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Bioplastics Aren't the Stretch They Once Seemed

DuPont, Cargill Dow and Metabolix bring sustainability to plastics manufacture. Clay Boswell reports.

Plastics, like the petrochemicals used to make them, present two growing problems: dependence on a finite natural resource (crude oil) and persistence in the environment. As the American Plastics Council would point out, though, plastics are essential to our way of life. We therefore make do. But a compromise may not always be necessary. Bio-based plastics from DuPont, Cargill Dow, and Metabolix are addressing the problems of sustainability and pollution while maintaining and even improving our standard of living. Drawing on the latest tools of biotechnology, they are breathing new life into an older production model, whereby the chemical industry drew its raw materials from the agricultural sector.

Three emergent polyesters represent different degrees of bio-basis. Corn-derived 1,3-propanediol is to be a primary feedstock for DuPont's Sorona, which also draws on petrochemical-derived terephthalate. Cargill Dow's NatureWorks, a polylactide (PLA), is being produced entirely from lactic acid derived fermentatively from corn. In both cases, polymerization is ultimately accomplished chemically. Metabolix, however, has eliminated chemical synthesis altogether by developing organisms that not only produce monomers but also go a step further, producing actual plastics—in this case polyhydroxyalkanoates (PHAs).

Sorona, DuPont's newest polymer platform, is a family of polymers based on fiber-grade 1,3-propanediol (PDO, also known as 3G) and terephthalate (DMT, TPA or simply T). Generically the polymer is known as 3GT. DuPont has been aware of 3GT polymers for over 50 years, but only recently has fiber-grade PDO been available at a cost that makes the product commercially viable. Sorona is a versatile polymer, according to DuPont. Superior stretch recovery, soft touch, and dye and print capabilities appeal to the apparel market. Upholstery can draw on Sorona's stain resistance and resiliency. For resins, Sorona offers toughness, flexibility and puncture resistance, and a barrier to oxygen and water. For other applications, such as medical garments, monofilaments and brushes, Sorona provides higher hot- and wet-strength and the ability to make soft, resilent non-wovens.

DuPont has already begun producing 20 million pounds per year of Sorona at a new continuous polymerization plant located in Kinston, N.C. However, the process now uses petrochemical-based PDO manufactured by Degussa in Wesseling, Germany, under an exclusive DuPont license. Sorona will become a bio-based plastic when production using PDO based on corn begins, perhaps within the next couple years. DuPont already has a fermentative process to convert corn-derived glucose to PDO, developed in a collaboration with Genencor that began in 1995. Using Genencor's DesignPath technology, scientists combined DNA from three different organisms in one production strain; the new organism showed an improvement in productivity of greater than 500-fold. To scale up the process, DuPont has partnered with Tate & Lyle, a major corn-based products company experienced in fermentative production. In May, DuPont announced that the transfer to Tate & Lyle's Decatur, Ill., pilot plant was successful. Commercial scale production of bio-based PDO will begin in 2003, and if the economics are right, the Kinston Sonora plant will be switched to the new feedstock.

Cargill Dow's new NatureWorks plant in Blair, Nebraska. With a capacity of 140,000 metric tons, the facility will be completed in 2002 and serve the global demand for NatureWorks PLA until further capacity is added in Europe and Asia.

"We are extremely pleased with this development because it offers solid proof that biotechnology can and will deliver far-reaching, transformative benefits in a wide variety of areas," says Ellen J. Kullman, DuPont group vice president and general manager of DuPont Bio-Based Materials. Sorona, she adds, is "the first in what we believe will be a family of bio-based products with exciting consumer and industrial applications." DuPont intends that by 2010 the company will make 25 percent of its products using renewable materials.

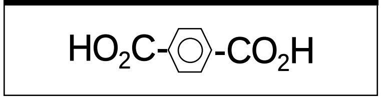
Cargill Dow's NatureWorks is a completely bio-based polymer, a polylactide (PLA) formed from lactic acid, an alpha-hydroxy acid derived fermentatively from corn sugar. Developmental work began 12 years ago. By 1996, Cargill had announced plans to manufacture and market a compostable leaf and lawn bag made with a version of its PLA, trademarked as EcoPLA Renewable Biopolymer. In 1997 Cargill and Dow formed a partnership, Minnetonka, Minn.-based Cargill Dow LLC, that has considerably expanded the potential of PLA and brought it to the brink of world scale manufacture as NatureWorks. Construction is well under way on a manufacturing facility in Blair, Neb., that will produce up to 140,000 metric tons of PLA per year beginning in 2002. Short-term demand is being met by a semi-commercial facility outside Minneapolis, Minn.

