1/2023

EVONIK
Leading Beyond Chemistry

ELEMENTS

Research. Knowledge. The future.

Getting to Work

How the chemical industry is tackling the transformation to sustainable production → p. 10

Singapore: An amino acid with an improved climate footprint → p. 22
mRNA therapies: A new envelope keeps antibodies away → p. 42

Defossilization

(The chemical) industry's efforts to become independent of fossil raw materials

The combustion of fossil raw materials releases about 35 billion tons of CO_2 into the atmosphere every year. The energy sector, industry, and transportation are responsible for most of these emissions, and thus for the advance of global climatic change. The term "decarbonization" refers to the implementation of measures to replace fossil fuels and raw materials with renewable alternatives. The aim is to minimize CO_2 emissions and pave the way toward a climate-neutral economy. The focus is on wind and solar energy as well as the use of green hydrogen, for example. In the chemical industry, the concept of decarbonization is a target of criticism. Instead, people in the industry prefer to talk about defossilization. The aim is not to replace carbon but to integrate it into a circular economy in order to reduce the extraction and combustion of fossil raw materials.

Fossil raw materials Natural carbon deposits that were formed from the remains of plants and animals and are extracted in the form of petroleum, natural gas, and coal

Climate-neutral The condition in which processes, products or activities do not increase the amount of climate-damaging gases in the atmosphere. It is achieved by reducing one's own emissions or by compensating for the remaining residual emissions

Green hydrogen is produced by the electrolysis of water using electricity from renewable sources. As a result, its production is CO_2-neutral

DEAR READERS,

The Ruhr region is regarded as Germany's biggest industrial region. And Herne is a typical city in this conurbation. It has been a home for industry for decades, with many people living in a small space. For outsiders, the boundaries between it and neighboring municipalities are barely visible. Like most of these neighboring communities, Herne was built on coal. This valuable raw material lying deep beneath the earth's surface formerly brought industry into the region.

Today carbon still plays an important role at the Evonik facility in Herne. After all, the chemical industry uses this building block of living things for many purposes. But the reorganization of industry and society away from carbon derived from fossil sources is increasingly becoming an urgent necessity and is releasing unexpected strengths and new ideas. This change is impressively visible in Herne. In the midst of this former coal mining region, the Evonik location in Herne is working to create a future that is not dependent on fossil fuels.

The biggest lever for change is in the area of energy and raw materials. If an alternative can be found to coal, natural gas, and petroleum as a basis, the chemical industry can operate without needing to reinvent its well-established production processes. In Singapore, Evonik is taking a similar approach in order to make the production of the amino acid methionine more sustainable and more efficient. You can read about its plans in the article starting on page 10. And in an interview that begins on page 26, the carbon researcher Ferdi Schüth explains how this approach can boost the project of creating a climate-neutral chemical industry.

We look at carbon from a very different angle, as a building block of living things, in our report that begins on page 42. Lipids are a key component in the successful transportation of mRNA-based active ingredients to their destination in the human body. In this area, Evonik is cooperating with the University of Mainz to create a kind of Harry Potter cloak that makes mRNA practically invisible to antibodies.

I wish you pleasant reading and new insights. If you have any questions, recommendations or criticisms, please write to me at elements@evonik.com

Jörg Wagner
Editor in Chief

All of the articles from the printed magazine, as well as additional current contents, are also available on the Internet at elements.evonik.com

Plant Manager Rainer Stahl (left) and his head of Electrical, Instrumentation, and Control Technology, Lutz Komorowski, are tinkering with dozens of projects that aim to make the Herne location more climate-friendly

DEFOSSILIZATION

10 Carbon from New Channels
In Herne, Evonik manufactures products that are important for building wind turbines, for example. Many projects are now being initiated at the plant to make the production process itself more climate-friendly. Raw materials, energy, waste—in the future, alternatives to fossil sources will take precedence in many areas

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Ferdi Schüth has worked for decades to find out how the chemical industry can successfully undergo a green transformation. As the director of the Max-Planck-Institut für Kohlenforschung, he calls for putting the raw material base and the energy supply on a sustainable foundation as soon as possible

Délicieux! Macarons are among the many delicacies that make France a paradise for gourmets

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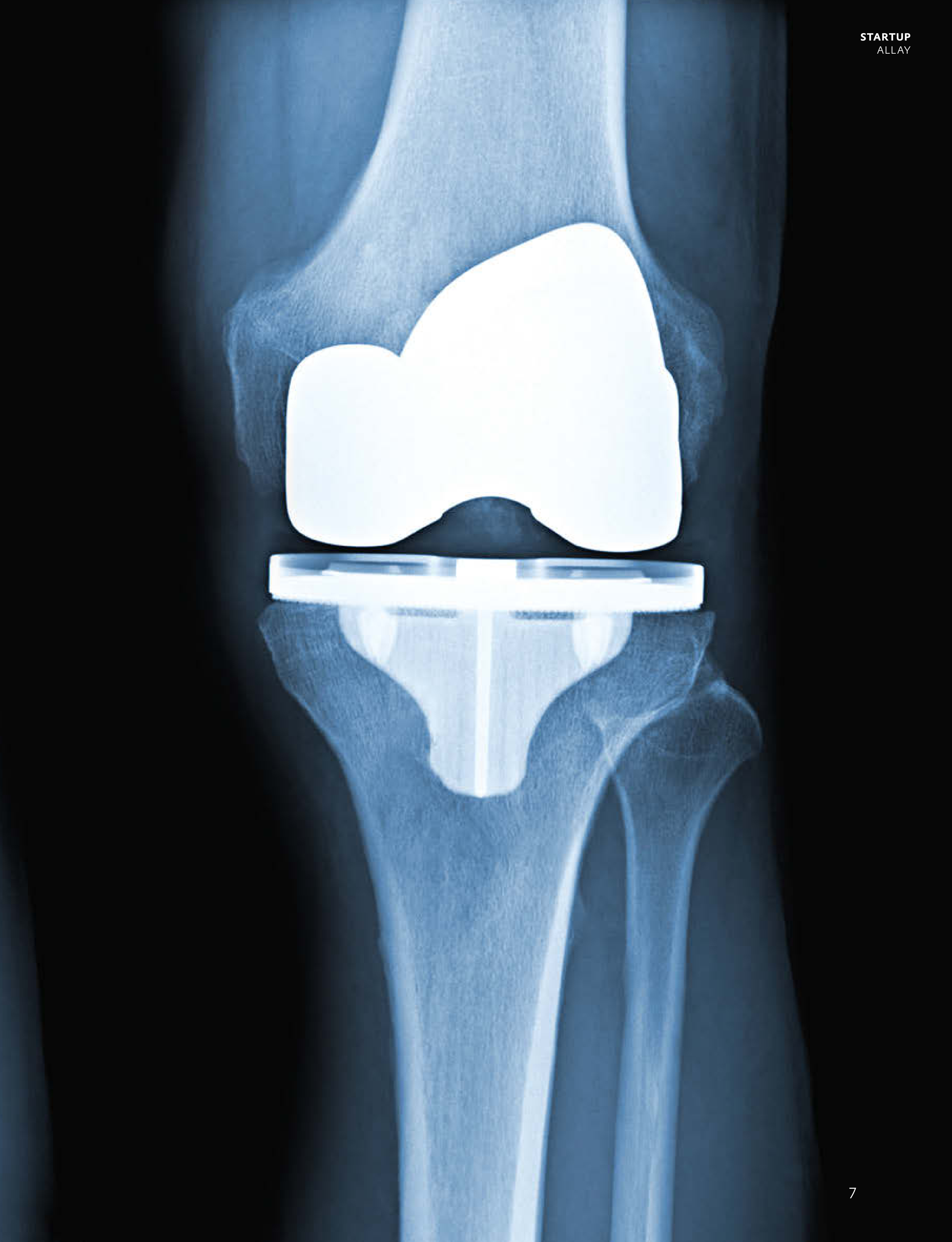
KNEE THERAPY

The insertion of an artificial knee joint is one of the most common operations worldwide. Patients often complain of discomfort for a long time after the procedure and are dependent on strong painkillers such as opioids during the acute phase as well as the subsequent recovery process. However, these painkillers have side effects, including a high risk of dependence. This is where the pain implants from the California startup Allay Therapeutics, in which Evonik has been investing since 2022, come into play. These coin-sized triangular implants are placed around the artificial knee joint at the conclusion of an operation. They don't appear in X-ray images. Thanks to the novel structure of biodegradable polymers from Evonik and the use of an opioid-free local anesthetic, the implants relieve pain for up to three weeks and can subsequently be easily metabolized by the body.



A cycle for pantyhose

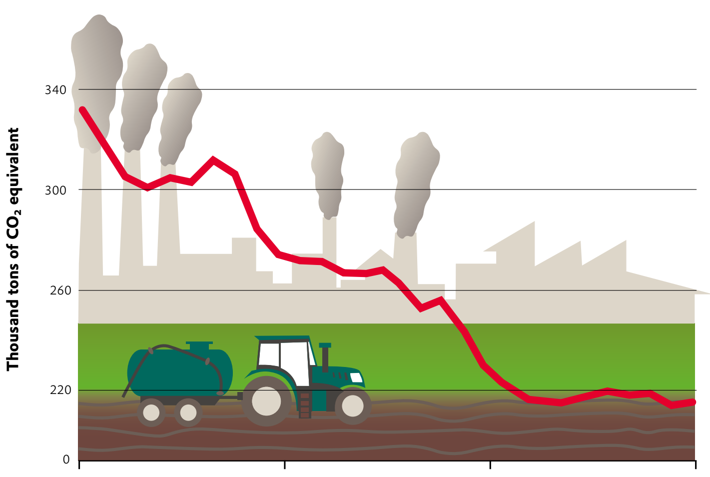
A catalyst based on rare earths enables the recycling of polyamide

Elastic, tear-resistant, and resistant to chemicals: These properties make polyamide 6 (polycaprolactam) a highly sought-after plastic for numerous products—from pantyhose in the textile industry to nets in the fishing industry. But what makes polyamide 6 so attractive in application turns out to be a serious disadvantage after use: This polymer is not biodegradable and therefore pollutes nature—polyamide fishing nets alone are responsible for ten percent of plastic waste in the oceans. In addition, the production of polyamide causes an enormous carbon footprint, as fossil raw materials and a complex process are required for the production of the starting monomer ε-caprolactam. To successfully incorporate plastic into a circular economy, researchers from the USA have developed a novel recycling process: With the help of a rare earth-based catalyst, they depolymerized polyamide 6 back into the monomer ε-caprolactam. The process works without solvents or toxic chemicals at relatively low temperatures. It thus enables efficient recovery of ε-caprolactam. As a result, it could form the basis for an environmentally friendly material cycle for polyamide.

THAT'S BETTER

Getting away from gas

Nitrous oxide emissions (N_2O) in Europe



Nitrous oxide (N_2O), or laughing gas, is an extremely climate-damaging greenhouse gas that is released primarily by nitrogenous fertilizers, by animal husbandry in agriculture, and by combustion processes, for example in industry. While N_2O emissions are skyrocketing worldwide, measurements in the European Union show that emissions are declining here. This is due in part to reduced livestock numbers and more efficient use of fertilizers in agriculture. More resource-efficient industrial processes have also helped to reduce emissions.

Source: The World Bank

1.2

BILLION

dollars in revenue are estimated to be generated from edible insects worldwide this year. Grasshoppers, mealworms, and crickets play an increasing role in the sustainable nutrition of the world's growing population. Compared to meat, their production is significantly more resource-efficient. In addition, insects are full of important nutrients.

SUPERCAPACITORS…

…are power storage devices that can supplement or partially replace rechargeable batteries. They quickly provide large amounts of electricity—but only for a short period of time. To enable a longer service life, researchers from China and the USA have developed a novel process: An electrode made of porous carbon materials holds chlorine gas after it is immersed in a saline solution that serves as an electrolyte. During charging, electrons are transferred to the chlorine atoms, causing them to dissolve as chloride ions in the liquid. This process is reversed during discharging and chlorine gas is formed again. Thus the energy density of the supercapacitor increases dramatically while the power density remains the same.

Cool rooms thanks to quantum computers

A new type of window film lowers the indoor temperature without using energy

Climate change means that buildings have to be cooled more frequently and more intensively, and that consumes a lot of energy. New technologies start where a large part of the heat comes from: the window. Rooms heat up because of the invisible ultraviolet and near-infrared light of the sun. It passes through the window glass, bringing the heat inside. But what if the light didn't get through the windows in the first place? A new coating technique developed by a team of researchers from the USA and Korea aims to answer this question. The basis for their novel transparent radiative cooler (TRC) is thin layers of materials such as silicon nitride, aluminum oxide, and titanium dioxide—as well as a quantum computer. With this, the researchers ran through numerous scenarios to figure out the optimal type and combination of material layers based on machine learning. The result was a window film that repels UV and near-infrared light, helping to save energy when cooling buildings. At the same time, the coating is transparent and allows visible light to pass through.

PEOPLE & VISIONS

"I have developed a new material that serves as the basis for more robust fibers"

THE PERSON

Dr. Boris Marx grew up in the Belgian Eifel region and has always been very attached to nature. After completing a degree in mechatronics, the scientist earned his doctorate at the University of Hohenheim. His dissertation focused on reducing soil compaction in arable farming to relieve the environment. The desire to protect the natural environment led Marx to his current job at Faserinstitut Bremen (FIBRE). Here he conducts research into alternatives for petroleum-based plastics in the field of biopolymers. Above all, he is interested in technical fibers. "I'm also motivated in my work by my children, because I want them to benefit from a more sustainable world," he says.

