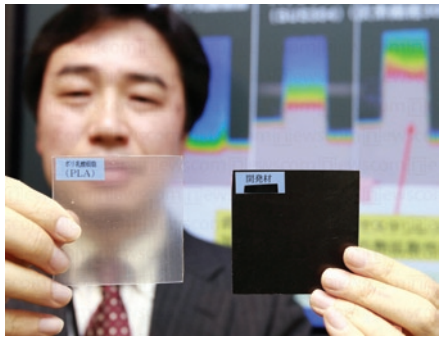
Do biomaterials really mean business?

Receiving only a fraction of the investment set aside for biofuels, biomaterials will likely have to piggyback on technological advances in energy production to compete with petroleum-based products in the marketplace. Emily Waltz reports.

The biomaterials sector is the neglected stepchild of industrial biotech. Consider the US Congress's farm bill that passed in May: more than $1 billion was appropriated for advanced biofuels, whereas biomaterials received a paltry $9 million over the next five years. The bill gave biofuels a panoply of incentives: loan guarantees for the construction of next-generation biofuels plants, funding for conversion technologies to break down plant matter, support for R&D in feedstock development and cellulosic biofuels production efficiency, as well as payments to farmers near biorefineries to help them make the transition to dedicated energy crops. All that nonfuel biobased products got was a rule that requires federal agencies to give purchasing preference in its contracts to biobased products and an expansion of the products that qualify.

The priority given to biofuels exemplifies a trend in industrial biotech: biofuels first, biomaterials later. Biomaterials, also referred to as biobased products, are industrial products that are composed of biological materials, such as plant matter, or biomass (**Box 1**), which can be converted into high-value chemicals, polymers or intermediates. Biobased products compete with their fossil fuel counterparts made by the petrochemical industry.

Despite the myriad options, it's three biofuel products, ethanol, biodiesel and biobutanol, that are receiving all the attention in the biobased economy. The market for fuels swamps that of chemical and materials markets, and the prospect of commanding just a piece of it is a draw that many entrepreneurs, governments and investors cannot resist. Of all the US federal funding for R&D in biomass and bioenergy since the 1970s, as much as 70% has gone to biofuels, according to the US Department of Energy (DOE). Venture capital investors have followed a similar line. The situation is almost the same in Europe, although not quite as dramatic as in the US. "Biobased products are still in the shadows," says Matt Carr, a policy director in the industrial and environmental section of the Washington, DC–based Biotechnology Industry Organization (BIO). "We've been working with Congress to expand incentives from biofuels to other products."



Biomaterials are turning up in a myriad of consumer products. Shown here is the first heat conductive plastic, made by Japan's NEC Nano Electronics Research Laboratories in Tokyo. Source: Newscom.com

True, the biobased products industry could benefit from some of the biofuel provisions in the farm bill, such as feedstock development. And, industrial and academic researchers, with or without government help, are making progress in turning biomass into chemical building blocks that could serve as the basis for everything from plastic to paint (**Table 1**). But the question remains: can the biomaterials industry find a way out of the shadows?

Second-class citizen

Biofuels and biobased products have a lot in common. They are often made from the same raw materials, such as corn and oilseeds. Their futures depend on the success of some of the same emerging conversion technologies that use next-generation feedstocks. Their competitiveness in the market is at the mercy of oil prices and, to some extent, the green movement. They share many of the same manufacturers. They can even be produced at the same facility. In fact, a number of studies[1] have shown that coordinating biobased fuel and chemical production—called an integrated biorefinery—can achieve efficiencies.

Yet the trend among companies in the biobased economy is to focus on fuels. South San Francisco–based LS9, for example, is engineering microbes to metabolize sugars into the molecular building blocks of petroleum. The technique gives the company the flexibility to make anything—fuel or chemicals—that can be made with real petroleum. The company has chosen to focus first on a diesel-like product, with the idea of working on chemicals for nonfuel products down the road. "The chemicals markets are smaller, more controlled, difficult to penetrate, and the product specification has a consumer acceptance criteria which is harder to predict," says Stephen Del Cardayre, vice president of R&D at LS9. "The demand for diesel is enormous and growing and the specification is much clearer."

Lignocellulosic feedstock conversions are also key cross-industry technologies. Cheap, efficient ways to break down biomass into sugar could be the breakthrough that makes biofuels' and biobased products' prices competitive with their petroleum counterparts. Yet nearly every company working on those technologies in the industrial biotech sector is focused on biofuels. Again, it comes down to market demand. "The volume is not such that you can support a cellulose-to-sugar research program just for bioplastics," says Bob Pangborn, a director at Novomer, in Ithaca, New York, and a consultant with expertise in biobased and petrochemical-based plastics.

