"Green plastics" as substitutes for petrochemistry

PUre climate protection

Effective climate protection is a top priority for scientists worldwide. Researchers at Bayer MaterialScience are also doing their bit, for example by searching for alternatives to petrochemistry. Their idea is to turn renewable raw materials into the biological basis for high-quality plastics. Using vegetable oils or vegetable waste from paper and biodiesel production, they want to manufacture organic mattresses, car seats and "green" shoe soles.

Trendscouts are always a step ahead of the times. They know today what will be popular tomorrow. Dr. Ralf Weberskirch, a chemist at Bayer MaterialScience, is a trend researcher of this kind, one who explores the world looking for renewable raw materials. Currently he is looking for plant substances that could become the future building blocks of polyurethanes or polycarbonates, the two largest groups of plastics manufactured by Bayer MaterialScience. Until now, chemicals made from petroleum have been the basis of most plastics, but this fossil raw material will become increasingly scarce and expensive as time goes on. "Renewable resources offer us an ideal alternative for expanding our range of raw materials," says Weberskirch. In addition, more and more customers are showing interest in biobased products. Be it floor coverings, refrigerators, athletic shoes or foam mattresses, an organic origin lends any product a hint of natural identity.

However, Weberskirch and his co-workers face a major challenge, because vegetable starting materials such as sugar molecules and vegetable oils differ significantly from the typical petrochemicals used in polymers. Moreover, the end products in some cases therefore also display altered properties.

Renewable raw materials for polyol molecule chains

"The resulting molecules are similar, but not identical," Weberskirch explains. On behalf of Bayer MaterialScience, material specialists at universities and research institutes study how "green"

Focus on climate: The Bayer Climate Program photomontage shows the EcoCommercial Building (photo left, top left), the Bayer Climate Check for production plants (top right), stress-resistant plants (bottom left) and projects to use rapeseed oil plants for biofuels. Renewable raw materials as the basis for Bayer plastics also contribute to climate protection (photo right). These "green" polymers are already being used in floor coverings, refrigerators, and potentially also plastic soles for athletic shoes like the ones being inspected by Dr. Hartmut Nefzger (left) and Dr. Henricus Peerlings.

polymers can be brought to the same high standards as conventional plastics in terms of strength, water permeability and UV resistance.

The Bayer researcher's current focus is polyurethanes (PU). Making this plastic involves a reaction between two types of molecules: polyols and polyisocyanates. Depending on the elementary compound, the reaction produces either linear chains or highly cross-linked polymers. "Polyols in particular are conducive to incorporating more renewable raw materials," Weberskirch says, pointing out that vegetable inputs, like glycerin or sugar, have already been an important part of polyurethane chemistry for many years.

Car seats and mattresses from castor oil plant seeds

For "green" polymers to live up to their name and consume fewer resources in production than petroleum-based plastics, the vegetable substances must enter the process in a virtually unchanged state, because extensive chemical pretreatment would quickly negate the otherwise good ecological rating of "green" plastics, explains Dr. Klaus Lorenz, polyether process engineer at Bayer MaterialScience. For this reason, scientists are continuously on the lookout for suitable vegetable raw materials and new processes.

