A paper cup that is coated inside and out with a thin film made from a blend of biodegradable polyester and PLA can be composted, but also disposed of quickly and without any need for additional processing in a paper recycling facility (photo: BASF)

Resource Use and Waste Management. As the current discussions about nuclear power, oil and E10 show, there are on the one hand intense efforts to find alternative forms of energy and sources of raw material as well as efficient means of disposal. On the other hand, there is a great deal of confusion among the public and media about how to judge the variety of different approaches. The buzzword "bio" is heard everywhere, but what do the expressions "bio", "sustainable", "environmentally friendly", "energy efficient" really mean? Only eco-efficiency analyses provide an escape from the terminological labyrinth.

Bio above All?

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The Earth's oil, gas and coal resources are limited. In the future, renewable energy and biomass will replace and supplement these limited fossil sources of energy and raw materials to a certain degree.

As a consequence, renewable sources of raw materials will continue to gain in importance in the long term. But renewable resources are not good per se, just as crude oil is not bad per se. In the same way that oil can either be burned or converted into valuable chemical raw materials, corn, wheat and cane sugar are also subject to competing interests, of which their use as foodstuffs has the highest priority. They also serve, however, to generate electricity and heat, production of biofuels and not least used as raw materials in the chemical industry. Since from this standpoint renewable raw materials are treated in the same way as fossil-based raw materials, the same criteria should be applied to their use.

On the basis of eco-efficiency analyses, such as those conducted by BASF, or other LCAs (life cycle assessments), it is possible to establish which of several product alternatives is the most ecologically efficient over the entire life cycle in terms of overall environmental compatibility and economics. Here, both renewable raw materials and bio-based plastics do not always come out on top [1] (**Fig. 1**). When transportation distances, water usage or fertilizer requirements, deforestation or the energy used to refine the biomass are considered on a case-by-case basis, what is assumed to be a more environmentally friendly material may in fact be less eco-efficient than a fossil-based

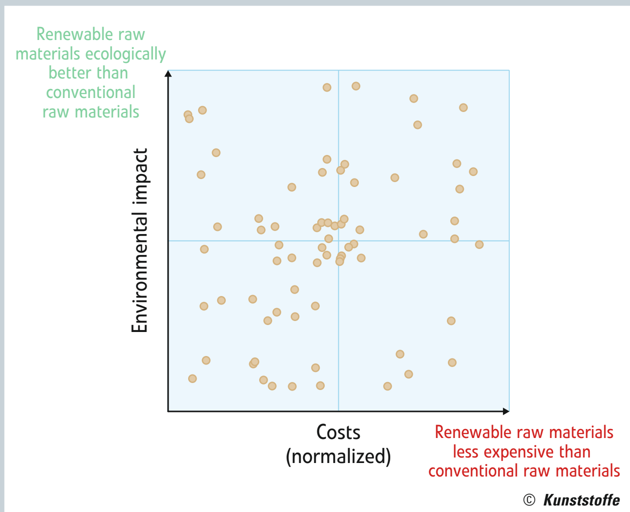

Fig. 1. The unstructured distribution of data points in this illustration shows that renewable raw materials are not always ecologically better or more economical than conventional raw materials. Each of these points is based on an eco-efficiency analysis (source: BASF)

Translated from Kunststoffe 8/2011, pp. 39–43
Article as PDF-File at www.kunststoffe-international.com; Document Number: PE110825

precursor. Plastics experts in particular know that it is possible to conserve fossil-based energy sources and reduce greenhouse gases entirely without biomass **(Fig. 2)**.

Biodegradable Plastics: Conserving Resources with Compost

On the other hand, however, plastics can also contribute to making biomass useful on a large scale. This does not necessarily require bio-based materials, but rather biodegradable ones. It is now recognized that these two properties – biodegradable and bio-based – are not necessarily related. The origin and ultimate destination of a product do not have to be linked: A bio-based plastic component can end up in a trash incinerator, while a bag with its origins in the petrochemical industry that is biodegradable according to EN 13432 should be recycled in a composting facility **(Fig. 3)**.

In the course of discussions about the use of biodegradable plastics in recent years, attention is starting to focus on composting and biological waste management. Composting is aerobic conversion of organic refuse by microorganisms. Such waste arises not only in the kitchens of private households, but also during large-scale food processing and everywhere food is produced, stored and transported.

Biological Waste Management: Greenhouse Gases and Resource Utilization

The plastics industry and other industries have long been familiar with the three-pronged approach to waste disposal: energy recovery, mechanical recycling and feedstock recycling. Depending on the amount, quality, heterogeneity and logistics, any one of these three approaches can be the optimal choice in a particular case.