Understandably, the pull toward biofuels is strong. For US fossil fuels, such as oil and natural gas, energy applications consume more than 94%, according to figures from the US Energy Information Administration. The petrochemical industry consumes the remaining 6%, turning it into countless products, such as plastic, fibers, detergent and adhesives. In Europe, the figures are similar. The petrochemical sector consumes about 8–10% of fossil resources, according to European Bioplastics, a Berlin-based industry organization. The profit margins on chemical production tend to be larger than those for fuels, but the demand for fuel is so massive that the market dwarfs that of chemicals. Because the petroleum-based fuel market is so large, just capturing a small fraction with biofuels represents an irresistible lure for many entrepreneurs.

Designing a technical route to a biofuel product can be a bit simpler than designing one to a chemical or polymer for a biobased product. "The question 'What chemical should we make?' is a really difficult question to ask," says Joe Bozell, a biomass chemistry researcher at the University of Tennessee in Knoxville. "The number of chemicals you can make is in the ten thousands. So it's kind of off-putting to see that huge list and try to decide which route to take when there are only two or three fuels you need to choose from." Bozell says he's been involved in half-a-dozen attempts by entrepreneurs to identify a 'best list' of structures they can make.

Box 1 What is a biobased product?

Biobased products (colloquially referred to as biomaterials) are industrial or commercial materials composed of biological feedstocks such as agricultural crops, grasses, forest residues, plant oils or other biomass. The feedstocks are broken down into sugars and converted into various building block substances, such as lactic acid. From there, the substances can be converted into countless secondary chemicals, polymers and intermediates, which often have high profit margins and can be sold on their own, or fashioned into consumer products such as antifreeze, car seats, carpets, food packaging, paints, cosmetics, adhesives and detergents. Plastic, or 'bioplastic' as it is known when it originates from biomass, is one of the largest applications. Fuel can also be considered a biobased product, but the term generally refers to nonfuel products.

Biobased products generally offer different properties from their petrochemical competitors because their compositions are not equivalent. Bioplastics sometimes are less heat resistant, for example. Some biobased products can also offer desirable properties that petrochemical products cannot, and finding markets for such properties is a key to commercialization. *EW*

"Picking the best one or best ten that are going to be commercially successful is pretty hard to do," he says. The DOE in 2004 published a 'top 12' list of building block chemicals and descriptions of the needed technological routes[2].

Another deterrent to getting into the biomaterials products industry is the technical sophistication needed to make products that meet customer specifications. Consumers' expectations of fuels are pretty simple. But when it comes to products such as plastic, customers expect all sorts of properties: brittle, elastic, freeze tolerant, heat resistant.

Minnetonka, Minnesota–based Natureworks, a spin-out of Cargill of Minneapolis, makes polylactic acid (PLA) from corn and has found success selling the polymer as a product for packaging and fibers. Its properties compete with petrochemical products such as nylon and polyethylene. But finding this niche wasn't easy. "They have struggled," says Gene Petersen, a scientist and project officer at the DOE. "Natureworks has been working on PLA since the late 1990s, and they're just now starting to see real potential." The company opened a biobased polymer plant in 2002—the world's first.

Before a biomaterials products industry can mature, it just may have to wait for biofuels to establish some infrastructure, such as a distribution and harvesting system for lignocellulosic feedstocks. "The infrastructure in place to drill oil wells and transport oil—that's all in place to provide fuel," says Pangborn. "If those huge fixed costs hadn't been able to be spread over the 94% of that product that goes to fuel, those fixed costs would have been far too large for the petrochemical industry. I can see similar effects with regard to biofuels and bioplastics."

The lack of attention on biomaterials may also be a result of government philosophies toward oil. "EU policy makers and member states have not been focused on opportunities in bioplastics and other biobased materials," says Harald Kaeb, chairman of European Bioplastics.

"It is clear that the funding is going toward biofuels," adds Camille Burel, a manager of the industrial biotech section at EuropaBio in Brussels. "The key reasons are the targets set at the European level," she says. The European Union (EU) in 2003 set a target of replacing 5.75% of transportation fuel with biofuels by 2010, and in 2007 set a goal of 10% biofuels by 2020. "There has been a wave of investment in biofuels because of these targets," she says.