Cargill Dow is highly optimistic about the market for NatureWorks PLA.

1, 3-propanediol (PDO or 3G)

$$HC-CH_2-CH_2-CH_2-OH$$

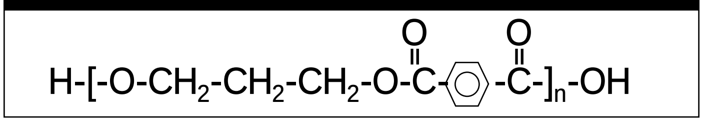
terephthalic acid (DMT/TPA or T)



"Demand... has been so strong that we could very well be sold out on the first day the plant opens," says Randy Howard, president of Cargill Dow. "Given the global interest in this new technology, we will likely begin the development of a second plant within a few years of bringing the Blair facility on line."

The product was formally launched in January 2000, and Cargill Dow has since then introduced several new commercial grades for specific end-uses. Apparel is one. Nature-Works PLA fibers are, says Cargill Dow, the first material to allow production of fabrics that successfully bridge the gap between natural and synthetic fibers. According to independent tests cited by the company, plaited fabric made from NatureWorks and cotton performs better than plaited polyester/cotton fabric,

DuPont's Sorona (3GT)



resulting in improved physiological comfort. Other fabric blends being developed for apparel include wool and silk. Fabrics are also being developed with 100 percent NatureWorks fibers. Cargill Dow has applied to the US Federal Trade Commission for a new generic fiber designation, "synterra", to encompass fibers of PLA.

The widespread availability of PLA yarns is not far off. Unifi Inc., a leading producer and processor of textured yarns based in Greensboro, N.C., and Dow Cargill recently announced the development of a 1 denier per filament yarn, the successful package dyeing of air jet-textured fiber yarn, and the availability of large-scale sampling beginning in early 2002. Unifi expects to have four yarn counts comercially available, including the 1 denier per filament yarn, and a true micro denier product is "right around the corner."

NatureWorks' biodegradability opens up the food service market. For example, Cargill Dow and Biocorp Inc., a leading developer and manufacturer of biodegradable products based in Redondo Beach, Calif., have premiered clear cold-drink cups made entirely from NatureWorks. The physical properties of the cups are competitive with petroleum-based plastics, says Biocorp, but the cups are also compostable. The company estimates that the ability to fully compost food scraps without separating disposable utensils, packaging and the like can save up to 35 percent when compared with landfill options.

Biodegradability also figures in other consumer markets. Sumitomo Rubber Industries recently began using NatureWorks as the exterior packaging film on sleeves of Dunlop golf balls, the polymer's first non-pilot packaging application. And a NatureWorks film wrap newly developed for Sony mini-discs will be the first product to carry the GreenPla logo, a Japanese initiative to encourage the use of compostable "green plastics."

Cambridge, Mass.-based Metabolix Inc. recently made news with the purchase of Monsanto's polyhydroxyalkanoate Biopol, but the company is no newcomer to the field of PHAs. Its founders, Oliver Peoples and Anthony Sinskey, were the first to show that PHAs could be produced by recombinant organisms through work they did at the Massachusetts Institute of Technology during the 1980s. In 1992 they started Metabolix to commercialize the technology, since then developing a library of integrated microbial strains able to produce a range of PHAs, including copolymers, through fermentation with much greater efficiency than the wild strains used by Monsanto. Metabolix has also made important progress toward producing PHAs in plants.