THE VISION

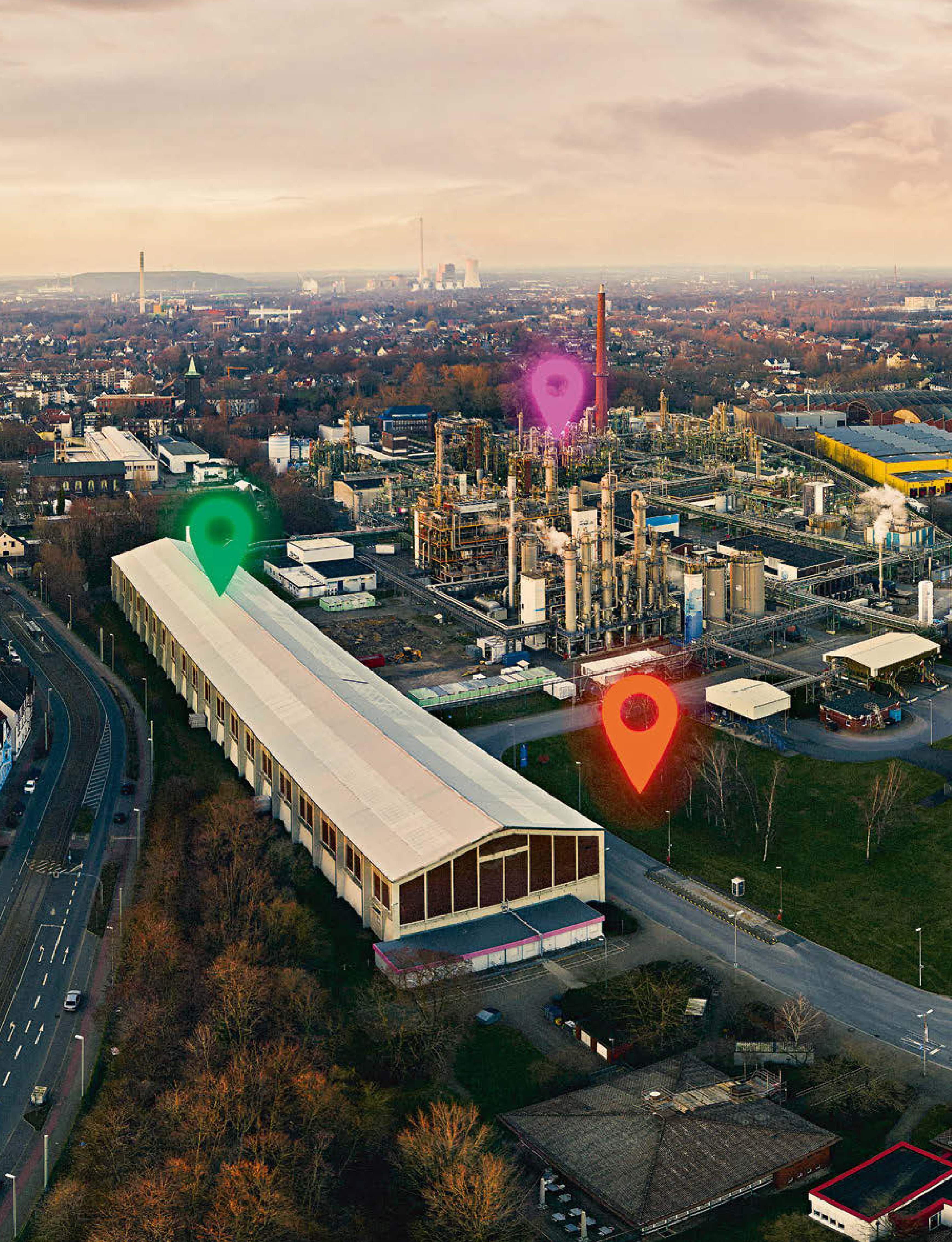
From sofa cushions to trampolines, technical fibers are everywhere. They are mostly based on petroleum, but could be produced in a more environmentally friendly way from biopolymers such as polylactic acid (PLA). PLA has so far only been suitable for simple structures such as textile fibers. This is where Marx's research comes into play. "I have developed a new material that serves as the basis for more robust fibers," he says. Using a special compounding process, the scientist modified two PLA starting materials into a stereocomplex PLA blend in powder form. Marx's material can also be used to sustainably develop technical fibers for more complex industries such as aeronautics or medicine, thus further replacing conventional plastics.

GOOD QUESTION

Professor Faisal, can smart clothing cure diseases?

Yes, if you go about it the right way. We use artificial intelligence to diagnose and monitor neurological diseases. This affects people who are physically impaired by diseases such as multiple sclerosis or a stroke. Sensors attached to clothing, called wearables, measure the patients' movement patterns, for example the speed of their movements. The crucial role is played by a new algorithm that analyzes these patterns extremely precisely and enables 24-hour detection of the health status of a sick person. On this basis, previously unnoticed changes in behavior can also be registered. The AI understands the observed patterns so well that it can be used to derive therapies tailored to individual patients, disease prognoses, and even genetic markers.

Prof. Aldo Faisal holds the professorship of Digital Health at the University of Bayreuth and is a professor at Imperial College in London



Chemical products have been manufactured at Evonik's current site in Herne, Germany, for almost 100 years—with the help of fossil raw materials and fuels. In the future, new technologies will enable greater use of sustainable alternatives at the points marked in color

A PLANT IN TRANSI-TION

There are many ways to make chemical production sustainable. One of these ways is to convert not only the big reactors but also just about everything around them. Managing raw materials, energy or waste flows smartly can be the key to a green future. Evonik wants to demonstrate this with its Herne Green Deal. A site visit

TEXT **TOM RADEMACHER**

The roller shutter rattles up, Dr. Rainer Stahl spreads his arms wide and lets his gaze wander through the hall. “We have a lot of space here!” he exclaims. The huge hall extends 100 meters toward the left and right. In the past, fertilizer was stored here—thousands of cubic meters of special salts. But that was decades ago. Now, spare parts and some old equipment are stored in the hall’s more than half a hectare of space. “We can free up these areas,” says Stahl, who has big plans. Green hydrogen for the chemical plant will be produced in the hall. Construction of the electrolyzer will start this year.

Rainer Stahl holds a doctorate in chemistry and has been the head of Evonik’s Herne site for three years. The plant in the heart of the Ruhr region has a long and eventful history, and the structures have grown over several generations. In the past, hard coal was mined here deep underground. Today, complex chemicals are produced for the world market, with manufacturing processes that are sophisticated down to the smallest detail. Things are to remain that way, but a number of measures have to be taken to ensure this is the case. After all, it is not just customers and governments who demand sustainable production. Evonik itself has made innovation and sustainability its strategic principles.

To make Evonik’s Herne site climate-neutral and bring it into the circular economy, many things have to mesh together. The prospects here are particularly promising. “We don’t have to fundamentally change our chemical processes,” Stahl says. “All it takes is an adjustment of raw materials and energy.” Moreover, economic and environmental interests are going hand in hand. “We are cutting costs and hedging raw material supplies and energy requirements more strongly against risks,” adds Lutz Komorowski, the head of Electrical, Instrumentation, and Control Technology. “In addition, the technologies that are available today are more sustainable and future-proof.”

The plan is comprehensive and aims to successively replace fossil sources of carbon and close material and energy cycles. With its holistic concept, the Herne plant could become a showcase for a defossilized chemical industry. Evonik calls it the Herne Green Deal.

PART OF THE ENERGY TRANSITION

The substance around which everything revolves in Herne is called isophorone. This molecule consists of a simple ring made of hydrogen, carbon, and oxygen. Evonik has been producing it from acetone in Herne for many years. In fact, this industrial process originated in Herne. In the 1960s, isophorone was sold primarily as a solvent. Today it is a much sought-after precursor product for the chemical industry.

However, Evonik’s biggest business is with more complex downstream products. For this purpose, functional groups are added step by step to the isophorone molecule in the I-chains and T-chains. This produces isophorone diamine, for example, which wind turbine manufacturers need to cure special epoxy resins. Evonik is one of the world’s most important manufacturers, and Herne is home to three of the Group’s five I-chains.

“We produce chemicals for a rapidly growing global market, and with our products we are part of the green energy transition,” says Lutz Komorowski, who is Stahl’s right-hand man when it comes to technological matters. The two men are a well-rehearsed duo who like to joke together and verbally pass the ball to each other. Komorowski has been in Herne for nine years. Stahl came here three years ago as the site manager; before

A case for two: Together with the head of Electrical, Instrumentation, and Control Technology, Lutz Komorowski (left), Plant Manager Rainer Stahl is driving forward the transformation of the Herne site

that he was responsible for production and technology at the Evonik location in Shanghai. The two are united by their technological background and the irrepressible fun they have in constantly questioning established processes. They also like to tinker with tricky technology questions after work, and Herne has plenty of such questions to offer.

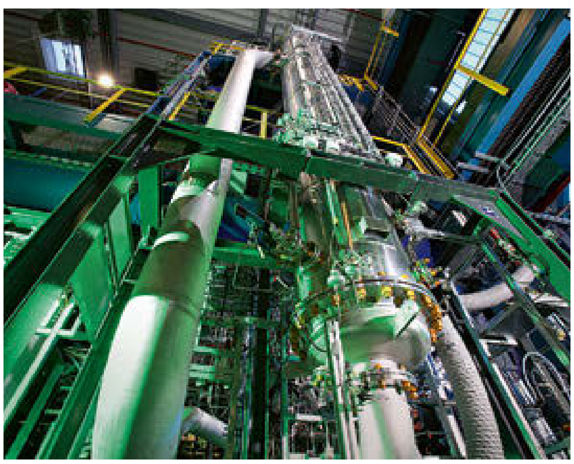
HOW MUCH DOES THE REVOLUTION COST?

Their plans are huge in scope, as Stahl and Komorowski want to make the location completely independent of fossil raw materials and fossil sources of energy. They already have plans in hand for more than a dozen construction projects, which could reduce CO_2 emissions by a total of 26,600 tons per year. It's also conceivable that the Herne location would become emission-free. These projects are a perfect fit for Evonik's strategy: The company aims to reduce Scope 1 and Scope 2 emissions by 25 percent by 2030. Scope 1 emissions include climate gases produced by Evonik itself. Scope 2 includes CO_2 from purchased energy. Evonik plans to invest €700 million throughout the company in Next Gen Technologies, which are technical measures that help conserve resources and reduce energy consumption and emissions while cutting costs.

"The chemical industry is the toughest nut to crack," says Professor Martin Stuchtey. "It is the ultimate fossil-based and energy-intensive industry." Stuchtey, who co-founded the consulting firm Systemiq, has published a study together with the University of Tokyo that shows how it could be done. According to this study, the global chemical sector could become not only climate-neutral but even climate-positive by 2050—in other words, it could relieve the atmosphere of carbon dioxide. To do this, instead of using carbon from oil and natural gas, it would have to use mainly carbon that is already in circulation—whether in the air, in plants or in waste. Ferdi Schüth, a professor at the renowned Max-Planck-Institut für Kohlenforschung (Max Planck Institute for →

“The chemical industry is the toughest nut to crack”

MARTIN STUCHTEY, CO-FOUNDER OF THE CONSULTING FIRM SYSTEMIQ



RHETICUS
SPECIALTY CHEMICALS MADE FROM CO_2

Evonik is working on various projects to biotechnologically convert waste and waste gas streams that contain CO_2 into valuable chemicals. One of the most promising projects is the Rheticus research project, which the company is running together with Siemens Energy. The project partners have developed a technology that uses artificial photosynthesis to produce valuable specialty chemicals from carbon dioxide (CO_2). Renewable electricity is used for this, along with water and bacteria. The test plant in Marl consists of a water electrolyzer and a bioreactor. In a first step, water (H_2O) is converted to hydrogen (H_2) using electricity. Special microorganisms combine this hydrogen with CO_2 into hexanoic acid. This can be used, for example, as a raw material for coatings, cosmetics or even lubricants. Evonik is holding talks with potential customers. The company is already cooperating with Beiersdorf on a research project on the use of Rheticus products as raw materials for cosmetics.

Green instead of gray: In the former salt storage facility, an electrolyzer will produce hydrogen from green electricity in the future. Construction is scheduled to begin this year

Coal Research) in Mülheim, is somewhat more skeptical. For him, climate neutrality for Europe is already a very ambitious goal (see the interview on p. 26). However, he believes that the path being taken in Herne is the right one. “It is important to move forward now as quickly as possible. In doing so, we have to maintain the links in the value chain, but focus on a sustainable basis,” says Schüth.

The fact that relatively few different and comparatively simple raw materials are used in Herne makes the plant an ideal candidate for testing. “Hydrogen, ammonia, methane, acetone, oxygen—we need almost nothing here at the site that you don’t know from basic chemistry class,” Komorowski says. “We could also get these raw materials from green sources—or produce them ourselves.” Even the CO_2 emissions and waste materials could be fed back into production as raw materials.

GREEN INSTEAD OF GRAY

We start off at the old salt warehouse. The location currently requires up to 30 million cubic meters of hydrogen per year. Until now, this has come by pipeline, produced from natural gas in steam reformers that spew out ten tons or more of CO_2 per ton of hydrogen. This is not only a concern for the climate, but also for ensuring reliable production, because a single pipeline supplies the entire location with over 3,500 cubic meters of hydrogen per hour at peak times. A pressure tank with a capacity of 6,000 cubic meters serves as a buffer. If the pipeline fails, Stahl’s employees in the control room have to shut down the facilities in an orderly manner. “Even if everything goes well and the supply resumes after a few hours, we’ll be standing still for a few days,” Komorowski says.

