Going green: Environmentally-friendly packaging

The development of new food packaging materials in the twentieth century was driven largely by the perennial considerations of performance and cost. New materials needed to be better, or cheaper, but preferably both, to succeed in the market place. Now, as the twenty first century nears the end of its first decade, this is changing fast. Environmental concerns are increasingly important considerations for many of the packaging industry's customers, who are looking for food packaging that is not only better and cheaper, but greener too. After a slow start, technologists are rising to the challenge and practical, green alternatives to many 'traditional' packaging materials are starting to gain a foothold in the market.

Modern food packaging materials have to perform a wide range of functions equally well, notably protecting the product from biological and chemical contamination and from physical damage. The packaging also has to be easy to handle and to open, while at the same time being resistant to tampering. Finally, it has to look good and supply surfaces that can carry eye-catching brand identification and ever-expanding labelling information. To help meet these demands, the packaging industry has at its disposal a huge number of materials, including a wide range of plastics, paper and card, metals and glass, as well as more complex materials like laminates and coated plastics. Furthermore, packaging performance continues to improve as new developments, such as active and intelligent packaging and nanotechnology, open up exciting new possibilities.

But suddenly, this is not enough. Driven by changing consumer attitudes, unfavourable media coverage and growing regulatory pressure, many large retailers and food manufacturers are now looking for packaging alternatives that provide the performance and low cost of conventional materials, but which also have a much reduced environmental impact. Demand is rapidly rising for packaging that is derived from sustainable resources and is recyclable, or biodegradable. Green packaging is now a positive selling point for many European consumers, and the race is on to develop affordable materials that can claim marketable green credentials, while performing as well as conventional packaging.

A small, but growing market

A recent study by UK-based packagingconsultants PIRA International found that more than 42,000 tonnes of biodegradable packaging were produced in 2006, with Western Europe being the biggest consumer. This is predicted to grow at an annual rate of 22% in the next few years and should reach around 116,000 tonnes by 2011. Nevertheless, this still represents only about 2-3% of the global food packaging market. Despite this, interest at the research and development level is growing fast, as demonstrated by over 2,300 patents and patent applications for biodegradable food packaging identified in a recent industry report from US research and advisory concern, Nerac. While the demands of consumers, retailers and food manufacturers have opened up the field for a new breed of green packaging materials, there are obstacles facing anyone planning to enter the market. One of the most important of these is obtaining regulatory approval. For instance, in the EU, the safety of materials that may come into contact with food is strictly controlled in legislation (Regulation (EC) 1935/2004) and any new material must be approved before it can be marketed. Obtaining approval is a time consuming and costly process and will involve presenting a comprehensive dossier of scientific and safety data for assessment by the European Food Safety Authority (EFSA). Only when this dossier has been evaluated, and the EFSA is satisfied that the new material is safe, will approval be given. Regulatory demands may be encouraging a conservative approach to new packaging materials and slowing the pace of development, but the demand for novel materials remains strong.

The ecotainer coffee cup is made from a bio-plastic based on corn.

Making plastics greener

While paper-based packaging already boasts strong green credentials and glass and metal concentrate on increasing their already significant recycling rates, plastics have a comparatively poor environmental image. Most plastic is derived from non-renewable sources, is non-biodegradable and, even though recycling is possible for many plastics, recycling rates are low in many countries and most still goes to landfill. This means that although the plastics sector has a poor environmental image, it also has the greatest scope to exploit new technologies and new materials.

Making packaging from materials that are biodegradable is one important step in improving consumer perception of plastics. Some manufacturers have been able to achieve this by modifying traditional petroleum-based plastics. Examples include the Ecoflex family of biodegradable copolyester plastics from BASF, and SuperEco, a biodegradable biaxially oriented polypropylene (BOPP) film made by the Turkish company Superfilm. But it is in the field of plastics made from renewable natural resources that the greatest investment in research and development, and in production facilities is being made. Driven by rising oil prices as well as environmental concerns, many manufacturers are now developing so-called bioplastics that can compete on a cost and performance basis with existing petroleum-based materials.

PLA leads the way

Polyactide (PLA) is currently the leading bioplastic and accounts for about 43% of the market at present according to the PIRA study. PLA is not a new material – it was first discovered more than a hundred years ago – but it remained far too expensive for packaging applications until the late 1980s, when scientists working for Cargill in the USA developed a more efficient production method. The raw material for PLA can be any biomass that is high in starch or sugars, including corn, sugar cane, sugar beet and potatoes. The starch is first converted into fermentable dextrose, which is then used as the food source for a microbial fermentation that produces lactic acid. The lactic acid is then polymerised by means of some clever chemistry. The process can be controlled and modified to produce different types of PLA suitable for various applications.

