from the raw material used (see, e.g. FNR 2006: 292, or Karus 2003). The following table gives an overview of the most common biopolymers and some of their applications.

In the scientific literature bioplastics are also subdivided into a first and second generation of bioplastics, comparable with biofuels (FORASSET 2006: 1). While the first generation of bioplastics is mainly manufactured directly from natural or chemically modified polymers like starch or celluloses (e.g. thermoplastic starch), the second generation of bioplastics is based on monomers like lactic acid that are extracted from renewable resources via polymerisation (e.g. polylactides or polyhydroxyalkanoates). The second generation of biopolymers offers

---

[1] There is no single, clear definition of the term bioplastic or of the minimum amount of renewable resources that a biopolymer should contain. Some sources also define petrochemical but biodegradable plastics as bioplastics. In this text, purely petrochemical but still biodegradable plastics are not classified as bioplastics.

more possible modifications in the synthesis from monomers to polymers and therefore allows a bigger variety of applications for the polymers.

Name	Property	Main applications
Thermoplastic Starch	• contain starch and natural or fossil additives like softeners or plastification agents • thermoplastic, short life span, biodegradable, compostable	• films, injection moulding, extrusion
Polylactides (PLA)	• biotechnological manufacturing by fermentation of lactic acid from sugar or starch • long life span, quickly to slowly biodegradable depending on the content, partially compostable	• films, injection moulding
Celluloses (-acetate)	• manufactured from celluloses e.g. by esterification with acetic acid • weather resistant, transparent, elastic, thermoplastic, not biologically degradable, not compostable	• films • in part functional polymers
Polyhydroxy-alkanoates (PHA)	• manufactured by biotechnological processing of sugar or starch • forms clear films with good mechanical properties, biologically degradable, partly compostable	• injection moulding

Table 2-1: *Classification of Bioplastics*

In comparison with their petrochemical counterparts, bioplastics feature a number of new and specific properties such as being antistatic, having good printability, biodegradability or water vapour permeability that make them suitable for applications in medical technology, agriculture and the food industry (Kaeb 2006: 3). Most bioplastics can be blended with regular fossil polymers and additives. For stronger structures they can be combined with fibres made out of renewable or other resources.

3 Potentials of Bioplastics

3.1 Potentials for the Environment

Bioplastics have the potential to contribute to reducing environmental burdens in a number of ways. The actual realization of this potential depends on the raw materials and production processes used and the specific application of the bioplastic. Depending on the environmental indicator used, the effects of bioplastics can be ambiguous as the following examples show:

- Resource efficiency: Bioplastics can contribute to the protection and more efficient use of resources if their main components consist of renewable resources. Especially the biotechnological production of bioplastics could reduce the resource and energy consumption for the production of plastics by new fermentation processes and catalysts as well as the use of new fractions of biomass such as straw and lignin (Beucker, Fichter, Marscheider-Weidemann 2007: 7). Today the chemical industry is responsible for approx. 7 % of crude oil consumption, of which approx. 4 % is used to manufacture plastics[1]. These figures show that the potential for substituting fossil by renewable resources in the sector of plastics is limited under current conditions, but will grow in importance as the worldwide consumption of plastics continues to rise.

- Contribution to climate protection: In contrast to crude oil-based plastics, bioplastics imply a reduction of carbon dioxide emissions. How much difference bioplastics can make depends on the resource and energy consumption needed to produce the raw materials, the basic materials and the additives needed for plastic manufacturing as well as the useful life and the disposal options for the material. In the case of bioplastics, the combustion of the waste material can positively contribute to the energy balance as the embodied energy is used e.g. for the generation of heat or electricity. A first assessment of the European Bioplastics organisation for the European Climate Change Programme (ECCP) concludes that bioplastics have the potential to reduce carbon dioxide emissions by approx. 4 million tonnes until the year 2010 if the market reaches a share of 1 million tonnes[2].

- Environmental pollution and landfill capacities: In many countries and especially in the world's oceans plastics cause a significant amount of pollution that results from their persistence and the extremely slow decomposition of the material (see e.g. Greenpeace 2006). The substitution of packaging material in particular could reduce these effects and could contribute to lessening the load destined for landfills.