The solution is called H2annibal—in reference to H_2 for hydrogen and the abandoned Hannibal coal mine in the immediate vicinity. The planned water electrolysis system in the salt store is a cooperation project with Siemens Energy and is funded by the German Federal Ministry of Education and Research. It splits water into hydrogen and oxygen using electricity from renewable energy sources. The hydrogen output is expected to meet half the plant’s needs. If the pipeline should fail in the future, the site could continue to operate at a reduced rate. Electrolysis also supplies oxygen as a byproduct, which is used in production as well.

RECYCLING WASTE

Sustainable sources could also be developed for all the other raw materials used in Herne. Today, 50 tons of ammonia roll into the plant every day by tank car and more than 300 tons of acetone by truck. Both could soon be produced locally, at least in part, from waste and exhaust gas streams.

This is comparatively easy with ammonia. Stahl and Komorowski already have an idea for this. In front of the salt storage facility rises the site's imposing skyline—a tangle of pipes, reactors, and chimneys, some of which stretch dozens of meters into the sky. Stahl points to two chimneys where his engineers are planning retrofits. In the HAmst:ER project, ammonium sulfate produced as a by-product is to be split back again by electrodialysis. The abbreviation stands for "Herne Ammonium →

The H2annibal project is funded by the German Federal Ministry of Education and Research under the code 03HY131B

SPONSORED BY THE

Federal Ministry of Education and Research

sulfate: Electrodialysis-based Recombination." Clearly, Komorowski and Stahl demonstrate their creativity not only in technical matters.

So far, the Herne location has found customers for its ammonium sulfate in agriculture, where it is used as a nitrogen fertilizer. But because farmers also want to get by with less nitrogen fertilizer in the future, the industry has to think about what it should do with the large quantities it has.

Continuing with ammonia, the second project is called HASe for "Herne Ammonia Separation." Residues of the raw material are to be separated from the waste gas streams prior to incineration and thus recovered. Incidentally, less nitrogen oxide is then produced during combustion.

The Herne location also has plans for acetone. Right next to the old salt warehouse, a handful of birch trees form a line on a green space. The possibly most revolutionary innovation of the Herne Green Deal could be created in the shade of these trees. It would consist of a facility for the production of acetone from carbon dioxide by biotechnological means using bacteria. Acetone is one of the most important raw materials for the isophorone chain. It also contributes the most to CO_2 emissions. Around half of the total Scope 3 emissions of the Crosslinkers business line come from acetone. Scope 3 includes, among other things, the climate impact of purchased raw materials.

Evonik already buys smaller quantities of bio-acetone from certified sustainable sources and feeds it into the production process. The company's customers can then buy downstream products with a lower carbon footprint from Evonik. This will be done on the basis of the mass balance method, similar to the approach used for green electricity (see box on the right). But recovering acetone even from exhaust gases or waste would be something like the gold standard of the circular economy.

"The technology for this exists," says Stahl. The US company Lanzatech has developed a process in which an anaerobic bacterium produces acetone from carbon dioxide and hydrogen. A plant that is not overly large would be enough to "kill two birds with one stone," as Stahl puts it. The fermentation process supplies acetone and swallows CO_2 emissions. "The green acetone thus provides an additional payoff, because we need fewer CO_2 certificates." Not surprisingly, there is already a suitable name for the project: SAcHer—"Sustainable Acetone for Herne."

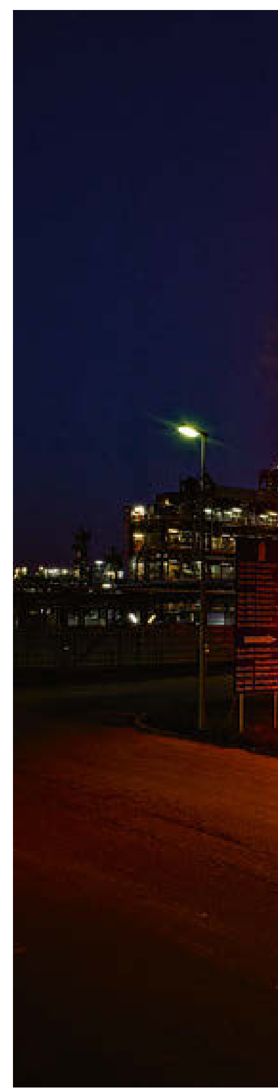
HEATING FOR HERNE

Raw materials are a decisive factor, not only in Herne but at Evonik as a whole. The biggest climate burden of the entire company comes from purchased raw materials. But the second big lever is the energy supply. In Germany, chemical production currently accounts for around a quarter of industrial energy consumption. In

MASS BALANCE

GREEN ACCOUNTING

The chemical industry needs carbon. However, the carbon does not need to come from out of the ground. Today about 85 percent of the carbon in chemical products comes from fossil sources, especially petroleum. Evonik already relies on renewable resources for around eleven percent of its raw material base. In addition, Evonik currently offers customers the option of choosing from an increasing number of its products based on renewable and circular raw materials. For example, the company's portfolio includes isophorone and downstream products in which the acetone is derived exclusively from renewable or circular sources using the mass balance process. The mass balance process allows raw materials from different sources to be used in one and the same process. The amount of renewable starting materials used can nevertheless be clearly attributed to an end product, even along complex processing steps. Like green and conventional electricity, renewable and fossil raw materials flow through the same lines here and are processed together. The final balance is calculated at the end of the process. Independent institutes check and certify the mass balance result according to internationally recognized standards. This has the big advantage that instead of having to invest in new green facilities, companies can switch their production to sustainable raw materials piece by piece.



Energy from waste: In Herne, robust combustion turbines could generate process heat and up to six megawatts of electricity from production residues

Herne too, the hunger for energy is enormous: The location currently draws ten megawatts of electricity from the grid at peak times, plus consuming 22 million cubic meters of natural gas per year. Although the natural gas is mainly used as a raw material, together with the plant's residues it is also used to supply energy.

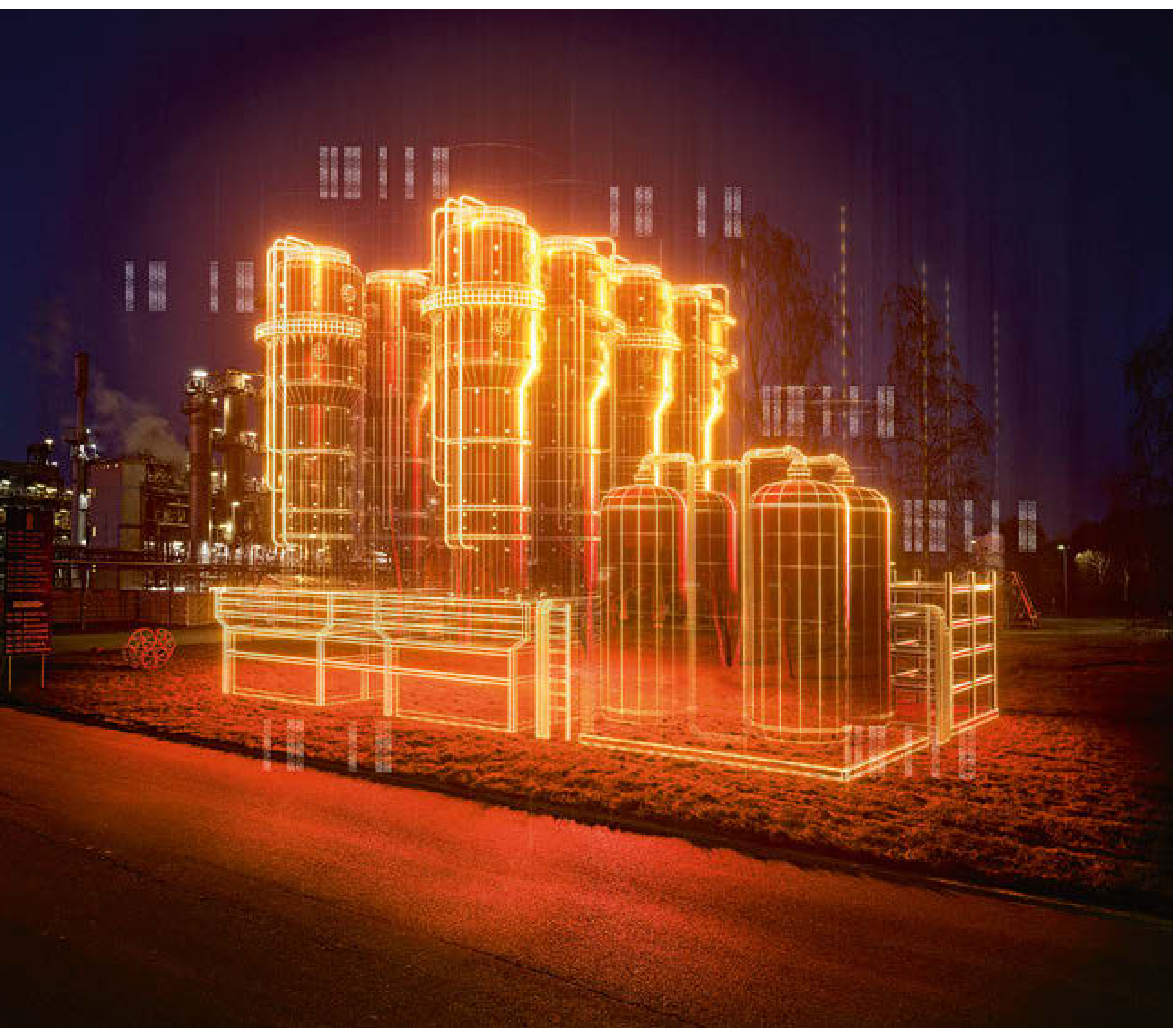
Across the company, Evonik already covers 27 percent of its externally sourced electricity requirements from renewable sources; from 2030, Evonik will only purchase electricity from renewable sources. The supply of green electricity is one thing, the efficient management of the energy used is another. Herne is laying the groundwork for this as well. The associated project is called TORTE ("Technical Options for the Recovery of Thermal Energy"). In the future, the site will feed large parts of its waste heat into the district heating network of the energy company Uniper. Initially, this will be enough for around 1,000 households.

The fact that the chemical and energy industries are so closely intertwined in the densely populated Ruhr region has advantages. "This is where the high-temperature heat pump will be located," says Stahl, pointing to a gap next to the cooling towers and just a few meters away from two thickly insulated district heating pipes snaking past. SAcHer would directly benefit from TORTE. According to Stahl, it's pure coincidence that the names of the two projects fit together so nicely (a Sachertorte is a type of cake). "The names were coined completely independently of each other, and it took us a while to realize how well they fit together," says Stahl.

The HerMES ("Herne Managing Emissions and Sustainability") construction project will also be launched this year. In this project, Evonik will install a state-of-the-art incineration plant for production residues.

TURBINES INSTEAD OF FURNACES

A good bit further into the future are plans for three of the existing incinerators. Stahl and Komorowski look up. Their gaze wanders up the brick factory chimney that towers over everything at the site. Right next to it, but much less prominent, is one of the site's three incinerators. "They make sure our production residues are incinerated," Stahl explains. "We also use it to heat thermal oil, which brings the necessary process heat to our plants," Komorowski adds. →



FROM COAL TO GREEN HYDROGEN

The history of the Evonik's Herne location

1872

COAL MINING
Shaft 2 of the Hannibal colliery is dug next to the site of today's Evonik plant. The colliery is one of eleven in Herne to attract industrial companies from the mid-19th century on.

1928

GAS GENERATION
Industries that use the coke gas are built around the collieries. The Hibernia nitrogen plant is built on the present site.