The biggest commercial producer of PLA is currently NatureWorks LLC in the USA, a subsidiary of Cargill set up in 2001 to utilise the technology developed by the parent company. NatureWorks has built a dedicated factory in Nebraska to make up to 140,000 tonnes of its NatureWorks PLA every year from locally grown corn. PLA can be used in a variety of applications and can be formulated to be rigid or flexible. It can be thermoformed, blow moulded, injection moulded and used to make films, coatings and flow wraps. It can also be heat sealed at relatively low temperatures and has barrier properties similar to those of PET. It is already being used in the fresh produce and foodservice sectors and has been evaluated by several major supermarket chains in Europe. Its main limitations are poor resistance to high temperatures, and a lack of strength and translucence compared with some other plastics. In fact problems have been reported with clamshell-type fresh produce packs distorting even at high ambient temperatures.

The chemical and plastics industries have been busy developing some solutions for these problems. For example, Rohm and Haas markets Paraloid BPM-500, an additive for PLA that uses nanoparticles that increase the strength of PLA packaging, but do not scatter light and so improve the clarity of the material. Dupont too has developed a product to modify PLA to improve its strength and clarity. Biomax Strong 120 is an ethylene copolymer specially designed for food packaging, which is said to bring significant improvements in the toughness of PLA when added at levels as low as 2%. Bioplastics specialist Cereplast in California produces 15 different bioplastic resins in its Compostables range, including CP-TH-6000, a low-priced thermoforming PLA resin that has been 'nanoengineered' to withstand temperatures up to 68°C, rather than the 44°C of conventional PLA. UK-based Stanelco has also modified PLA to improve its strength and barrier properties and create its Starpol

2000 packaging material. Meanwhile, Dutch PLA producer Hycail has launched Hycail XM 1020, which it says is "the first truly high heat resistant, transparent PLA."

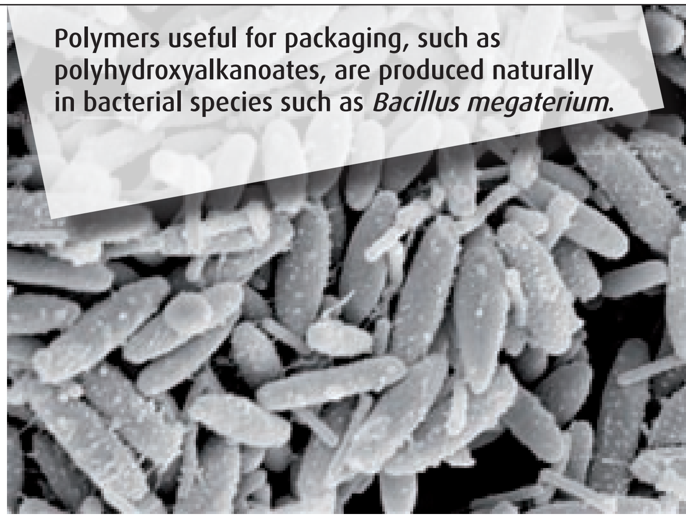
Other contenders vie for top spot

PLA may have the biggest slice of the market for bioplastics, but there is no shortage of new materials challenging for a greater share. Chief among these are starch-based biopolymers such as the Mater-Bi range developed by Italian producer Novamont. These plastics are made from mixtures of corn starch and thermoplastic binders, such as polyvinyl alcohol, polycaprolactone and PLA. These are biodegradable, though not all the components come from renewable sources. Mater-Bi resins are already reported to be in use by some of Europe's biggest packaging manufacturers, including Huhtamaki, Amcor Flexibles and Alcan Packaging, and Novamont is expanding production capacity. Mater-Bi has also been combined with other biodegradable materials, such as Innovia's NatureFlex films made from wood pulp, to produce packaging applications such as biodegradable bags for breakfast cereals. Stanelco too, is involved with biodegradable starch-based packaging materials through its Bioplast products made by Biotec in Germany. These are made from a blend of corn or potato starch with various proprietary copolymers and other components. The range includes products suitable for moulding and for producing flexible films and food wraps.

A different take on starch-based bioplastics is provided by the Plantic range of products from Plantic Technologies in Australia. These use a naturally high-amylose starch from hybridised corn varieties, which is chemically modified by a hydroxypropylation process to inhibit retrogradation and 'plasticise' the starch. The modified starch is then mixed with various other polymeric and non-polymeric ingredients, plasticisers and processing aids in several different formulations to give polymers with a range of properties. Formulations are available for rigid packs, injection moulding resins, flexible films and barrier resins. Plantic products are highly biodegradable and have been shown to outperform PLA in terms of environmental impact. Although Plantic Technologies was only founded in 2001, it has already developed a number of food industry applications for its products, such as a flexible tray for a new range of Swiss chocolates launched by UK retailer Marks & Spencer.

PHAs – the next big thing?