- Surface consumption and concurrent applications for renewable resources: The intense use of renewable and agricultural resources for manufacturing bioplastics and other potential applications such as the production of biofuels would require an increase in agricultural production or raw materials being imported into Germany. Increased agricultural production is often linked with well-documented side effects such as monocultures, over-fertilisation, deforestation and the loss of biodiversity. These effects should be addressed in a national discussion and plan that takes the different requirements and needs of the concurrent applications of renewable resources into account. A contribution to solving such problems could come from new biotechnological approaches and more efficient manufacturing processes.

These examples show that only an extensive assessment of individual biopolymers according to Life Cycle Assessment standards like ISO 14040 f can provide satisfactory answers concerning the reduction potentials of environmental effects. Such analyses are

---

[1] All data see Plastics Europe http://www.plasticseurope.org/content/default.asp?PageID=39 (May 2007)

[2] See http://www.european-bioplastics.org/index.php?id=53 (May 2007)

being done and first results published by the companies NatureWorks LLC und Toyota Motor Corporation seem to certify the positive effects of bioplastics[1].

3.2 Economic Potentials

The consumption of plastics has risen strongly in the last few years. Worldwide consumption amounted to 224 million tonnes in 2004 of which 23.6 % were produced in Western Europe. According to a current forecast of the German organisation of plastic producing industries, worldwide consumption will grow to 270 million tonnes per year worldwide (Beucker, Fichter, Marscheider-Weidemann 2007: 17). This corresponds to an annual growth of the market of 4.5 %.

The share of bioplastics in this market is relatively small at the moment. Approx. 350,000 tonnes of bioplastics were produced in 2006. This is equivalent to approx. 0.2 % of the plastics produced worldwide, but experts believe the market for bioplastics will grow at a rate of 25 – 30 % in the near future and reach the one million tonne mark by the year 2010.

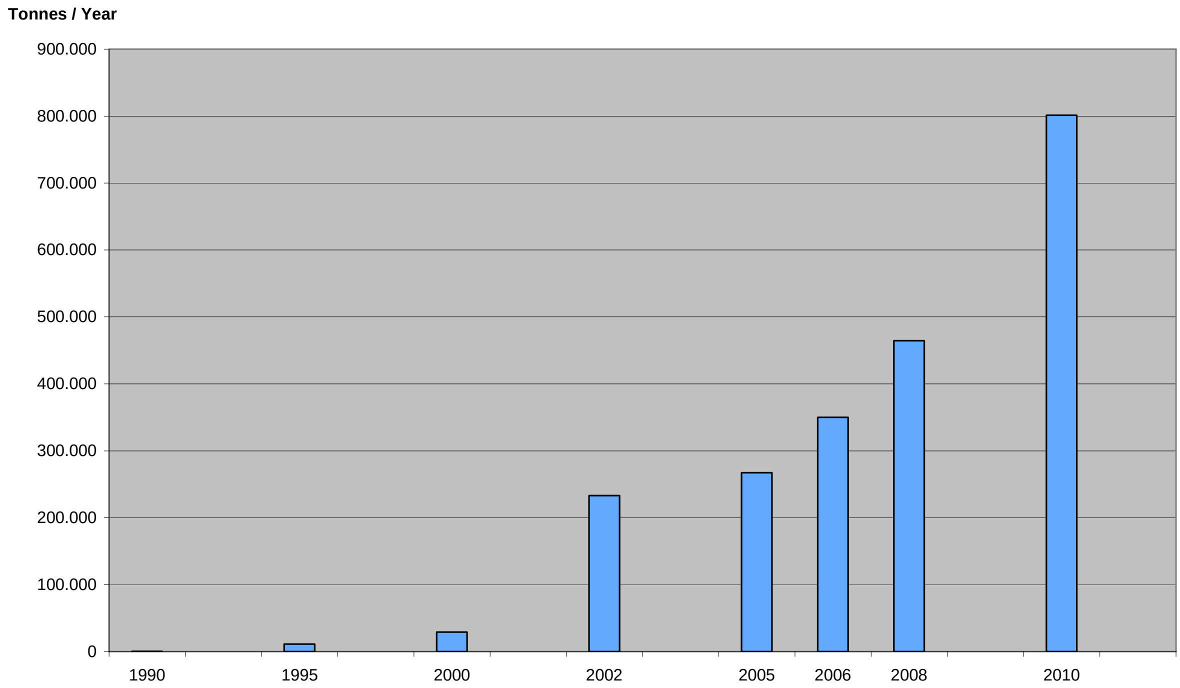

Figure 1: *Expected growth of production capacities for bioplastics (modified according to data from Kaeb 2006: 22)*