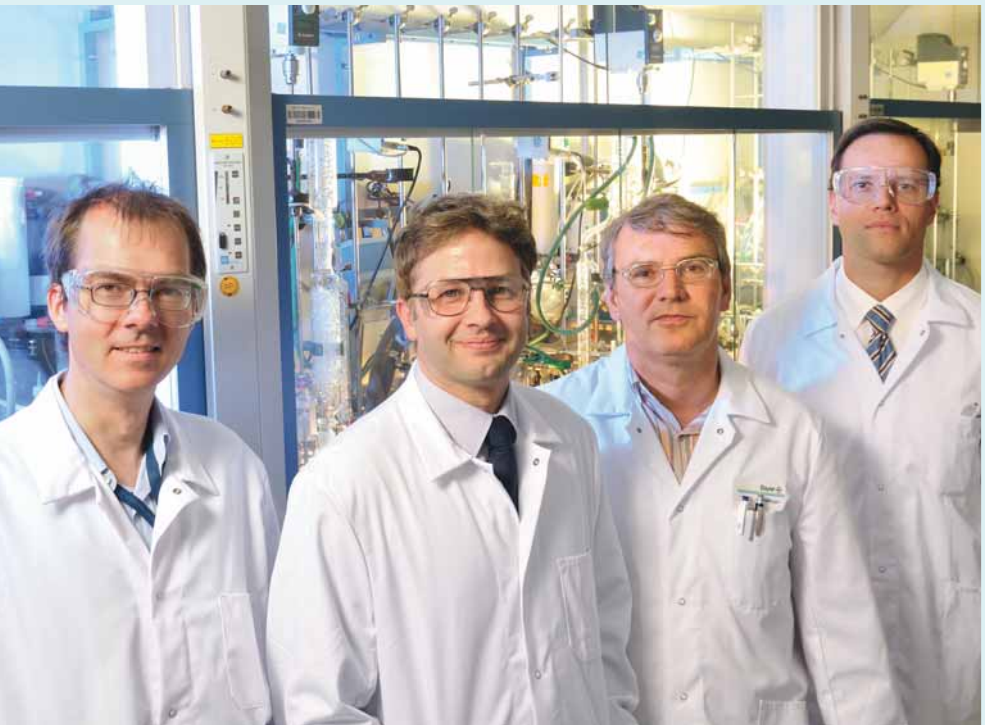
In addition to sugar and glycerin, castor oil has been another very promising basic constituent for polyurethane production, because it already displays the required chemical properties. For many years now, Bayer has been using this vegetable oil, derived from the seeds of the castor oil plant (Latin: Ricinus communis), to manufacture polyurethanes for car seats, floor coverings and high-quality mattresses. Lorenz and his co-workers have now developed an innovative process for converting other vegetable oils, such as rapeseed and soy oil, into polyols with customized properties without any further treatment. The resulting foams, used in building insulation and other applications, contain between ten and 15 percent renewable raw materials. They are therefore categorized as "biobased items" according to the criteria defined by the U.S. government, for example. Some of these "green" rigid foams even boast better material properties than conventional products, since the vegetable oils improve compatibility with the blowing agent pentane, used to foam the plastics.

Polyurethane: sugar and cellulose instead of oil

Thanks to the activities of Weberskirch and his co-workers, Bayer researchers are even a step ahead of general industry developments when it comes to a specific type of polyol: the chemist discovered that two basic substances for what are known as "polyester polyols" will soon be available in large quantities from a biotechnology process.

The first is 1,3-propanediol, obtained in bio-reactors either from glycerin (a waste product of biodiesel production) or cornstarch. The second is succinic acid, which is produced by bacteria from sugar or cellulose and can serve as

Polymer researchers at Bayer MaterialScience: Dr. Henricus Peerlings, Dr. Hartmut Nefzger, Dr. Ralf Weberskirch and Dr. Klaus Lorenz (right to left) have developed a process that allows rapeseed and soy oil to be converted into polyols with customized properties without any further treatment. The resultant foams are used in applications such as heat insulating boards in floors (center photo) and to insulate entire buildings like the ultra-low-energy house in Munich (right).



a "platform chemical" to manufacture a number of starting materials for plastics. Succinic acid further can be incorporated into polyurethanes to replace adipic acid, a petroleum product. Says Weberskirch, "These substances differ with regard to only two methylene groups." A team of plastics specialists headed by Dr. Hartmut Nefzger and Dr. Henricus Peerlings in the Product Research department of Bayer MaterialScience is still experimenting with petrochemical succinic acid to optimize the material properties of the resulting polyurethane. Once organic succinic acid is available on the market in the near future, Bayer MaterialScience will be in a position to immediately launch production. Customers are already interested in organic polyurethane: "Leading athletic footwear manufacturers want to make biobased shoe soles with it," Nefzger and Peerlings confirm.

"Green" polyols are probably only the beginning of a major new trend. Bayer MaterialScience would like to work together with interested customers in this field. However, several petrochemicals cannot yet be replaced by renewable raw materials, above all aromatic hydrocarbons such as benzene, toluene and phenol.

Lignin: an inexhaustable source of raw material for biopolymers

These substance groups are the origin of both aromatic isocyanates, the second basic building block of polyurethane, and polycarbonates, the second substance class produced by Bayer MaterialScience. "No process exists at present that would enable us to produce aromatic compounds from renewable raw materials," Weberskirch explains. But the far-sighted chemist thinks in larger time dimensions: he currently is having a feasibility study done to determine whether lignin would be suitable for producing organic aromatic compounds. A substance that gives wood structural support, lignin is a waste product of the paper industry that largely goes unused. After cellulose, it is the most abundant biopolymer on

Interview

"No competition with food"

Dr. Herbert Vogel is a professor of chemical engineering at Darmstadt University of Technology. *research* spoke with him about the challenge of replacing petrochemicals with renewable raw materials and the conflict between biofuel and food.