1935

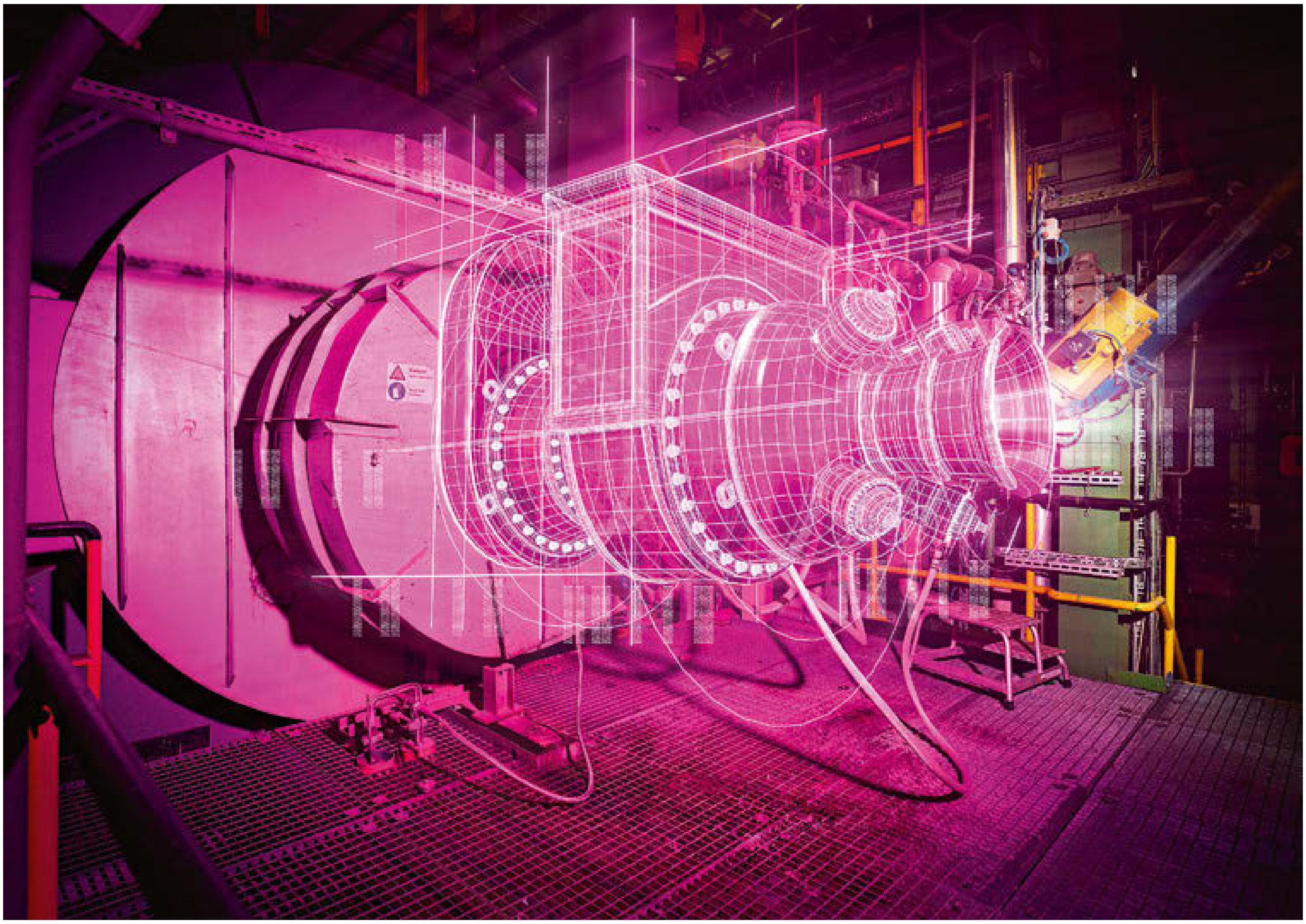
GASOLINE FROM COAL
Prior to World War II, Krupp takes over the plant and shifts to coal-based production of tar, gasoline, and kerosene.

1945

A RUINOUS ENDING
After the site's destruction by the Allies, production is initially at a standstill. For a brief period, the plant then produces raw materials for soap.

1952

FERTILIZER AND WAX
In the postwar period, paraffins are produced first, followed by ammonia and ammonium sulfate.



Alternative acetone: The US company Lanzatech has developed a process in which a bacterium produces this important raw material from CO_2 and hydrogen

Here too, the two have something new in mind. They also want to generate electricity with the site's own waste. To this end, the current furnaces are to be replaced by combustion turbines. They will generate a total of up to six megawatts of electricity for the site from combustible production waste in addition to process heat. It goes without saying that this project also has a resounding name: HErOdoT, which stands for "Herne Energy-Optimization by means of an optional Turbine."

Stahl and Komorowski worked out the concept for this with turbine experts from the project partner Siemens Energy. "It wasn't easy," Stahl recalls. Today's turbines are highly sophisticated, trimmed for maximum electricity yield and minimum emissions. However, a drawback of this is that they can no longer consume all kinds of fuel. "Our project turns the requirements upside down," Komorowski says. In Herne, the main focus is on the targeted disposal of production residues. "It's not the last percentage point in efficiency that matters," says Komorowski. Siemens Energy and Evonik found a very robust turbine design, proven over decades, that could potentially make the plans a reality. Siemens Energy is currently testing in Sweden how well production residues can be used in a turbine—with residue samples sent by Evonik from Herne. Even the turbine's exhaust gases, which contain CO_2, can still be used for something. The nitrogen oxides are removed from the exhaust gases, and the carbon dioxide serves as nutrient for the acetone-producing bacteria.

ROTOR RECYCLING

In Herne, however, they don't only think about the cycles in their own plant, because the location's products are supplied to many industries. Among the most important are hardeners for epoxy resins used in the construction of large wind turbine blades. The first generation of wind turbines is now being decommissioned. Industry experts estimate that more than 100,000 tons of old rotor blades will accumulate in 2030—rising to around 700,000 tons in 2040. People in the industry are already asking themselves how the materials in these rotor blades can be recycled.

Researchers and developers at Evonik are currently working on processes to separate the organic components of end-of-life wind turbine blades from the glass or carbon fibers they contain and then break them down again into a raw material for new rotor blades or other appli-

A new life: Developers at Evonik are currently working on recovering the organic components of end-of-life wind turbine blades as a raw material

cations. A residual organic fraction from this recycling process could be reused in Herne. “Synthesis gas can be obtained from it by means of pyrolysis. Or you can completely burn it right away into CO_2, which our microbes then process into acetone,” Stahl explains.

The many ideas at the Herne location fit into the surrounding environment. Herne’s mayor, Dr. Frank Dudda, has set his city the goal of being climate-neutral by 2045. “We want to become the greenest industrial region in the world,” Dudda says. “The chemical industry is playing a big role in this development and showing that it is on the right track.” Traditionally, the residents of this region have had very close ties to industry. That’s why Stahl wants to not only reconfigure the local Evonik plant to be more sustainable but also to open it up more. Regional universities are already eying collaborations and space for startups that could move into rooms in the old salt warehouse. An investor can build a photovoltaic system on the roof of the industrial building. It would be visible far and wide from the busy road next to the plant. To provide a view of the new hydrogen electrolysis plant, Stahl is considering installing a large window in the wall of the hall and having banners hung on the facade. “Everyone should see how much we’re doing!” he exclaims.

Tom Rademacher is a freelance journalist based in Cologne. He writes about scientific and industrial topics, among others

1962

NEW PRODUCTS FROM ACETONE

Isophorone based on acetone is produced in Herne for the first time. In subsequent years, more and more expansion stages are added for new downstream products such as isophorone diamine and isophorone diisocyanate.

1979

THE PATH TO EVONIK

After several changes of name and ownership, the plant now belongs to Chemische Werke Hüls—later absorbed into Degussa, a direct predecessor of Evonik.

1992

EXPORT MODEL

In Mobile, Alabama (USA), an integrated isophorone production network (I-chain) is built according to the Herne model.

2012

EXPANSION IN CHINA

In Shanghai, China, Evonik Industries, which received this name in the previous year, builds an isophorone (I-chain) production network that is almost identical in design to the one in Herne. Production begins in 2014.

2023

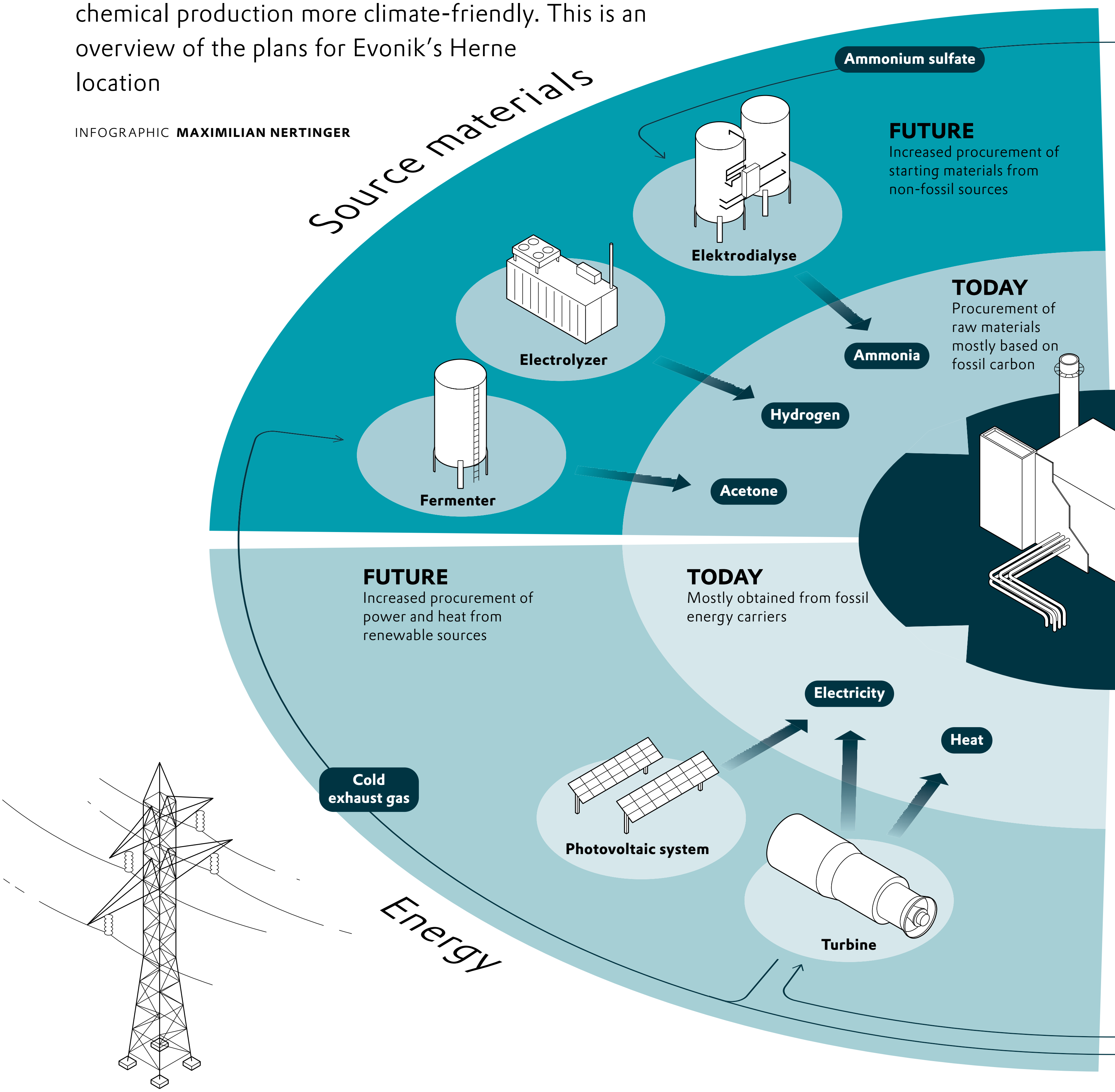
HERNE GREEN DEAL

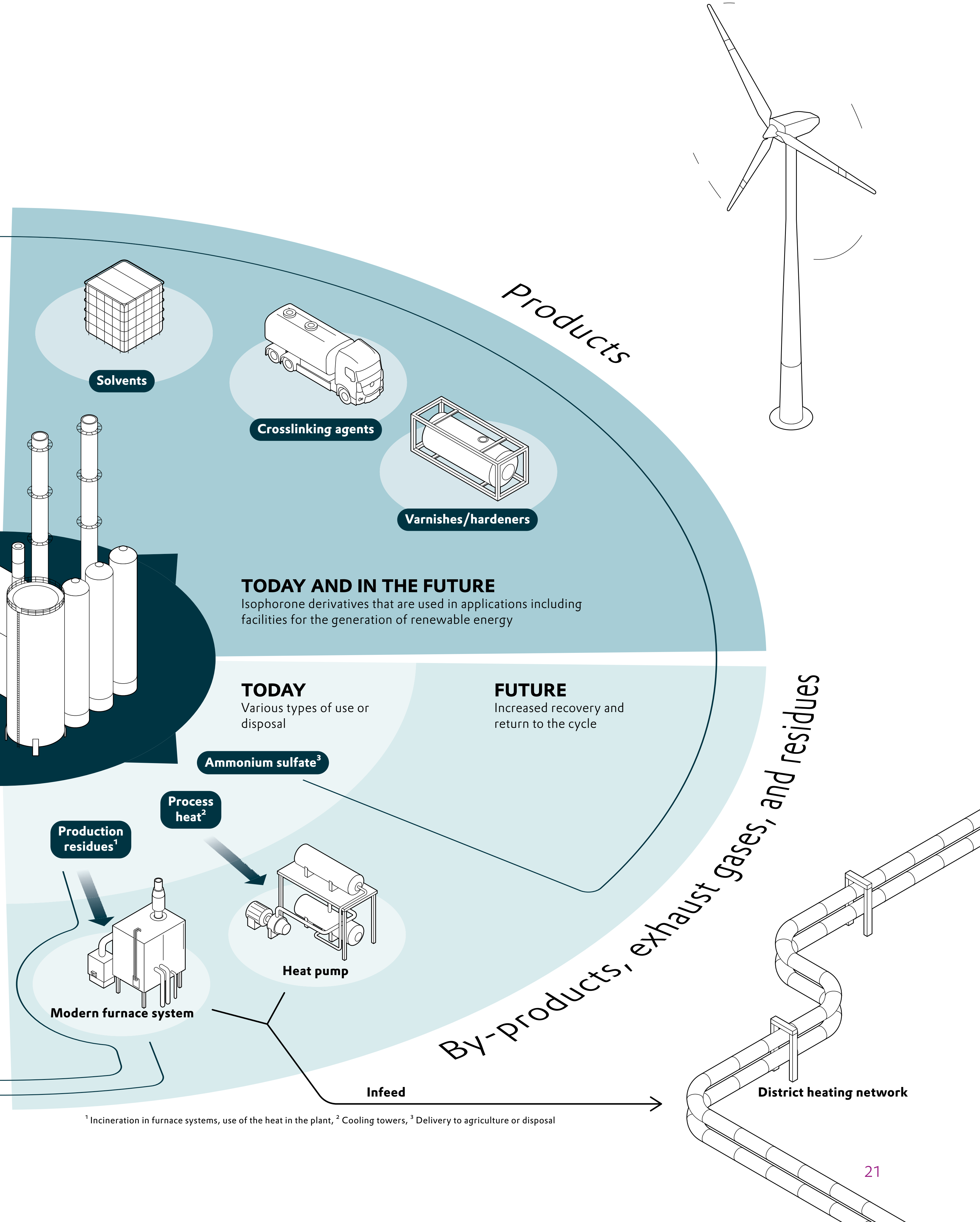
Planned start of construction for an electrolysis plant to supply the location with hydrogen.

