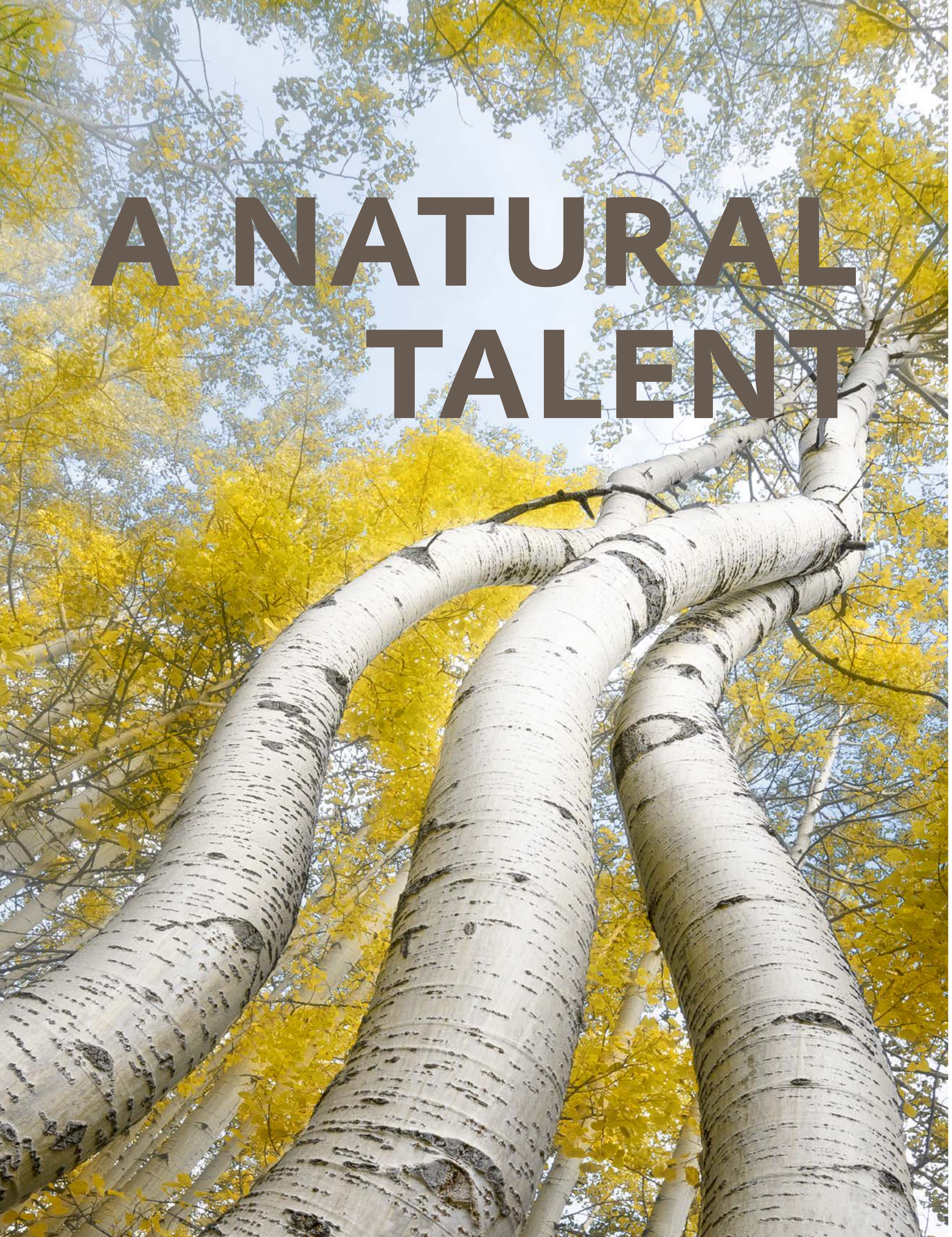


A NATURAL TALENT

“We turn a seemingly worthless material into a valuable one”

FRANK WEINELT, HEAD OF PRODUCT AND PROCESS DEVELOPMENT AT THE HIGH PERFORMANCE POLYMERS BUSINESS LINE OF EVONIK

For a long time, lignin was considered a waste product of cellulose production. This wood component was mainly burnt to generate energy. However, this natural raw material holds hidden talents—as a component of high performance polymers.