In 2007, the White House set the fairly lofty goal of reducing gasoline consumption by 20% in ten years. The DOE, charged with helping achieve that goal, measures success, in part, by the amount of oil displaced with biomass, says DOE's Petersen. Given that set of metrics, it makes more sense to focus on biofuels rather than biobased products, he says. "As an agency and country, we get what we measure and right now, $4-a-gallon gas is a big target that biofuels can impact," he says. "Biobased products don't do much to change that cost, if any."

The case for biomaterials

With or without government support, not everyone in the biomaterials world is waiting for biofuels to do their technological dirty work. Plastic is the largest sector of the global petrochemicals industry and bioplastics comprise 10–15% of it—a market share that will increase to 25–30% by 2020, according to a study released in January by the Helmut Kaiser Consultancy in Zurich.

There are signs that this estimated increase may become a reality. Cambridge, Massachusetts–based Metabolix, a biobased polymer manufacturer, is expected to begin operations of its commercial-scale plant in late 2008. Cereplast, based in Hawthorne, California, develops starch-based and hybrid resins for use in plastic products and is building a new facility in Seymour, Indiana, with a planned capacity of 500 million pounds—the largest of its kind.

Several companies outside of the US have invested in PLA plants, and as many as four new plants will likely come online in the next 18–24 months, estimates Frederic Scheer, CEO of Cereplast, which buys PLA from Natureworks to make resins for plastics.

There are smaller signs, too. Five biomaterials startups joined BIO in the first half of 2008, according to BIO's Carr (**Table 1**). In March, Vancouver-based Lignol Energy, a cellulosic biofuels company, announced the launch of its specialty chemicals division. BASF, a Ludwigshafen, Germany–based chemical giant, has partnered with St. Louis–based Monsanto to develop more drought-tolerant, higher-yield crops. The company has also commercialized a hybrid plastic that is composed of a blend of renewable and petrochemical three new projects in biobased products in the last year.

In some ways, biomaterial makers are already capitalizing on the successes of the biofuels industry. Glycerin, for instance, which is an overabundant byproduct of biodiesel (ethyl/methyl ester) production, can be converted by microbial fermentation into useful polymers, such as polyhydroxyalkanoate (PHA), which is used to make insulation and carpeting.

As biodiesel production has increased dramatically in the past few years, a glut of byproduct glycerin has flooded the market. About 45 million gallons of crude glycerin were produced in the US in 2007, and the figure is higher in Europe. "The glycerol situation is a difficult one because the amount being produced is more than the market can bear—especially the crude glycerin produced," says Rick Ashby, a scientist at the US Department of Agriculture's Agricultural Research Service in Wyndmoor, Pennsylvania. "Companies are paying people to take it away," he says.

Cambridge, Massachusetts–based Flagship Ventures will launch this year a startup called Joule Biotechnologies that will develop a conversion technology to turn multiple waste products, including glycerin, into glucose, chemicals or "whatever the market or customer needs," says David Berry, a principal at Flagship.

Some companies are using fuels as feedstocks to make biomaterials. Mazda Motor Corporation announced in June that it would partner with Hiroshima University, both in Hiroshima, Japan, to convert lignocellulosic ethanol into ethylene and polyethylene, which are traditionally petrochemical products derived from natural gas.

"That type of technology—where one takes a renewable resources–based product and makes [it] into exactly polyethylene or exactly polypropylene or exactly whatever—I think those have

Table 1 Selected start-ups in the biomaterials sector

Company (location)	Technology/product
Draths (Okemos, Michigan)	Develops routes to benzene derivatives using synthetic biology and organic synthesis
Elevance Renewable Sciences (Lisle, Illinois)	Converts plant-based oils into specialty chemicals
Heliose (Chicago)	Converts waste glycerin from biodiesel production into high-value compounds
Segetis (Golden Valley, Minnesota)	Develops proprietary monomers from renewable feedstocks for production of polymers, functional prepolymers and specialty chemicals
SPC Biotech Pvt. Ltd. (Secunderabad, India)	Manufactures PLA for applications in plastics

PLA, polylactic acid.

a lot of potential," says Patrick Gruber, CEO of Gevo in Englewood, Colorado, and a founder of Natureworks. Gevo is using renewable feedstocks to make isobutanol, a product that can be converted to isobutylene, a fundamental building block in the petrochemical industry. Gruber says his company will target the fuel markets, as well as plastics and materials.