Climate-friendly, Please

Solar power, green hydrogen, carbon dioxide from exhaust gases—energy and raw materials must increasingly be obtained from non-fossil sources in order to make chemical production more climate-friendly. This is an overview of the plans for Evonik's Herne location

INFOGRAPHIC **MAXIMILIAN NERTINGER**





[1] Incineration in furnace systems, use of the heat in the plant, [2] Cooling towers, [3] Delivery to agriculture or disposal

LESS IS MORE

TEXT **ANNETTE LOCHER**

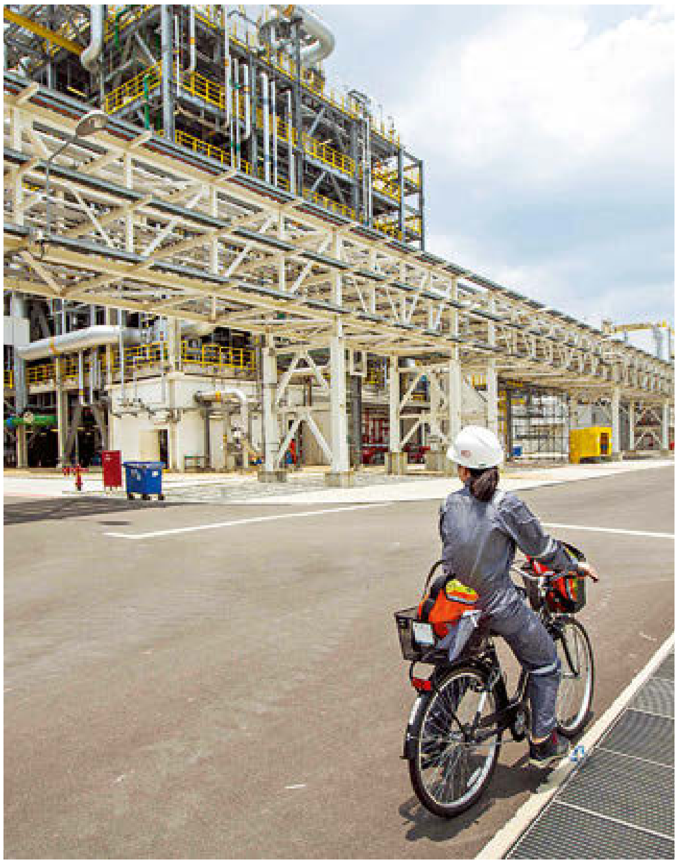
The amino acid methionine enhances the sustainability of livestock farming. Evonik is now using an extension of its production facilities in Singapore to also significantly reduce the CO_2 footprint of this animal feed additive

The noise of construction machinery is ushering in the future at the production plant of Evonik's Animal Nutrition business line on Jurong Island. Here in the southwestern district of the city-state of Singapore, excavators are leveling the earth's surface at a site on the outskirts of the plant. Plans call for a steam turbine to be installed here in the near future. At another site, stakes mark the place where a new plant building will stand in a few months' time. And a patch of lawn will soon give way to an electrolysis unit that is expected to produce green hydrogen starting next year. The aim is to make the production of methionine, an important amino acid for animal feed, more climate-friendly.

"We're using an upcoming expansion of our methionine production plant's capacity to optimize the entire process at our Singapore location—and paying particular attention to our energy and raw material efficiency," says Dr. Jan-Olaf Barth, who heads the Essential Nutrition product line at Animal Nutrition. In the future, power from renewable sources is to be used preferentially in these processes instead of fossil fuels. According to Barth, that makes Evonik a pioneer in this Southeast Asian country. "We will be one of the first major companies in Singapore to utilize green hydrogen," he says. To date the company has mainly used "gray" hydrogen, which is extracted from natural gas, coal or petroleum.

In order to make production on Jurong Island more environmentally friendly, Evonik is cooperating with the German-American industrial gas company Linde, which is building the electrolysis unit. "We decided in →

Starting in the 1990s, seven islands located near the main island of Singapore were connected to form Jurong Island (in the center of the photo) by means of land reclamation. Many petrochemical companies, including Evonik, have established facilities here



Singapore is one of three locations where Evonik produces methionine for animal feed. Up to 300,000 tons of methionine leave the plant on Jurong Island every year

favor of a technology that is especially fit for the future and will bring us cost advantages in the long run, "says the project director, Dr. Christof Grüner, who is in charge of making sure the technology Evonik uses on Jurong Island is state-of-the-art. Evonik uses green hydrogen to produce methyl mercaptan, a DL-methionine precursor product.

HALVING CO_2 EMISSIONS

Within an international project team, Dr. Henning Kaemmerer and his colleagues Poh Leng Teh and Foo Chay Chong are responsible for the implementation of the various construction plans. The three process experts are facing some tough challenges. "Not only the electrolysis unit but also all the other subprojects must be so far advanced by next winter that we can integrate them into the process during a maintenance shutdown of our methionine production," says Kaemmerer. To make sure this happens, they need to coordinate very closely with the site manager, Kevin Kennedy.

Evonik has high hopes for the modification of its methionine production. The additional 40,000 tons of MetAMINO® per year should then be produced with a specific CO_2 footprint that is only half as big as it was previously. In terms of the total volume of 340,000 tons of MetAMINO® from two plants, this means a six-percent decrease in emissions.

The project in Singapore is part of the green transformation known as Next Generation Evonik, which the company initiated in 2022. Its two key aims are to make production at the locations more climate-friendly and to increase sales by means of sustainable innovations. MetAMINO®, the DL-methionine from Evonik, has already been playing an important role in sustainable agriculture for decades. Farm animals take in methionine with their feed. If this essential amino acid is missing, other components of the animals' feed cannot be optimally metabolized. The plant-based components of the feed often contain insufficient amounts of methionine by comparison with other amino acids. As a result, the animals excrete all of the feed components they were unable to metabolize. This is neither environmentally friendly nor cost-efficient.

Adding a small amount of methionine to animal feed can significantly reduce the amounts of other raw material feed components that are needed. This reduces the amount of agricultural land needed for cultivating soybeans or legumes and decreases the nitrogen emissions due to animal farming. It thus has a positive effect on sustainability, as is shown by several certified life cycle assessments. "If we want to provide a growing world population with high-quality animal protein under conditions of limited natural resources, we need to operate as efficiently as possible," says Barth.

Evonik's Animal Nutrition business line is part of its life sciences division, Nutrition & Care. It is completely oriented toward improving the lives of human beings and animals—by means of solutions that also offer advantages in terms of sustainability.

ONGOING IMPROVEMENTS

In order to conserve resources during production, Evonik is continually improving the production process of MetAMINO®. As a result, the Animal Nutrition business line has always stayed ahead of the global competition in terms of technology, production volumes, and efficiency. Its methionine plants are located in Antwerp (Belgium), Mobile, Alabama (USA), and Singapore.

The basic conditions for this are developed by people like Dr. Martin Köstner, a member of Evonik's research and development team, where he is responsible for innovation and technology at Animal Nutrition. For a number of years, his team has been working to reduce the CO_2 emissions generated during methionine production. "We conduct analyses to find out at which points in the production process we can achieve significant savings with existing technologies quickly and with minimal resources," says Köstner.

“Steam is a key element of energy integration at the methionine plant in Singapore”

HENNING KAEMMERER, PROJECT RESPONSIBLE

Work is already under way on the expansion of the methionine plant. Plans call for the new components to be integrated into the existing process next winter

The conversion to green hydrogen is only one of many measures that are now being implemented in Singapore. Another measure is the improvement of the unit’s energy and raw material efficiency. Instead of simply building an additional production plant, the process itself is being intensified. “In the future, one part of the process stream will be running through an extra loop,” Köstner explains. “That way we receive more product and fewer byproducts.” As a result, the specific energy and raw materials requirement of the end product is reduced.

POWER FROM STEAM

However, major changes cannot be carried out during day-to-day production. That’s why the team uses time slots during which the plant’s operations are shut down for regular maintenance work. The prolonged downtime of the methionine production that is needed for building the extension is enabling Evonik to make additional alterations in parallel. For example, a process unit that is used in part of the methionine production process is being replaced with a new unit in an innovative design that generates fewer byproducts and requires less steam for heating.

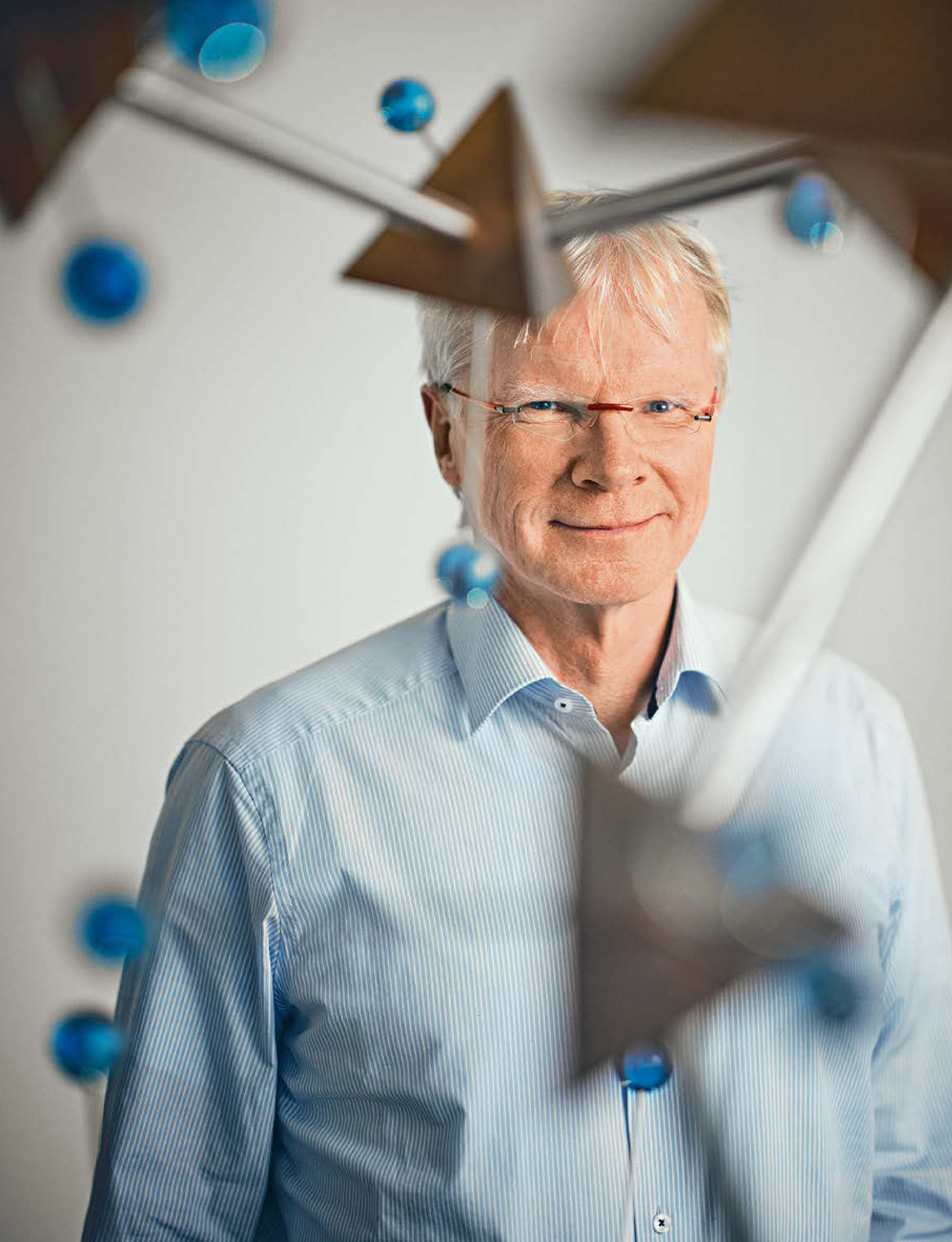
“Steam is a key element of the energy integration at the methionine plant in Singapore,” says Kaemmerer. In addition to methionine, the plant produces all of its important precursor products: methyl mercaptan, acrolein, and hydrogen cyanide. Whereas steam is generated during the production of acrolein and hydrogen cyanide and the thermal use of secondary process streams, steam is needed to run the methionine production process.

“Sometimes we already have a small surplus of steam today,” Kaemmerer says. “When we generate more steam in the future during the production of acrolein and hydrogen cyanide for the additional quantities of methionine, and when the methionine process itself consumes less steam, this surplus will grow.” In the future an extraction steam turbine will generate additional electric power from the steam that is not needed, so less energy will have to be purchased.