TEXT **NICOLAS GARZ**

Renewable raw material: The natural polymer lignin is a component of wood and accumulates in large amounts during the production of cellulose

For most people, this viscous brown liquid that accumulates in large amounts at cellulose factories looks like waste. However, someone like chemist Dr. Frank Weinelt considers it to be a promising candidate for the development of high performance polymers. Experience has given Weinelt a good eye for a material’s potential. As Head of Product and Process Development at the High Performance Polymers business line of Evonik, Weinelt is always looking for raw materials that can be used to produce components for plastics. His goal is to discover natural alternatives to crude oil, which has served as the basis for petrochemical products for decades.

One of Weinelt’s most promising natural talents is this brown liquid. It consists of lignin, which is a component of wood. This natural polymer is a waste product that is created during the production of cellulose, which is used, for example, for writing paper and toilet paper. Each year, the paper industry generates more than 50 million tons of lignin worldwide. “Lignin is a renewable resource and inexpensive,” says Weinelt enthusiastically. “Nature supplies this material in large amounts for free.”

However, because it biodegrades very slowly, lignin has, to date, been mainly dried and burnt to generate electricity. But the polymer specialists at Evonik consider it to have much more potential. “Lignin is a sustainable raw material that is well-suited for the production of interesting monomers,” says Weinelt. “For example, it can be used to create substituted adipic acid, which is a possible component of high performance polymers. It hasn’t been available to us previously and probably can’t be extracted from petrochemical raw materials very easily.”

A NEW SOURCE FOR HIGH-TECH MATERIALS

Weinelt’s search began in 2017. Back then, Weinelt regularly met Siegfried Waldvogel, a professor at the Johannes Gutenberg University in Mainz and an expert in electrochemistry. Their discussions initially revolved around the renaissance of electrolysis, which is being increasingly used as a result of the big drop in the cost of renewable sources of energy. This method is also employed for the production of basic chemicals. During their meetings at the Marl Chemical Park, the two researchers gradually came up with the idea of using electrolysis to convert the biopolymer lignin into monomers, which can then be processed further into high performance polymers. “That way, we turn a seemingly worthless material into a valuable one,” explains Weinelt.

Electrolysis is suitable for this purpose for a number of reasons: “For one thing, the electricity is supplied completely by renewable energy sources that are now readily available,” says Waldvogel. Moreover, electrolysis doesn’t create any reagent waste as a by-product, as is the case with traditional organic processes.” →

One project, 16 partners

The research program LIBERATE (Lignin Biorefinery Approach using Electrochemical Flow) encompasses a total of 16 partners who are working on electrochemical applications of the starting material lignin. In addition to Evonik, the consortium consists of the two chemical manufacturers Perstorp and Oxiris, seven small and midsized companies, four international research institutions including the Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung (Fraunhofer Society for the Advancement of Applied Research), and two universities. The project receives a total of around €10 million in funding.

The project was supported by the European Union's research and innovation program Horizon 2020 as part of the funding agreement No. 820735.

The researchers submitted their idea to the EU funding program Horizon 2020—and their project was accepted at the beginning of 2018. Since then, the company and the professorship have been part of the Europe-wide LIBERATE consortium (you can find more details in the information box). "LIBERATE consists of several subprojects," explains Head Coordinator Angel Manuel Valdivielso, who works at the LEITAT technological center, which is based in Barcelona. "What all of them have in common is their use of electrochemical processes to transform lignin into a variety of basic chemicals."

While Evonik and the researchers in Mainz are extracting monomers from lignin, other partners are working on the transformation of kraft lignin into the flavoring vanillin. Another part of the consortium is forging ahead with the conversion of this biopolymer into oligomer phenol derivatives (see the diagram).