On the basis of comprehensive eco-efficiency analyses, energy recovery is often the option for waste plastic. Conversion of biological waste into compost can also be considered a form of feedstock recycling: After composting, apple peels and rotten tomatoes end up as organic material that can be used to grow apple trees and tomato plants.

The use of bags made from high-grade biodegradable plastics makes it even simpler to return these organic materials to the raw material cycle cleanly and hygienically by means of industrial composting. →

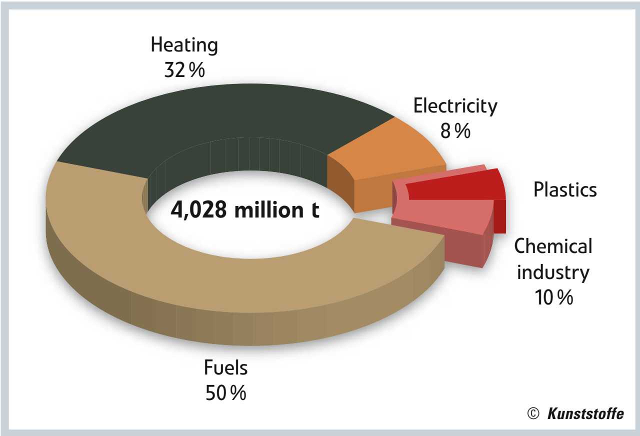

Fig. 2. Oil consumption worldwide in 2010: 80 to 90 % of all petroleum is still consumed for heating/cooling and transportation: Production of chemical products, including plastics, is responsible for only about 10 % of crude oil resources (source: BP Statistical Review of World Energy 6/2011)

Fig. 3. Bags made from a specially formulated blend of biodegradable polyester and PLA are certified and completely biodegradable according to EN 13432 (see test in the photo) (photos: BASF)

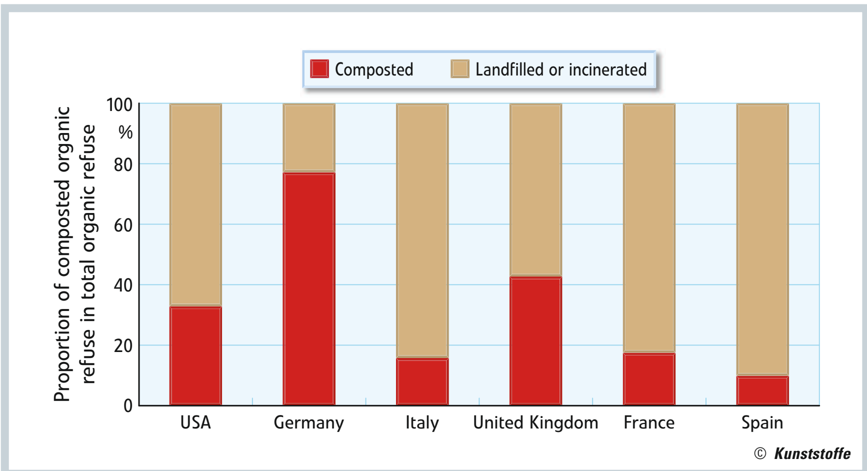

Fig. 4. In an international comparison of composting of organic refuse, Germany is already quite advanced, but there is still much to do in other countries (source: European Bioplastics Association, End of Life Factsheet Composting)

It is true that this was also possible before without plastic bags: In Germany, separation of trash and composting of biological waste is quite highly advanced compared to many other countries: Until now, many people have used their old newspapers to take their organic household waste to the respective trash. But this is unhygienic and the newspaper soaks through so even in Germany there is the potential to collect even more organic waste **(Fig. 4)**. Viewed globally, on the other hand, there is an enormous amount of catching up to do. Take Asia, for example: Together with the GTZ (German Society for Technical Cooperation) and local authorities, BASF started a project in 2010 in Samutsonkram, Thailand, to distribute bags for biodegradable/organic refuse, coupled with an information campaign on the subject of waste disposal. In Thailand there is still no infrastructure for collecting or recycling organic household waste. After the project, more than 90 % of the participating households confirmed that they had a better understanding of the subject matter and signaled interest in systematic collection. An infrastructure like that which has long existed in Germany is a prerequisite for converting organic refuse into compost as a resource in an economically efficient manner. Even Australia is a country that, in 2006, still disposed of 62 % of the organic refuse generated annually (14 million t) in landfills, according to information from the Australian Bioplastics Association.