Bioplastics can be feedstocks for fuels as well. Richard Gross at the Polytechnic Institute of NYU, Brooklyn, New York, is developing a bioplastic from plant oils that breaks down into fuel when exposed to certain enzymes that are produced by genetically modified bacteria. The technique could be useful to the military: soldiers in remote areas would receive the bioplastic materials, and when they are done with them, break them down into fuel.

With some of the building blocks of biobased materials already in production, manufacturers are getting creative with applications. BioSolar, a Santa Clarita, California–based manufacturer of solar cells for photovoltaic panels, is commercializing the first biobased components for solar cells. San Francisco-based Green Toys plans to introduce a line of bioplastic toys for toddlers this fall.

And not all government initiatives have focused on aiding the biofuels market. The European Commission established a lead market initiative for biobased materials to provide a roadmap for the industry. The report provides an analysis of existing markets and policy recommendations. The French Industrial Innovation Agency in Maison-Alfort financed, in part, a biomaterials initiative called Biohub. The program is slated to receive nearly €90 ($143) million over seven years and aims to develop new chemical and biochemical processes to make products from renewable raw materials.

Green movement

The current food crisis has stirred some negative press for bioplastics, which often get lumped together with biofuels when it comes to food-versus-fuel debates. After a widely circulated news report published in April in the UK's *Guardian* newspaper, many media outlets described bioplastics as the other culprit—second to biofuels—in the global food crisis and a contributor to greenhouse gases.

"The negative mood we have toward biofuels can in some ways influence the mood toward bioplastics," says Catia Bastioli, CEO of Novamont, a bioplastics manufacturer in Novara, Italy. "But this is an idea that is flawed." The amount of agricultural feedstocks used to make bioplastics is miniscule compared with that of biofuels, she says. Furthermore, bioplastics should not be seen as a way to replace traditional plastic, but rather as a way to fill in the market gaps with product properties different from those of traditional plastic, she says. "Bioplastics should be used when needed, with tailor-made properties."

What happens to waste bioplastic has also brought negative press. Most bioplastic can't be recycled with petroleum-based plastic. Some bioplastic is biodegradable or compostable, but much of it ends up in landfills where it slowly breaks down without the presence of oxygen and releases methane gas. "If bioplastic is not biodegradable, it's more damaging than it is an improvement," says Bastioli.

That's not to say the green movement's effects on the industry are all negative. According to an April survey sponsored partially by Dupont, nearly seven out of ten consumers are willing to pay more for products made with renewable resources. Calling a product 'green' is a marketing strategy in itself, as biomaterials manufacturers know well.

Anecdotally, however, experts have their doubts about consumers' willingness to pay more for green. "There are a number of examples where people in some geographies for some products will pay a premium, but that premium is always going to be finite," says Pangborn, citing as an example Toyota's (Tokyo) first commercial hybrid electric vehicle. "It's like a Prius," he says. "A certain number of people will pay extra for a Prius. The question is: how many people?"

Biobased packaging is also a hard sell to customers who are buying the product, rather than the packaging. "The best you can hope for is that the packaging creates a little good will [toward the company]," says Gruber at Gevo. "But it won't make the purchasing decision."

The green movement may have a greater effect on the biomaterials market if it influences the purchasing decisions of manufacturers and chain stores that are trying to improve their corporate images. Wal-Mart began in late 2005 switching to bioplastic packaging for its fruits and vegetables—a move that was well-covered in the media.

Regardless of the public's perception, life-cycle assessments suggest that overall, bioplastics require less energy and reduce environmental impact when compared with petroleum-based polymers[3]. Bioplastics also avoid toxicity issues. Canada's national health department is on track to ban the use of the petrochemical bisphenol-A in baby bottles, after concerns were raised over its health effects on humans. "That creates opportunities for renewable resources–based products and the reason is that things like PLA don't have impurities like that at all. You simply don't have those kinds of toxicities," says Gruber.

The industry may not have to rely on the world's purchasing habits for a boost. Green regulations and taxes proposed and implemented in Europe and in some US cities encourage the use of bioplastic. In April the German government passed a law that exempted from its mandatory deposit program bioplastic made of more than 75% renewable materials. Paris and San Francisco in 2007 banned nonbiodegradable plastic bags.

In Thailand, the country's Science and Technology Ministry's National Innovation Agency (NIA) plans to create an integrated complex of bioplastics industries. But in the US, biomaterials companies will just have to integrate themselves. And if they are smart, they'll use the wave of attention on the biofuel industry to their advantage.

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