The thermal aftertreatment system at the location will also be modified. Feeding certain waste gas flows into it in a different way will make it possible to reduce the combustion temperature. As a result, less natural gas will be consumed, less CO_2 emitted, and less surplus steam generated. The new electrolysis unit and the green hydrogen are also expected to provide an additional benefit: The oxygen generated during the reaction will help to reduce the amount of natural gas that is needed to operate the furnaces.

Köstner’s team is already thinking in terms of the far future and working to develop brand-new processes that use innovative raw materials. Meanwhile, Kaemmerer and his colleagues are focusing all of their attention on making sure that the modifications and expansions are all ready to go into operation by next spring. After that, the methionine plant on Jurong Island should go back into operation with a bigger production capacity and a smaller specific CO_2 footprint.

Annette Locher has a degree in biology. She has been working at Evonik since 2012. She writes primarily about health, nutrition, and sustainability



“We have to do it now”

Ferdi Schüth is one of the most renowned chemistry professors in Germany and the managing director of the Max-Planck-Institut für Kohlenforschung. He thinks it is technologically possible for the EU to achieve climate neutrality by 2050. However, the attainment of this goal will require the chemical industry to radically restructure its material and energy flows

INTERVIEW **RANA SEYMEN, JÖRG WAGNER & CHRISTIAN BAULIG**

Professor Schüth, for the past quarter of a century you have been working to make the chemical industry sustainable—often in the face of opposition. Does it give you a sense of satisfaction that defossilization is suddenly being promoted so much?
SCHÜTH In view of the war in Ukraine, satisfaction is certainly the wrong word in this case. But it is a good sign that when faced with this dire situation, we were able to build a liquefied gas terminal in Germany within five months, for example. I’m concerned, however, that we will revert to our former complacency and perhaps fail to feel the same urgency with regard to climate change once the current energy crisis is over. But at least we now have an example that shows that we can do it. It’s possible.

Not only governments but also industry has contributed to the fact that the transformation to a climate-friendly economy has been proceeding slowly for a long time. Do you think people are now realizing that action is needed?
I am 62 years old, and I have long since given up any illusions I may have had that things are done as a result of altruism. If you want radical changes, you either have to pass tough laws or make them pay off. Economic considerations are hard to beat. On days when I’m optimistic, I say to myself: People will behave differently because they’ve recognized the problem. On days when I’m pessimistic, I say to myself: Technology will have to solve this issue. We need to provide technological alternatives that enable us to operate sustainably.

In the chemical industry, there are essentially two paths to greater climate change mitigation. Either we change the core processes of production, or we rely more on the established processes—but with a green energy supply, renewable raw materials, and a circular economy. Which path is more likely to lead to the goal?
We have to pursue both paths. Of course you can implement entirely new processes, products, and platform molecules. However, the greatest effect will be achieved by means of a sustainable raw material base and a sustainable energy supply. It is important to move forward now as quickly as possible. In doing so, we have to maintain the links in the value chain but rely on a sustainable basis. →

Ferdi Schüth, 62, has been Managing Director of the Max-Planck-Institut für Kohlenforschung in Mülheim/Ruhr since 1998. From June 2014 to June 2020, the chemist was the vice president of the Max Planck Society, for which he represents energy topics. As early as 2007, Schüth coordinated a position paper within the German chemical organizations that highlighted the industry’s importance for energy supply and efficient energy use

What might such an approach look like in the chemical sector?
In the chemical production process, we need heat and compression. This is typically mechanical work. We can provide heat via electric heating or heat pumps. You have to do a lot of development work there, but it works. And instead of a gas turbine or a combined cycle system, you can use electric compressors. There are even plans for an electric-powered steam cracker—there's nothing that needs much more concentrated energy input than that. This shows that it's possible!

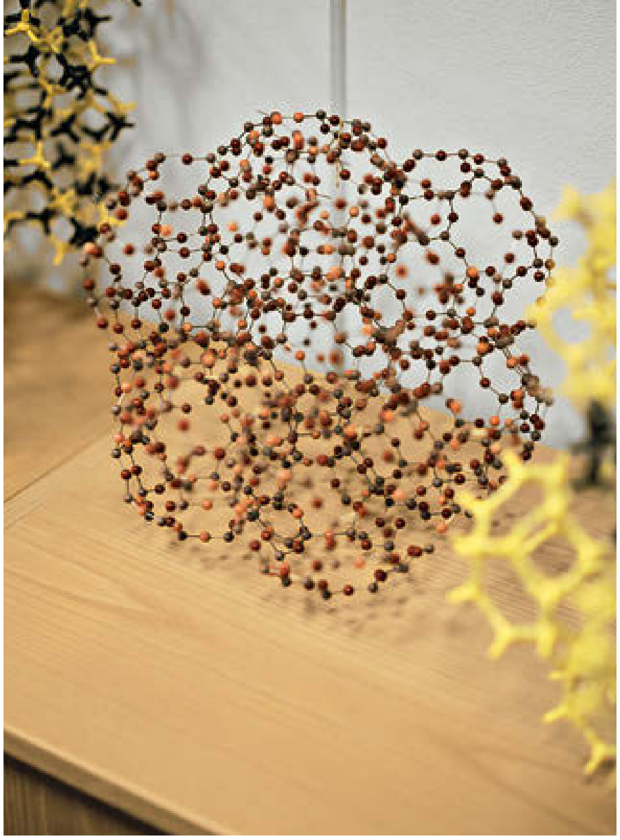
And what about raw materials?
Achieving a sustainable basis is a bit more difficult here. We need to move away from our basic chemicals, which are derived from oil or natural gas. And we can only accomplish that if we use CO_2, biomass or waste materials—especially plastics—as a source of carbon. From CO_2, I can get directly to methanol via hydrogenation with hydrogen. Or we generate synthesis gas via a reverse water gas shift reaction: CO_2 plus hydrogen results in CO and water. I can then extract methanol, hydrocarbons or aromatic compounds from this synthesis gas. There are already plants that produce several tens of thousands of tons per year. Many of them are in China. What worries me a bit on behalf of German companies is that even though the methanol in China is still produced from coal, the manufacturers there are gaining the experience needed to eventually operate plants that may produce 100,000 tons per year.

What role do plastics and biomass play with regard to raw materials?
If you want to use polymers as a carbon base, you have a number of options. They can be selectively depolymerized to return them to monomers or to monomer-related molecules. Or you pyrolize them. The resulting pyrolysis oil must be reprocessed to obtain a feed for the steam cracker. Biomass is probably a good source of raw materials for part of our supply of aromatic compounds, because the lignin it contains is rich in them. Here too, companies already have experience with the operation of plants producing several tens of thousands of tons per year.

Where do you see opportunities to switch to alternative raw materials relatively quickly and without compromising quality?
Take polyethylene terephthalate, for example, which we know as PET. The terephthalic acid it contains is ultimately produced from petroleum. We could replace it with an alternative monomer: furandicarboxylic acid that can be produced from biomass, namely cellulose. This means that the product does not have exactly the same properties, but this problem will be solved.

At Evonik and in many other companies, ammonia is needed for chemical processes. What climate-friendly alternatives to fossil sources such as natural gas or naphtha do you see there?
If we use green hydrogen instead, produced via electrolysis with sustainable electricity, a large part of the CO_2 footprint disappears. If the compressors required for the process are also operated electrically, ammonia can be produced in an almost climate-neutral manner. In addition, however, it's necessary to conduct a life cycle analysis of the plant itself. As long as I need steel and concrete to construct chemical plants, we'll be lugging around the CO_2 burden of these materials, but we can lighten that too.

When you think of steel, do you think of production methods such as direct reduction with hydrogen?
Exactly. Of course, this only makes sense if we use electrolysis hydrogen and not hydrogen produced from natural gas. It is much more difficult when it comes to cement for concrete, for which we have to roast calcium carbonate to get lime. The carbon dioxide



Research subjects: Numerous molecules are on display at the Max-Planck-Institut für Kohlenforschung, for example a model of zeolite A—an aluminosilicate used as a softener or desiccant. On page 20, the institute's director, Schüth, can be seen behind an artistic representation of a polyethylene chain

"What the chemical industry has invested here over the past decades is a huge asset"

released in this process accounts for about three percent of global emissions—more than all air traffic. To be honest, I don't see a real solution here yet.

A lot of what you're talking about works with electricity, which ideally is produced sustainably. What makes you so confident that this green energy will be available in sufficient quantities in the foreseeable future?

If we wanted to supply the entire chemical industry with hydrogen from sustainable energies and hydrogenate CO_2, we would have to install about 1.5 square kilometers of photovoltaics every day worldwide from now until 2050. These are gigantic numbers, but it seems feasible. We just can't afford to spend another ten years thinking about what we want to do. We have to do it now.

In Europe, especially in Germany, it will hardly be possible to build such capacities. Do you see a danger that the chemical industry will migrate to regions of the world where it is easier to produce green electricity?

I am reasonably confident that Germany will remain an important industrial site. Even today, chemical production only partially takes place where the oil and gas wells are located. The raw materials are transported here instead. Why should this be fundamentally different when we use raw material sources generated with green electricity? If methanol were to become an essential molecule in the chemical industry, then hydrogen could be produced with solar energy in North Africa or Australia, for example. This hydrogen would also be used to produce methanol in those regions. The methanol can then be shipped to Leverkusen, Ludwigshafen or Herne to produce raw materials.

However, the current value chain was created when Europe was still a dynamic market. Many countries that are suitable for the methanol production you mentioned want to keep a significant share of the value creation process within their borders and set up their own chemical production facilities.

That can happen, of course. But what we have invested here over the past decades is a huge asset. Why tear it all down and build anew elsewhere? If we maintain value chains, logistics, and distribution, but make our raw material base sustainable, we may stand a chance against what is being →

“If we diversify our energy sources more, the system will be less vulnerable to disruption”

newly installed elsewhere. In addition, I am convinced that it is easiest to transport the basic raw material on a large scale to the point of consumption, where it can be further processed into the many differentiated products of the chemical industry close to the customer. Doing this in the Sahara, for example, wouldn’t make any sense. But we will probably have to give up a part of the pie.

Green power producers are one group of competitors, the other are countries where CO_2 certificates are cheaper than in Germany—for example China and India. Do we run the risk of industries with high CO_2 emissions relocating there at short notice?
I do see a danger of that happening. And we should counter it with import taxes, the amount of which is determined by the CO_2 burden that a product carries with it. I know that economists are generally not in favor of tariffs, because trade that is as unrestricted as possible makes life easier and produces cheaper solutions. But if we recognize the need to reduce CO_2 emissions to zero as quickly as possible to keep the Earth habitable, then we have no choice. The more countries that agree to this, the better, because it means that countries with lax limits for carbon dioxide will no longer be so attractive.

We can no longer rely on natural gas or electricity coming from the grid at any time of the day or night—at least since the Russian invasion of Ukraine. Isn’t this one of the reasons why industrial sites have to secure their energy supply better in order to ensure continuous production?
The idea of being self-sufficient won’t let us achieve this goal. The world is networked and will become even more networked. If we diversify our energy sources more, the system will be less vulnerable to disruption. The same applies to raw materials.

But shouldn’t we still make greater use of waste heat and waste from production sites as sources of energy and raw materials?
Definitely. One should look at everything that offers opportunities. But before I go to a lot of expense to

Ferdi Schüth in his Mülheim office, together with *Elements* editors Jörg Wagner, Rana Seymen, and Christian Baulig (connected by cell phone)

use a heat flow of 50 degrees locally for production, I should rather get electrical energy from the Sahara, which can be produced there for 0.8 cents per kilowatt hour. With the waste heat of 50 degrees, we can heat a greenhouse in the neighborhood to grow tomatoes in winter rather than using it to run a high-temperature process, for example.

Do you have the impression that at least the European countries are pulling together on the climate issue?
The willingness is certainly there, because there is a rapidly growing realization of the problems we face due to climate change. Still, it's difficult to get different countries to follow the same path. The French, for example, reproach us for continuing to operate lignite-fired power plants and shutting down nuclear power plants—which increases the price of CO_2 throughout Europe. We have to act together because we are all in the same boat now.

As a scientist, what is your position on this issue?
This debate has to be conducted by society as a whole. Put simply, we cannot simultaneously insist on maintaining security of supply, keeping the moral high ground, safeguarding our industrial base, and pushing CO_2 emissions down to zero. Compromises will have to be made in some areas. Germany lacks a list of priorities on which we as a society can largely agree.

Over the next ten years, 800 billion euros are to be invested in Europe to drive forward the green transformation of industry. What will it take to make this mammoth undertaking a success?
First and foremost, planning security. Clearly, we need to expand renewables here at home as quickly as possible, and—where reasonably low cost is possible—enter into reliable contracts with energy producers elsewhere in the world. If in doubt, I would also have the state subsidize such supply relationships so that the business models can be firmly established. If we don't get these logistics chains up and running now, the German chemical industry will be cut off at some point. At the same time, we need the priority list that I mentioned. And we must not call it into question every two years. It would be best to clarify this at the European level, even if it makes the discussion more difficult.

Around a quarter of a century from now we'll be in the year 2050, when the European Union aims to be climate-neutral. Based on your experience, how likely do you think this is?
We'll achieve it technologically if we launch a kind of mega Apollo program. There are, of course, sectors such as the cement industry where we currently don't even have any idea of how we can get rid of CO_2. We will therefore have no choice but to take CO_2 out of the cycle elsewhere to compensate—for example, through reforestation programs, land use change or through carbon capture and storage, or CCS for short. The biggest difficulty, however, is that we are not dealing with a purely technological problem, but instead have to get society to pull together globally. That will be the real challenge.