How do renewable raw materials, as a basis for chemical products, benefit the environment?
Renewable raw materials contribute to environmental and climate protection because they are CO_2 neutral. They also offer other advantages: they create jobs on a local level and reduce our dependence on petroleum. But we cannot simply convert everything to biomass in one day.

Biofuels have become a target of criticism because of the competition with food. Do problems of this kind also arise when polymers are increasingly manufactured from renewable raw materials?
No, not at all. The fuel market is ten times larger than the chemical market. The chemical industry uses only five to seven percent of available petroleum. The rest goes on transportation and heating. In other words, chemical products do not compete with food; the quantities are simply too small.

Can the same plastics we use today be made from renewable raw materials?
Any substance could theoretically be made from renewable raw materials. The problem is the price. Molecules exist that can be made from petroleum or biomass with roughly the same work. For reasons of efficiency, some molecules are obtained only from petroleum, others only from biomass. Substances will also exist that can be replaced one-to-one, such as acrylates. Acrylic acid is manufactured today from petroleum. However, it can also be made from glycerin, and from oils and fats or from carbohydrates.

How do biorefineries differ from petrochemical facilities?
Biorefineries are much more complex. Petroleum comprises hydrocarbons, which all display a similar structure. In contrast, biomass is a mixture of highly complex molecules, such as carbohydrates, proteins, oils and fats. They require significantly more sophisticated processes. But the philosophy is the same: you collect the raw materials at one location, convert them by means of suitable chemical strategies into liquids and gases, and then build a production chain.

Climate protection in action: The Bayer Climate Program

With its achievements in climate protection, Bayer is already recognized internationally as the best in its class and a leading company in the industry. In November 2007, the Bayer Group combined its climate activities in a company-wide climate program, in which it not only defines ambitious targets for its own production facilities, but also commits to investing in the development of climate-friendly products and processing methods. Bayer has already initiated a number of "lighthouse projects" to promote pioneering solutions for climate protection, and for coping with the consequences of climate change:

EcoCommercial Building
- *A concept for energy-optimized industrial and office buildings, adaptable to all climate zones*
- *Targets the zero emissions building*
- *Combines Bayer materials with innovative technologies*
- *As an open forum for amassing expertise, it stimulates dialogue among all stakeholders in the building industry*

Sustainable biofuels
- *Reduce potential conflicts between climate protection, biodiversity and food production*
- *Aim to increase yields (e. g. InVigor® hybrid seed)*
- *Are planted in soils that are unsuitable for food production (jatropha research project)*

Development of stress-tolerant crops (see also the "Title story" starting on page 26)
- *Improves tolerance to stress factors, such as heat, drought, cold and soil salinity*
- *Strengthens plants and yields through the use of biotechnology*
- *Reduces the effects of climate stress through the use of conventional crop protection active ingredients (e. g. Confidor® Stress Shield)*

Bayer Climate Check
- *Expands efficiency calculations to include comprehensive, climate-related decision-making criteria*
- *Describes the systematic analysis of production and production-related processes*
- *Systematically incorporates emissions in upstream process flows*
- *Certified by TÜV Süd, one of the world's leading auditing organizations in the field of climate protection*

Earth, making up 25 to 30 percent of all non-fossil organic carbon compounds. In other words, lignin would be a virtually inexhaustible resource.

Huge investment in climate-related research

These examples make clear Bayer's commitment in this regard. "Bayer takes climate change very seriously as both an ecological and economic challenge," emphasizes Dr. Wolfgang Grosse Entrup, Head of Environment & Sustainability for the Bayer Group and chair of the Bayer Climate Program. Bayer has already significantly reduced its own greenhouse gas emissions: direct and indirect greenhouse gas emissions were cut by 37 percent between 1990 and 2007.

Bayer has no intention of stopping there, however. On the contrary, it has set itself very ambitious targets in a new company-wide climate strategy. For example, Bayer plans to invest €1 billion between 2008 and 2010 in climate-related research and development, as well as in specific projects, ranging from the development and marketing of climate-friendly products, to the construction of energy-saving production facilities. The previous guidelines for the "Ecological Assessment of New Investments" will be expanded to include climate protection criteria.

www.climate.bayer.com
This website contains further information on the Bayer Climate Program and podcasts on the topic of climate.

www.nachwachsende-rohstoffe.de
The Agency for Renewable Resources founded by the German Government provides extensive information on this topic.

Lighter and more ecological: automotive engineers are increasingly turning to Mother Nature's construction kit and using materials based on renewable raw materials for seats and other plastic parts.