By the year 2020 the production potential could even rise to 3 million tonnes per year which would represent an estimated share of 1 % of the global plastics market (Kaeb 2006: 5). According to a survey by Roland Berger Strategy Consultants, bioplastics could replace as

[1] See Detzel, Krüger (2006) and www.toyota.co.jp/en/environmental_rep/03/pdf/E_p23.pdf (May 2007)

much as 5% of the regular oil-based plastics in the long term [1] and a recent study of the German Agency of Renewable Resources sees the biggest growth potential for the use of renewable resources in the sector of bioplastics (FNR 2006: 305).

In the short and medium term, the development of the market for bioplastics strongly depends on two factors:

- Development of the crude oil price: The market potential for bioplastics is heavily dependent on the crude oil price. Under the current situation of a rising oil price, the first bioplastics made from thermoplastic starch have become competitive. Last year the prices for polyethylene and polypropylene ranged between 1.1 and 1.5 Euro per kilogram. Thermoplastic starches in comparison cost around 1.4 Euro per kilogram (Kaeb 2006: 23).

- Economies of scale: A further important prerequisite for lower bioplastics prices is the construction of bigger and more competitive production capacities for specific biopolymers. Cargill Dow/Nature Works and Toyota (see e.g. Toyota 2006) have announced plans to build such capacities in the next few years and different companies like Mazda, Motorola and NEC are planning to use bioplastics in their products (Mazda 2006, FNR 2006: 295). These announcements also imply a shift in bioplastics use from simple applications to premium commodities for the electronics and automotive industry.

4 Conclusion

Despite their relatively small market share bioplastics have the potential to contribute to the mitigation of environmental effects and to become an economically successful new material group with manifold applications and beneficial properties. Europe and Germany are two of the strongest players in the research and production of bioplastics and could profit from the developing market.

Like many new technologies and their applications, the possible environmental effects and impacts of bioplastics have not yet been completely assessed and understood. Based on the limited sources available, bioplastics seem to combine the potential to increase resource efficiency and reduce environmental effects, but further research is necessary before conclusions and recommendations can be made for this new class of materials.

References

Beucker, S.; Fichter, K.; Marscheider-Weidemann, F. (2007): Fallstudie Biokunststoffe, Analyse der Leistungsfähigkeit in „grünen“ Zukunftsmärkten, Case Study in the project Green Future Markets (FKZ 206 14 132/05)

FNR – Fachagentur Nachwachsende Rohstoffe (HG.) (2006): Marktanalyse Nachwachsende Rohstoffe. meó Consulting Team, Institut für Energetik und Umwelt gGmbH, Faserinstitut Bremen, Gülzow

FORASSET – Foresight and Assessment of Environmental Technologies (2006): Case Study Biopolymers, Working Paper Work Package 1: Identification and Characterisation of Environmental Technologies, EU-Projekt FORASSET, Fraunhofer ISE, Karlsruhe

[1] Results of a non public qualitative survey conducted by Roland Berger Strategy Consultants in the project Green Future Markets.

Greenpeace - Allsopp, M.; Walters, A.; Santillo, D.; Johnston; P. (2006): Plastic Debris in the World's Oceans. Greenpeace International, Amsterdam, Netherlands

Karus, M. (2003): Marktüberblick: Bio-Kunststoffe auf Basis nachwachsender Rohstoffe, nova-Institut, Hürth

Kaeb, H. (2006): Biokunststoffe & Bioverpackungen. Informationen des Verbandes European Bioplastics für einen parlamentarischen Abend im Dezember 2006, Berlin

Mazda Motors GmbH (2006): Mazda entwickelt neuen Biokunststoff für Fahrzeuginnenräume, Meldung der Mazda Motors GmbH vom 18.05.2006, (http://www.mazda.de/AboutMazda/MazdaAktuell/NeuigkeitenArchiv/20060518.htm, May 2007)

Toyota Motor Corporation (2006): Sustainability Report 2006. Towards a New Future for People, Society and the Planet, August 2006, Tokyo, Japan