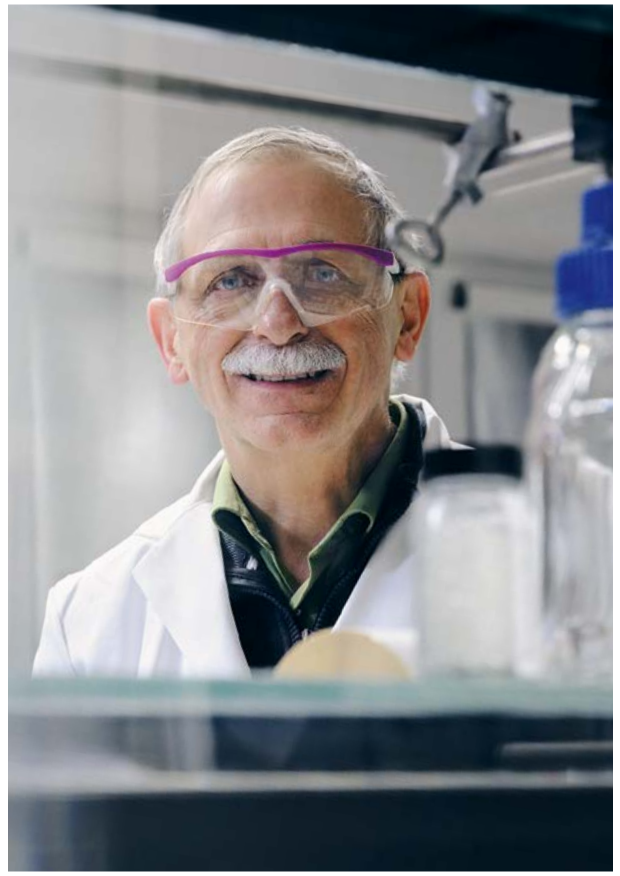
Time is of the essence. Plans call for an electrochemical pilot plant in Trondheim, Norway, in which the electrolysis of lignin can be conducted on an industrial scale, to be commissioned at the end of 2021. "This pilot plant will enable us to electrochemically produce lignin-based chemicals so efficiently that they can compete with conventional products in the future," says Valdivielso. "More and more companies all over the world are converting their production facilities to biogenic materials. As a result, there's a huge need for demonstrably sustainably produced chemicals, and it will continue to grow."

ELECTRIFIED

How the process already works on a small scale can be seen in the laboratories at Mainz University. Here Siegfried Waldvogel is working day after day with dissolved lignin, which is sent to him by cellulose manufacturers. The electrolysis of dissolved lignin proceeds in several steps. "First we dissolve out the necessary components from the polymer," says Waldvogel. In order to do that, his fellow researchers pass an electric current through the lignin, which is dissolved in a sodium hydroxide solution in a stainless-steel pressure tank.

This first step, depolymerization, creates phenols, which then react with hydrogen with the help of a catalyst. If this hydrogenation was successful, the researchers obtain wax-like cyclohexanols that are oxidized in the final step in a large glass cell. "Once the oxidation process is completed, we get biogenic dicarboxylic acids, such as substituted adipic acid, which can be used for further processing into copolymers," says Waldvogel.