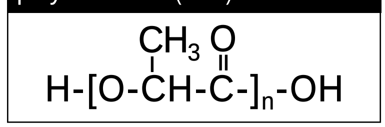
The acquisition of Biopol was nonetheless important, says Jim Barber, the company's president and CEO. Metabolix, he explains, has a commanding intellectual property position in regard to the genetically engineered approaches to PHAs. "But Monsanto had many particular improvements that were interesting, as well as a very large amount of intellectual property and know-how related to the processing of these polymers, applications and targeted work. What we accomplished was first to achieve a great clarity regarding the IP position in the area, taking it into one house… Second, we got know-how. And third, there were several application areas that had been pursued to a significant degree, and we can pick those up much more directly." Examples are water-resistant bio-degradable coatings, monoaxially oriented films, and credit cards.

PHAs are linear homochiral thermoplastic polyesters produced by bacteria for energy storage. In 1925, polyhydroxybutyrate became the first known PHA, and in the 1970s polyhydroxyoctanoate and a copolymer of 3-hydroxybutyrate and 3-hydroxyvalerate (PHBV) were identified. By the mid-1990s, almost 100 microbial PHAs had been found.

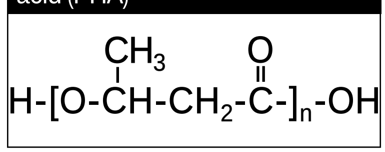
Metabolix is not positioning its PHAs primarily as biodegradable alternatives to existing polymers. "In many cases, that doesn't bring a great deal of value, unless it's a tie breaker," says Mr. Barber. "Our focus in these early years of commercialization is to identify specialty niches where these PHAs bring some unique performance benefit, and to compete on that basis." The company's first product will therefore be its Cleanburn binders for powder metal processing, a technology whereby metal products are formed by the injection molding or pressing of a metal powder that has been mixed with an organic binder. The binder is subsequently burned out. The technology is typically used for parts with complex shapes that are difficult to cast or machine, one example being metallic Swatch watches.

Traditional biopolymers were restricted to fairly rigid, thermoplastic-type applications, Mr. Barber notes, but Metabolix's PHAs can be produced with a wide range of properties by varying the composition of the copolymers produced by the organism. Molecular weights can be varied between 100,000 and 1,000,000, and elasticity from 5 percent to over 1000 percent at break. "[Our PHAs] can go from compositions useful for blow-molded products like bottles, at one extreme, to truly elastomeric materials that would be used for hot melt adhesives or pressure sensitive adhesives," he says. Non-woven fabrics, films and fibers, and latex coatings are all applications open to PHAs, he says. They can also serve as the basis for such specialty chemicals as solvents, polyurethane intermediates and surfactant precursors.

Cargill Dow's Natureworks, or polylactic acid (PLA)



Metabolix's Biopol, or poly-β-hydroxybutyrate, a polyhydroxy acid (PHA)



More commodity-type applications might be served best by plant-based production of PHAs; Metabolix is looking at tobacco, industrial rape seed and switchgrass. "What plants are good at is accumulating carbon in one form or another, and it's all nearly free," Mr. Barber observes. "You do have to do work in terms of planting, etc., but the carbon and sunlight are free and the land is a lot less expensive than building chemical plants.You'll still have the cost of an extraction plant to get the PHA out of the crop plant, but that's it. So from plant systems one can see economics that would be directly competitive with even the large volume thermoplastics that are petroleum derived, such as polypropylene and polyethylene." Mr. Barber expects the demonstration of a commercially interesting plant-based system to take about 5 years, with a few more years necessary to get worthy cultivars into the field. Metabolix aims to develop plants for which 10 to 20 percent of biomass is PHA.

The bacteria Metabolix has developed are, by contrast, 80 to 90 percent PHA, and Metabolix has developed means to dramatically increase their efficiency still further through metabolic engineering, resulting in reduced feedstock costs (glucose), shorter cycle times, greater throughput and reduced heat removal. But microbial and crop-based production are likely to co-exist perpetually, Mr. Barber predicts. Crop production will be cheaper but provide a limited number of grades. Fermentation will be more expensive but offer virtually unlimited flexibility. And the advantages of both will be combined by the blending or reactive blending of the PHAs they produce.

Metabolix currently has a pilot unit for production, and has turned to contract manufacturers to obtain material on a tonnage basis. The fermentation equipment necessary for PHAs already exists at very large scale for other purposes, being similar to that used for lysine fermentation, and partnering is a likely means to commercial scale production, says Mr. Barber.