Fig. 5. In the organic refuse composting facility in Grünstadt (Rhineland-Palatinate, Germany), BASF demonstrated the compostability of organic refuse bags made from the biodegradable plastic Ecovio in 2009. In 2011, a large-scale test will be conducted with 65,000 households; this test will be evaluated by the organic refuse composting facility in Grünstadt together with an independent institute (photo: BASF)

Through the generation of methane, 1 kg of organic refuse in a landfill generates 4,000 g of CO_2 equivalent, while only 19 g results from industrial composting [2]. Organic waste that decomposes in a landfill instead of a composting facility thus contributes significantly to emissions of greenhouse gases. At the same time, compost is a valuable substance that represents an important source of plant nutrients and improves soil properties, since it replaces some of the phosphorus depleted from the soil as the result of intensive agriculture. Compost has also proven beneficial in stabilizing the soil in areas that are subject to severe erosion, and it offers costs benefits over artificial soil improvements. Compost is therefore an interesting product from both ecological as well as economical standpoints.

Bags: For Shopping and Disposal

Bags made from biodegradable plastics can thus help on a large scale to collect compost in a clean and hygienic fashion. Because of its low weight, the biodegradable bag itself provides hardly any nutrients; its main function is to simplify or, in many regions, make possible the collection of organic refuse and thus the creation of valuable compost. In April 2011, BASF started a pilot project in the area around Bad Dürkheim (Rhineland-Palatinate, Germany) in which 65,000 households were provided with a test pack of organic refuse bags made from the biodegradable BASF plastic Ecovio. Having demonstrated in previous trials in Grünstadt, Germany, in 2009 **(Fig. 5)**, in Kingston, Canada, in 2010, and in Dandenong, Australia, in 2011, that organic refuse bags made from Ecovio degrade without difficulty in local composting facilities under industrial composting conditions, testing on a large scale and acceptance by the public are now being investigated. In Houston, Texas, USA, grass clippings and yard waste are already being collected in biodegradable plastic bags; in Straubing near Munich, Germany, organic refuse bags made from biodegradable plastics have become part of everyday life following an extensive pilot phase. Other German cities and districts have indicated their interest.

The biodegradable polyester blend Ecovio is beneficial not only in the form of organic refuse bags **(Fig. 6)**.

A shopping bag made of biodegradable plastic such as that provided by the supermarket chain Aldi Süd, for instance, is more eco-efficient than a conventional polyethylene (PE) or paper shopping bag when it is used several times for shopping

Fig. 6. A biodegradable shopping bag that can be used several times for shopping and then for collecting organic refuse is especially eco-efficient (photos: BASF)

because of its greater stability and subsequently used as an organic refuse bag. This shown in an eco-efficiency analysis that compared precisely these three types of bags for the same requirement profile **(Fig. 7)**.

Established: Biodegradable Plastics

Since BASF introduced Ecoflex, a biodegradable polyester based on fossil fuel resources, in 1998, the material has been developed further. Facilitated by the growing interest in and availability of sustainable raw materials, numerous blends of Ecoflex with PLA (polylactic acid) have been created under the brand name Ecovio that in contrast to Ecoflex are based on renewable raw materials to varying degrees. Ecovio FS Film has been developed for production of classic film/bags and contains even more renewable resources than its predecessor Ecovio F Film. Ecovio FS Paper has been optimized for the coating of paper **(Title photo)**, while Ecovio FS Shrink Film is intended for production of shrink film. All of the product grades offer a special benefit when used with organic materials, foods or organic refuse, whether as packaging film, bags or even as mulch film for agricultural use.

Not a Solution for Everything

Like bio-based plastics, biodegradable plastics are neither a patent solution for all plastic applications nor as a solution problem of littering, regardless of the raw materials on which they are based: Biodegradable plastics decompose quickly and completely only under defined conditions in an industrial composting facility. To control littering on land and at sea, requires education and a transition from a throw-away society to one that has learned to recognize the value of individual products, even after their useful life. It therefore does not make sense to ban conventional plastic shopping bags, especially when there still no adequate infrastructure for disposal of the alternative biodegradable bags.

BASF is therefore concentrating its biodegradable plastics on applications where biodegradability represents added value, where they offer improved properties, lower system costs or entirely new product solutions.