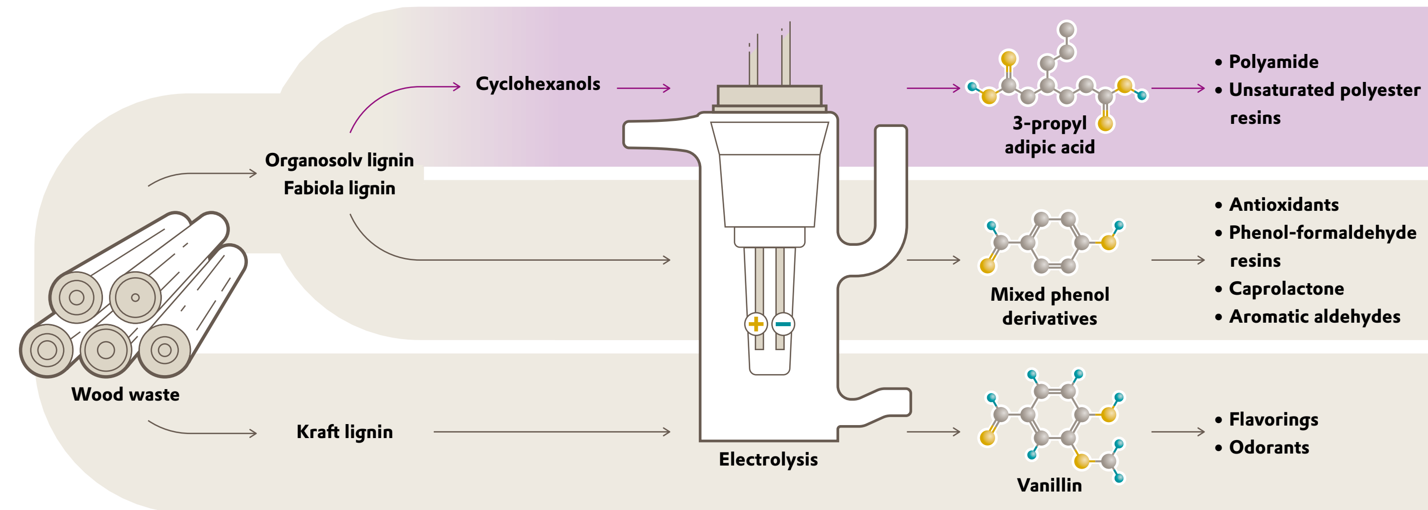
Because the lab in Mainz is conducting basic research, the amounts produced are correspondingly small. However, the electrolysis of lignin is to be conducted on a large scale in the future. "Whereas the steps needed up to the creation of cyclohexanols are performed externally, we want to carry out the oxidation into adipic acid derivatives at Evonik as soon as this is economically feasible," explains Weinelt. "The partnership with the University of Mainz provides us with the best basis for expanding our electrochemical know-how in this direction."



Evonik researcher Franz-Erich Baumann uses lignin-based adipic acid to develop polyamides

From vanillin to plastic

The LIBERATE partners work on a variety of subprojects throughout Europe: In addition to transforming lignin into high performance polymers, such as the polyamide produced by Evonik (upper path), the partners are testing techniques for converting the biopolymer into mixed phenol derivatives (center) or the flavoring vanillin (bottom).



FROM MONOMER TO COPOLYMER

The researchers are currently focusing on optimizing the process and the yield. It's all about the amount and quality of the material, because the purer the products that are supplied from Mainz are, the more the polymer specialists from Evonik in Marl can do with them. One of these specialists is Dr. Franz-Erich Baumann, who has been driving forward the development of base polymers in Marl for more than three decades. Baumann's laboratory is full of measuring equipment and apparatus in which he first checks the dicarboxylic acids that have just arrived. He has to determine if they are suitable for further processing into a copolymer. If this is the case, Baumann begins to study with which potential partners (i.e. other monomers and diamines) they can be combined. "This combination ultimately gives the polyamide its characteristic properties," says Baumann. "The lignin-based adipic acid is an important component for influencing these properties." Depending on the combination, this component can account for up to 62 percent of the entire amount of the substance.

If a compound turns out to be promising, the polycondensation begins. The starting materials are filled into a steel cylinder reactor, where they react at high temperatures and under high pressure. After a while, Baumann opens the cooled-off cylinder and uses tongs to carefully extract a thin tube that contains a solidified whitish melt: a new polyamide. "Our range of building blocks becomes a bit larger every time that we manage to do this," he says.

There are many possible uses for these materials. In the near future, lifestyle products such as sunglasses could be manufactured using polyamides made from lignin-based monomers. The same applies to components that are still made of steel and other metals, in the automotive and construction industries, for example. However, the researchers aren't that far yet.

"We have to become more efficient and intelligently pool the diverse range of know-how if we are to produce on an industrial scale," says Weinelt. To make this possible, he has now stepped up his cooperation with process technology engineers. Moreover, the polymer specialists are keeping their eyes peeled in the search for other biogenic raw materials, including those from unconventional sources. After all, experience has shown that even some murky liquids may hold a naturally talented substance.

Nicolas Garz is an editor at the Hamburg-based communications agency Bissinger+. He regularly writes about topics from the fields of research, digital technologies, and sustainability