KNOWING WHAT'S GOOD

The lifestyle in France is often referred to as *"savoir-vivre."* But France has even more to offer besides fine cuisine, exquisite fashion, and great art. Evonik's operations in France are similarly multifaceted. They range from innovations in the field of healthcare to the production of natural skin products, developments for the petroleum industry, and more sustainable solutions for future-oriented sectors

TEXT **PAULINE BRENKE**

The Château de Sacy nestles within an idyllic landscape. The guests of this five-star hotel can look out of any one of its windows and gaze at lush vineyards that spread themselves evenly across the hills of this province. Long before the Champagne region became famous for its sparkling wine, it was a center of textile production in the 16th and 17th centuries. Today it produces 300 million bottles of Champagne annually, about half of which are enjoyed by the French themselves (also see page 38).

The Biscuiterie de Montmartre in Paris entices customers with colorful macarons and other delicacies artfully arranged in its display window. Macarons, which are close relatives of meringues and petits fours, were reputedly served as early as the 17th century at the court of King Louis XIV. These sweet pastries are still extremely popular today. Creating this combination of a delicately crisp shell with a soft center and a perfectly matching filling is known to be a difficult art to master. Silicone baking molds made with AEROSIL® from Evonik ensure that these tiny almond meringue pastries always turn out flawless.


de tradition Française
Artisanales
Montmartre
176 RUE DE RIVOLI
PARIS
biscuiterie-montmartre-paris.com

The Tour de France is the world's most famous and most challenging bicycle race. The route is slightly different every year, but it always runs through picturesque landscapes and locations such as Aix-en-Provence (photograph). In order to withstand the physical stress, the cyclists must be supplied with energy along the entire route, which is more than 3,000 kilometers long as a rule. For example, before the race begins they make sure to consume carbohydrates as energy providers, and during the race the professionals receive isotonic beverages that offset the body's loss of minerals. Evonik provides support by means of REXIVA®, which supplies important amino acids for sport nutrition and dietary supplements.

From prêt-à-porter to haute couture: Twice a year, the *maisons* of the world of fashion present their latest designs on the catwalks of Paris Fashion Week. An overall look includes not only the clothes but also the appropriate hair styling and makeup. Cosmetic products made in France are held in high esteem all over the world. In 2022 about two thirds of French cosmetic products were exported and brought in sales of almost €20 billion. In Cosmetic Valley, which spreads across the Centre-Val de Loire, Normandie, and Île-de-France regions, Evonik's Advanced Botanicals product line develops a special kind of cosmetic products. A resource-conserving biotechnological process is used to produce high-performance plant-based active ingredients for cosmetics.

As in a treasure chamber, hundreds of bottles of Armand de Brignac are stored in the cellars of the originally family-owned Cattier company in Chigny-les-Roses. Today the US rapper Jay-Z and the LVMH Moët Hennessy – Louis Vuitton group are the joint owners of this brand of Champagne. The luxurious image of this sparkling wine is due to features that include its elaborate and strongly regulated production process. In the course of this process, the winemakers also use nitrogen to preserve the wine and prevent unwanted oxidation. SEPURAN® N2 membranes from Evonik can separate nitrogen from the ambient air and make it usable; as a result, winemakers are independent of gas suppliers.

Blue skies, pure air, and breathtaking nature: The French Alps attract hikers and athletes to the mountains during every season of the year. Mont Blanc, whose height of 4,810 meters makes it the highest peak in Europe, is especially popular. For an outing in the mountains, most people rely not only on sturdy hiking boots but also on clothing that is as breathable and water-resistant as possible. Synthetic fibers based on petroleum are still often used in order to obtain these characteristics today. VESTAMID® Terra from Evonik offers a sustainable alternative, thanks to bio-based artificial fibers made of castor oil. The outdoor outfitter Vaude has already used these fibers successfully in trekking pants and other products.

Patients used to share beds in this building, but today the former hospital rooms serve as the suites of a luxury hotel. The Grand Hôtel-Dieu (“God’s refuge”) on the shore of the Rhône River in Lyon used to be a hospital where paupers were taken in and cared for free of charge. According to historians, sick people were treated here as early as the 12th century. The field of medicine has repeatedly faced unexpected challenges in the past, and it is still doing so today. That was recently demonstrated during the COVID-19 pandemic. An Evonik location in the town of Ham in northern France produces plant-based amino acids by fermentation that are used for treating diseases including long Covid. The knowledge gained in the process could also enable progress in the struggle against cancer.

HEALTHY AND SMART

Evonik is represented in France by four production locations in the areas of healthcare, personal care, and specialty industries and a sales department. The growth division Nutrition & Care receives products from the company's biggest as well as its smallest location in France. In Ham, about 242 people work to produce ultrapure amino acids for the Health Care business line, and in the Centre-Val de Loire region seven employees develop advanced botanicals for the Personal Care unit. The other two locations specialize in smart materials and specialty additives.

Evonik locations
1 Ham
2 Lauterbourg
3 Roussillon
4 Parçay-Meslay

The

4

Evonik locations have

351

employees

STEALTH DELIVERY

A mask for medicine: At the Evonik laboratory in Darmstadt, rPEG lipids and other components are used to produce lipid nanoparticles (left). The rPEG for this is supplied by the University of Mainz (right)

From coronavirus vaccines to medicines for cancer, multiple sclerosis, and Alzheimer's disease—the applications for mRNA therapies are numerous and diverse. But how can the fragile RNA be delivered into cells effectively? A team of researchers from the University of Mainz in Germany and Evonik is working jointly to develop the perfect delivery system

TEXT **TIM SCHRÖDER**

Sometimes in science there are moments when things suddenly come together as if by magic. Thoughts and ideas that actually have nothing in common coalesce in a way that makes sense. That's what happened over two years ago to a team led by the chemist Professor Holger Frey from the University of Mainz. For many years now, he has been experimenting with polyethylene glycol, a non-toxic "jack of all trades" compound among chemical substances.

Polyethylene glycol is a polymer—a long-chain molecule. Known as PEG for short, it is made up of ethylene oxide (EO) building blocks and is easily soluble in water. Its applications include ointments, shampoos, and a wide range of cosmetics. Many thousand tons of PEG are used for applications like these all over the world every year. But PEG also plays an important role in medicine. One such application is the delivery of active ingredients into the human body. →

At the synthesis laboratory in Hanau, researchers run tests to find out under what conditions rPEG can be attached to a lipid

The rPEG lipid is purified by means of chromatography

The chemists in Mainz were looking for a way to modify PEGs that would give them new characteristics and open up an even wider range of applications. Holger Frey's postdoctoral researchers Rebecca Matthes and Philip Dreier were mainly focusing on a promising molecule that is very closely related to EO—glycidyl methyl ether, or GME for short. Like EO, GME can be used as starting material to form building blocks of polymers. And the two starting materials can be used in combination. The researchers from Mainz University created a polymer modified in this way, which they called rPEG. The "r" stands for "randomized," because the EO and the GME building blocks are distributed at random throughout the chain during its manufacture. It's interesting that all polymers made up of EO and GME building blocks are structural isomers. Compared with PEG, rPEG has additional molecular side chains, but is equally water-soluble. It also has other characteristics relevant for industrial applications.

Actually, the two researchers were not initially thinking about medical applications for rPEG at all. But suddenly various elements came together to form a picture: rPEG could present a breakthrough in the development of new types of mRNA therapeutics. Together with a research team from Evonik, Matthes and Dreier are now working to develop their discovery into a technology that can be used by the pharmaceutical industry.

mRNA therapeutics are regarded as one of the most promising developments in medicine. They first demonstrated their effectiveness and potential as vaccines during the COVID-19 pandemic, when they were used at large scale. Experts anticipate that in the future mRNA therapeutics will be used to treat many other diseases that are difficult to treat today, such as multiple sclerosis and Alzheimer's disease. Rare forms of cancer could also be combated with a mRNA therapy.

The various chromatography fractions are collected in test tubes

THE FREY RESEARCH GROUP

Polymers are Holger Frey's special field of expertise. His research group at the University of Mainz, where he has been teaching organic and macromolecular chemistry since 2002, deals with the synthesis, characterization, and applications of new functional polymers. Professor Frey (on the left) has been a co-publisher of the journal *Polymer Chemistry* since the fall of 2018. Dr. Rebecca Matthes and Dr. Philip Dreier wrote their Ph.D. dissertations under Frey's supervision and are now doing postdoctoral work in his research group. There they are continuing to forge ahead with the development of rPEGs for a wide range of pharmaceutical applications.

But so far there has been an obstacle: mRNA active ingredients are formulated with ultrapure special PEG lipids, among other substances, to ensure that they reach the target cells unscathed. However, it has been widely reported in literature that in rare cases PEG can trigger the formation of antibodies to PEG. Such reactions must be prevented in the future, especially for long-term applications, such as cancer therapeutics. As a result, the pharmaceutical industry has long been searching for alternatives to PEG.

Rebecca Matthes and Philip Dreier discovered exactly this kind of alternative—rPEG—just over two years ago. While Matthes and Dreier were working on the development of rPEG, several articles had been published in scientific journals describing how antibodies dock onto PEG and how the immune system recognizes PEG. "We immediately realized that our rPEG had the potential to prevent these immune reactions," says Matthes. "We thought that we could prevent the docking of the antibodies with the additional molecular branches in the rPEG," she explains. "That should make the modified PEG invisible to the immune system." →

“When I told the Evonik researchers about our rPEG, they were immediately enthusiastic”

HOLGER FREY, PROFESSOR OF CHEMISTRY AT THE UNIVERSITY OF MAINZ

Freeze-drying the reaction solution produces the rPEG lipid in powder form

A BREAKTHROUGH FOR THE PHARMACEUTICAL INDUSTRY

The researchers followed up with extensive experiments. Over several weeks, they used GME and EO as starting materials to synthesize various new types of rPEG polymer structures. The research duo then brought the new polymer into contact with antibodies. And, as predicted, there was no interaction with the antibody at comparable concentrations. The randomly distributed GME molecules' side chains prevented the antibodies from binding to the rPEG. The Mainz researchers' discovery could be very significant for the pharmaceutical industry. PEG lipids are among the most important ingredients of the lipid nanoparticles (LNPs) that are used to package mRNA active ingredients. LNPs are tiny spherical ferries that transport the active ingredient through the body into the cells. These delivery vehicles are needed because mRNA is extremely unstable and requires protection.

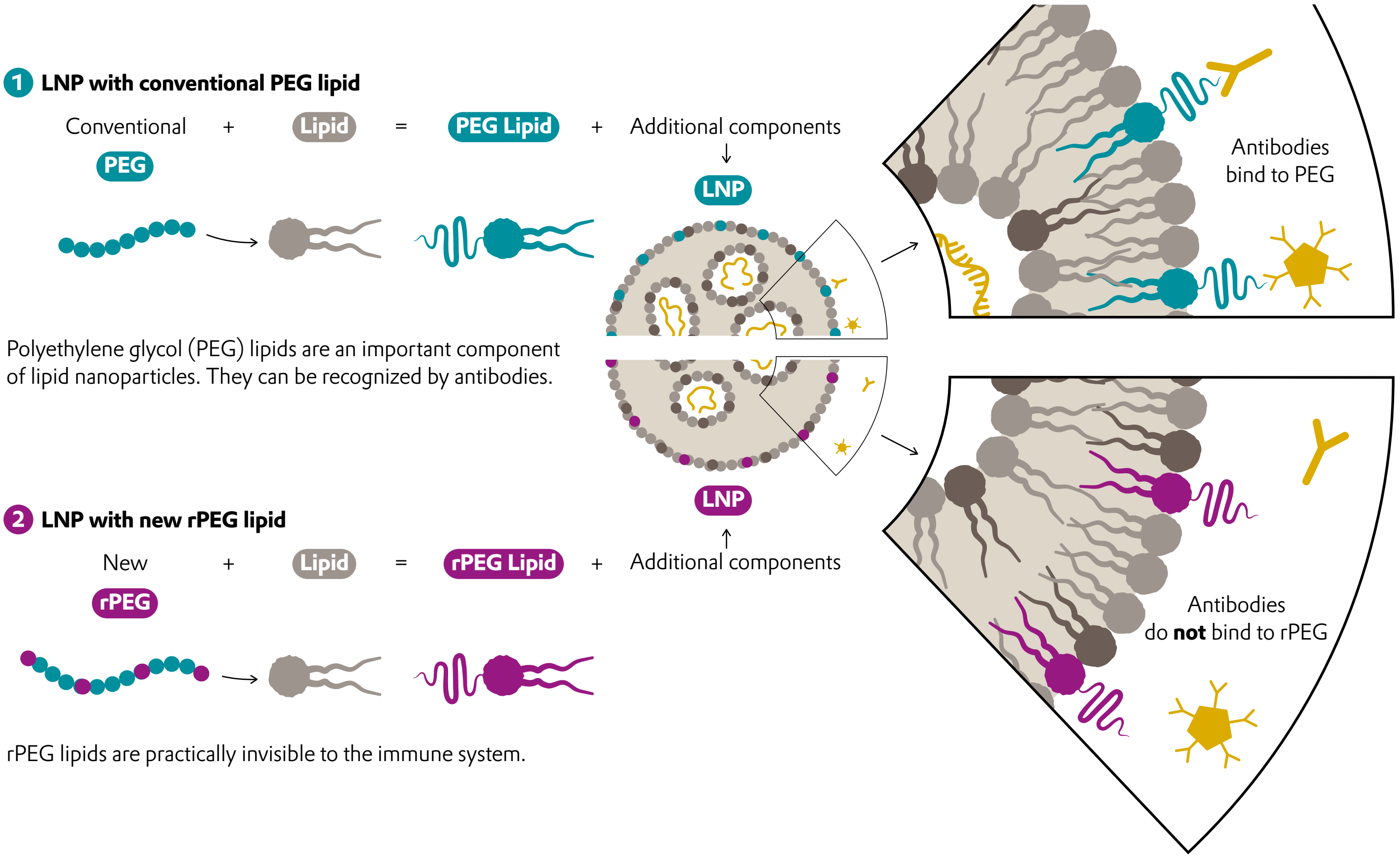
LNPs are similar to drops of fat in water. These nanometer-scale droplets of fat comprise a carefully designed combination of various lipids. The PEG chains are located at the surface of the LNP. They stabilize the particle and avoid recognition by the immune system. The hydrophobic fatty acid chains of the lipid protrude inwards. The mRNA is located inside the LNPs.