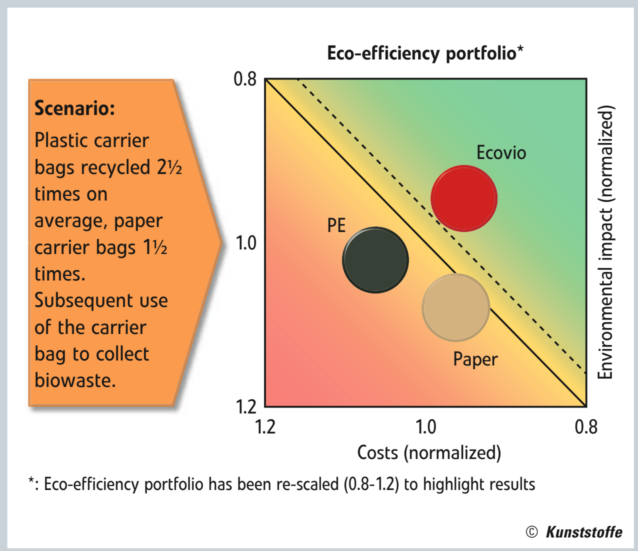

Fig. 7. If a shopping bag is used for shopping several times and then for collecting organic refuse, a bag made from an biodegradable polyester blend is shown to be beneficial in an eco-efficiency analysis shows. The PE bag cannot be used to dispose of organic refuse in the composting facility and the paper bag soaks through or tears, and thus does not last as long (the eco-efficiency portfolio was rescaled (0.8 to 1.2) to make the results easier to read) (source: BASF)

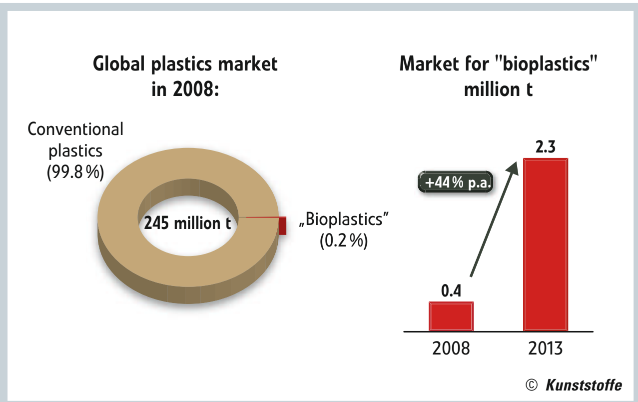

Fig. 8. The market for bio-based and biodegradable plastics will remain a niche market in the coming years; nevertheless, it shows high growth rates: For bioplastics overall (bio-based and biodegradable), an annual growth rate of 44 % is projected (source: Plastics-Europe market research group (PEMRG); PRO-BIP-Studie, June 2009)

Market Development and Political Framework

According to experts, the market for biodegradable plastics will grow by more than 20 % per year in the coming years; this is four to five times the growth rate of conventional plastics **(Fig. 8)**. Nevertheless, it will continue to be a niche market in the future, since biodegradability of a plastic is useful only in special applications.

Momentum in this specialty market is being created by the EU waste management policy, which focuses on waste prevention [3]. For EU experts too, composting is an important process for reducing disposal of organic refuse in landfills and for preventing harmful effects on water, soil and air [4]. After all, in 1995, 3 % of the greenhouse gases created in the EU resulted from the landfilling of organic refuse. Another issue is the amount of land devoted to landfills, a problem that in the meantime has been recognized especially by Asian countries, including China. Accordingly, the EU issued a directive in 1999 that commits the member states to reduce landfilling to 35 % of the 1999 level by the year 2016. To encourage composting in the EU, quality standards for compost were introduced in 2007 with the intention of promoting development of the market and increasing acceptance by consumers. With the same objective in mind, the EU Commission is working on legislation for organic refuse, a process that is being accompanied by studies of waste management [5]. These activities, with their focus on an overall waste disposal policy and resource conservation, are a further sign of a change in society that has become even more aware of the value of refuse.

Conclusions and Outlook

Not all composters are convinced of the benefit of biodegradable bags for organic waste: For years every conventional plastic bag in the organic refuse trash can was rightly a source of aggravation. With the aid of comprehensive certification and good identification, retailers, consumers and the operators of composting facilities should now be able to take a sig- →

nificant step forward. There is still much to do in this regard, since even in Europe not all organic refuse ends up in compost by any means.

A major advance in the utilization of organic refuse will be made when, in addition to composting facilities, biogas plants become more widely established. In addition to Germany, the leaders in this development are Spain and France [6]. Composting can be understood as the aerobic digestion of organic refuse by microorganisms during which, in addition to CO_2, water and biomass result. When air is excluded, anaerobic bacteria can convert organic refuse to CO_2 and the fuel methane, i.e. to biogas [7 to 8]. The combination of anaerobic digestion, or biogas generation, with subsequent classic composting yields a double benefit: Mixed moist household refuse can be used to generate biogas as an energy source for electricity in a first step. In a second step the remaining refuse can then be converted into valuable compost in a composting facility. The challenge faced by biodegradable plastics in the medium term is to be suitable for anaerobic as well as aerobic digestion. ■

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