One group of biopolymers seen as potentially strong competitors, both for PLA and for petroleum-based polymers, are the polyhydroxyalkanoates (PHAs), polymers that are produced naturally within some microbial cells. One of the best known PHAs is poly-3-hydroxybutyrate (PHB), produced by a range of bacterial species, such as *Bacillus megaterium*, but there are many other polymers in the group, including poly 3-hydroxyvalerate (PHV). PHAs have thermoplastic properties and are of great interest as bioplastics, primarily because their physical properties are so similar to those of polypropylene, but also because they are readily biodegradable. They have much higher melting points and glass transition temperatures than PLA, making them more resistant to high temperatures. PHAs are also hydrophobic and resistant to water and to oils.



Polymers useful for packaging, such as polyhydroxyalkanoates, are produced naturally in bacterial species such as *Bacillus megaterium*.

Rather like PLA, PHAs are not a particularly recent discovery. PHB was first discovered in 1925 as inclusions in bacterial cells. This discovery remained a scientific curiosity until the 1950s and ’60s, when US scientists produced small quantities for experimental evaluation and patented the process. UK chemical giant ICI later applied their experience of single-cell protein production to produce PHB in industrial quantities from sugar using a microbial fermentation process. The company eventually launched a range of PHB-PHV copolymers – formulated to overcome the brittleness of pure PHB – under the trade name Biopol. Since 1990, the Biopol name has had several owners, but in 2001, it became the property of Metabolix Inc., a US bioscience company specialising in environmentally friendly plastics and other chemicals.

In partnership with grain processor ADM, Metabolix set up a joint venture called Telles in 2006 to produce and market its own range of Mirel bioplastics for food packaging and other applications. Mirel products are PHA-based and are made by microbial fermentation of corn sugar. There are now Mirel products suitable for injection moulding applications, thermoforming, packaging films and for paper coating. A Telles production plant is expected to come on-stream this year and should be capable of producing 110 million pounds of Mirel each year. The company is also using its biotechnology experience to conduct research into genetically modifying plants, such as switchgrass, to produce PHA and other materials within the plant itself. This could mean that bioplastics might one day be harvested directly from crops grown in the field and refined without the costly microbial fermentation stage.

Research is also underway to improve the performance of PHAs. Although PHB has good heat resistance properties, it is notably brittle and much work has focused on additives to overcome this problem. For example, researchers at Cornell University have modified PHB with clay nanoparticles to create composites with better strength and barrier properties, but retaining the excellent biodegradability of pure PHB.

New polymers in development

As interest in bioplastics continues to grow, it is perhaps not surprising that researchers are investigating a range of natural polymers for possible application as packaging materials. Many polymers exist naturally in microorganisms, plants and animals, and while some may be of little use as plastics, others are more promising. Examples include chitin and chitosan, found in the exoskeletons of insects and crustaceans and the cell walls of fungi, and hemicelluloses, such as xylan, which are found in plants. A product based on the latter is under development in Sweden and is already being produced on a pilot scale and moving towards commercialisation. Xylophane is being produced by Xylophane AB, a spin-off company set up in 2004 to exploit technology developed at Chalmers University in Göteborg.

Xylophane is made by extracting xylan polymers from various plant materials, including wood, straw and the husks from rye and wheat. A cocktail of additives is then mixed with the xylan to produce xylophane itself in powder form. Xylophane can be dissolved or dispersed in water and then applied as a coating onto paper, board, or plastic substrates. Its primary application is as a barrier layer in packaging. Xylophane has oxygen barrier properties (less than 5 cm^3/m^2 per day) and is also said to be an excellent grease and aroma barrier. Added to these properties, xylophane is also flexible and biodegradable. The material is particularly promising as a barrier coating for paper and board packaging, providing a material with sufficient barrier properties to be used to pack foods such as snacks, coffee, spices and petfood, but which is derived from renewable resources and is completely biodegradable.

Making something out of nothing

Xylophane is also an example of a biopolymer that overcomes one of the biggest problems facing the growing bioplastics sector. As global food prices rise, there is increasing disquiet about devoting agricultural resources to the production of crops destined for biofuel and bioplastics production. There is also evidence that forest environments around the world are being destroyed to clear land for growing such crops. For this reason, there is much interest in developing bioplastics derived from agricultural waste, or other less environmentally damaging sources.

An example of this trend is provided by the work of Novomer in the USA. Novomer was set up in 2004, to commercialise research on catalysts carried out at Cornell University, and is developing low-cost green plastics and other polymers. The company recently announced that it had secured venture capital to develop plastics made from renewable feedstocks that include carbon dioxide. The process uses a new type of highly active zinc-based catalyst to copolymerise carbon dioxide and various epoxides derived from renewable sources, such as citrus fruit waste. The result is a range of biodegradable polycarbonate materials with obvious applications in packaging. There is clearly a long way to go before this technology brings products to the market, but it offers the tantalising prospect of low cost biodegradable plastics made from a mixture of food processing waste and carbon dioxide. Packaging materials don’t come much greener than that.

Reference

Biodegradable food packaging: an environmental imperative. Nerac Industry Report, August 2007. Available at: www.nerac.com/food/packaging-report-download/