“After we realized that rPEGs can be used to prevent the formation of antibodies to PEG, we approached industry,” says Frey. That's when he got in touch with Evonik. He knew that during the peak phase of the COVID-19 pandemic Evonik researchers had successfully produced important components for the vaccines from BioNTech/Pfizer—including customized specialty lipids. “When I told the Evonik researchers about our rPEG, they were immediately enthusiastic,” Frey says.

The Evonik researchers took on the task of conjugating the rPEG from Mainz to lipids and using the resulting compounds to develop functional LNPs. “We had the huge advantage that we could tap into existing resources

Built-in defense

How lipid nanoparticles (LNPs) become invulnerable to antibodies



in Hanau and Dossenheim for the synthesis and characterization of customized lipids," says Dr. Thomas Endres, who heads the project at Evonik. He formed a project team that brought together experts from several units—especially from the synthesis laboratory in Hanau and the formulation and cell culture laboratories in Darmstadt. The initial aim was to link the rPEG from Mainz with fat-soluble molecule segments to a lipid (see the infographic). Erich Kraus, a member of the lab team in Hanau, tested various conditions in small glass reactors. He varied the reaction temperature and the concentration of the individual reagents and the solvents, removed unwanted byproducts, and isolated the product.

INDUSTRIAL PRODUCTION ON A MINI-SCALE

"The first trials were sobering, with a yield of only about 30 percent of the desired rPEG lipid," reports Dr. Ulrich Klöckner, who heads the work in Hanau. It quickly became evident that the functional end of the rPEG molecule had to be modified to increase chemical reactivity. "Our colleagues in Mainz solved that problem very quickly," Klöckner adds. Using the modified molecule, the team in Hanau is now reporting yields of more than 70 percent. This is also important for potential industrial production, because a chemical process is cost-effective and sustainable only if a large proportion of the raw materials is converted into the desired end product. Currently, the researchers in Hanau are working to make the production process of the rPEG lipid even more efficient.

Many chemical products are produced by the ton. Quantities of LNPs and mRNA-based vaccines or medications are minute in comparison. The COVID-19 vaccine Comirnaty from BioNTech/Pfizer contains only 30 micrograms of mRNA. One vaccination dose has a volume of 0.3 milliliters. A 300-liter container would be big enough to hold vaccine doses for millions of people. →

Melanie Liefke, a member of the lab team in Darmstadt, fills small caps with lipid nanoparticles

"The rPEG technology has the potential to make mRNA medications safer and better"

THOMAS ENDRES, PROJECT LEADER AT EVONIK

At the Evonik lab in Darmstadt, Melanie Liefke uses the rPEG lipids and other components to produce the LNPs that are needed for further tests. Sitting at the laminar flow cabinet, she uses pipettes to precisely add doses of various liquids—rPEG lipids, three other lipids, and mRNA—to a thimble-sized plastic cap. Thanks to her experience and skill, she can produce functional LNPs in the desired sizes. "You have to mix the components quickly and gently, because the mRNA is very sensitive," she explains.

Well-structured LNPs are formed during the controlled mixing. This is partly because the mRNA, the rPEG lipid, and the other components assemble automatically, explains the molecular biologist Dr. Anne Benedikt, the head of the cell culture laboratory in Darmstadt. "This is because the material is self-organizing," she says. "For example, the fatty acids avoid water, and we can predict how the units assemble driven by their electric charge." The real challenge in handling mRNA lies in the fact that it can be degraded if the work is not performed in an ultraclean environment, she adds. "That's because we humans have enzymes on our skin that quickly degrade foreign mRNA—it's our innate protection system," Ben-

The initial characterization of lipid nanoparticles to determine their hydrodynamic diameter and zeta-potential

edikt explains. Researchers who work with mRNA in a laboratory therefore need to make sure the environment is ultraclean and free of these enzymes.

BIOLOGY AND CHEMISTRY ARE NEXT-DOOR NEIGHBORS

The LNPs are not only produced but also tested in Darmstadt. The team is investigating the interaction of LNPs with living cells. Katrin Häfner, a senior scientist at the cell culture laboratory, points to a transparent plastic microplate under the laminar flow cabinet. The panel has indentations that are filled with a liquid. In some the liquid is rather orange, in others it's purple. "In this test we determine the highest concentration of LNPs that the cells can tolerate," she says.

Next door, researchers are investigating whether the LNPs are successfully delivering mRNA into the target cells. To do this, they are using special test systems that emit a dim light if the mRNA has been successfully transferred and if the transfer has been followed by the production of the target protein. The light is detected by a sensor. The better the carrier system performs, the brighter the light. →

"AN INNOVATIVE FIELD THAT IS DEVELOPING VERY FAST"

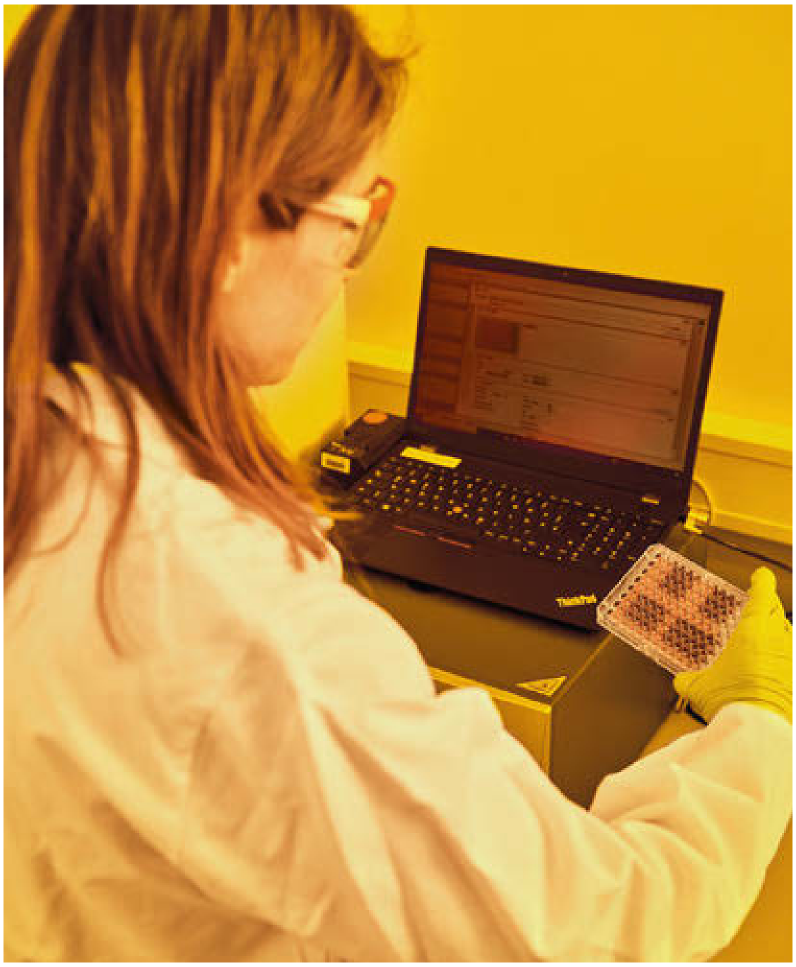
Dr. Andrea Engel, who is responsible for growth projects at Evonik's Health Care business line, talks about the significance of lipid nanoparticles (LNPs) for the mRNA active ingredients of the future

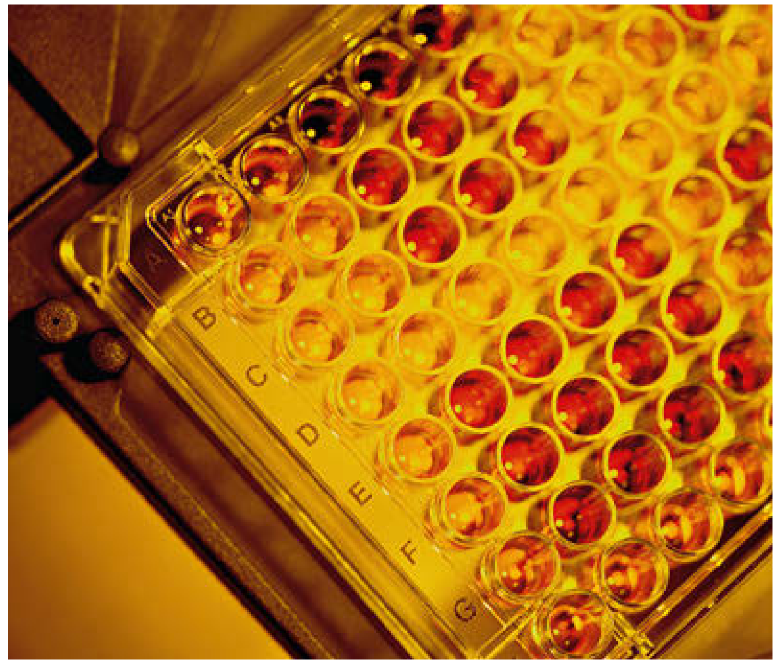
Ms. Engel, many people became aware of lipid nanoparticles during the COVID-19 pandemic. Why are these nanoparticles so important for the field of medicine?
LNPs have been regarded for quite a while now as a great source of hope for medicine, because they are smoothing the path toward medications that are tailored to individual patients. Before the COVID-19 pandemic, they were already used to make the active ingredients in cancer medications more tolerable for patients. As a partner of the pharmaceutical industry, we are constantly on the lookout for innovations so that we can continue to improve potential therapies. As the new rPEG lipids are demonstrating, LNPs are an especially innovative area that is likely to develop very fast in the years ahead.

How are you preparing for this boom?
We're developing new customized lipids, we can formulate active ingredients such as mRNA in LNPs, and we are proficient in the development of the relevant processes. We've got very experienced engineering teams that can convert the production of a few milliliters in the laboratory into a stable industrial process that can supply many liters of the product in pharmaceutical quality. Our customers can receive everything from a single source. That accelerates the development of new medications.

Where are your lipid operations based?
For customers in the pharmaceutical industry, it's important to safeguard the delivery capability of critical starting materials so that vital medications can always be produced. That's why we've distributed the development and production of lipids and LNPs all over the world. In Hanau, lipids are developed and produced in small amounts. At our location in Lafayette, Indiana, in the USA we recently invested in a big plant for the production of lipids for mRNA active ingredients. In Vancouver and Darmstadt we do the early development of formulations for LNPs and conduct the initial tests with them. In Vancouver we also develop the processes for supplying new products for clinical trials.

Who is supporting you in the development process?
We cooperate with several universities. For example, since January 2023 we've been a partner in a project supported by the German Federal Ministry for Economic Affairs, in which universities and companies jointly develop new special lipids for mRNA medications. We're working together with Stanford University in California to create a polymer-based envelope for mRNA. Our aim is to enhance our portfolio of lipid-based products with these polymer particles in the future. And the project in which we cooperate with the University of Mainz focuses on the novel rPEG lipids.





The biochemist Katrin Häfner monitors cell cultures to see how well the lipid nanoparticles are tolerated

Endres, the project leader, is proud of what has been accomplished so far. "We have demonstrated that rPEG can be used to produce fully functional LNPs that deliver mRNA effectively under cell-culture conditions," he says. Moreover, this was accomplished quickly. "We went from the initial idea to a successful proof of concept in only one year," he explains, adding that research and development in the pharmaceutical sector is complex and time-consuming, often requiring many years of work.

ON THE WAY TO INITIAL TESTS

Endres says that the beauty of the technology lies in the similar properties of rPEG and PEG. "rPEG blends seamlessly into industrial production processes," he adds. Other research groups all over the world are trying to replace PEGs with other water-soluble macromolecules in order to avoid antibody formation. However, these macromolecules were chemically so different from PEG that development of completely new production processes would be needed.

Another factor that promoted speed was the complementary expertise from both partners. "Together we cover the entire value chain from basic research to lipid production on a commercial scale under quality oversight," Endres says. The University of Mainz and Evonik also want to take the next step together. The LNPs made with the rPEG lipids must undergo further tests before the researchers can start thinking about applications in humans. If these tests are also successful, Evonik can offer pharmaceutical companies the rPEG lipids as a product and the LNPs based on them as a formulation option for mRNA active ingredients. According to Endres, "This would be an ideal addition to our portfolio."

During the peak phase of the COVID-19 pandemic, the magazine *Der Spiegel* devoted a long feature article to lipid nanoparticles and mRNA therapies. The article even speaks of a "magic bullet." Thomas Endres doesn't want to go quite that far. However, he's convinced of one thing: that rPEGs have the potential to make future mRNA medications better with an improved safety profile.

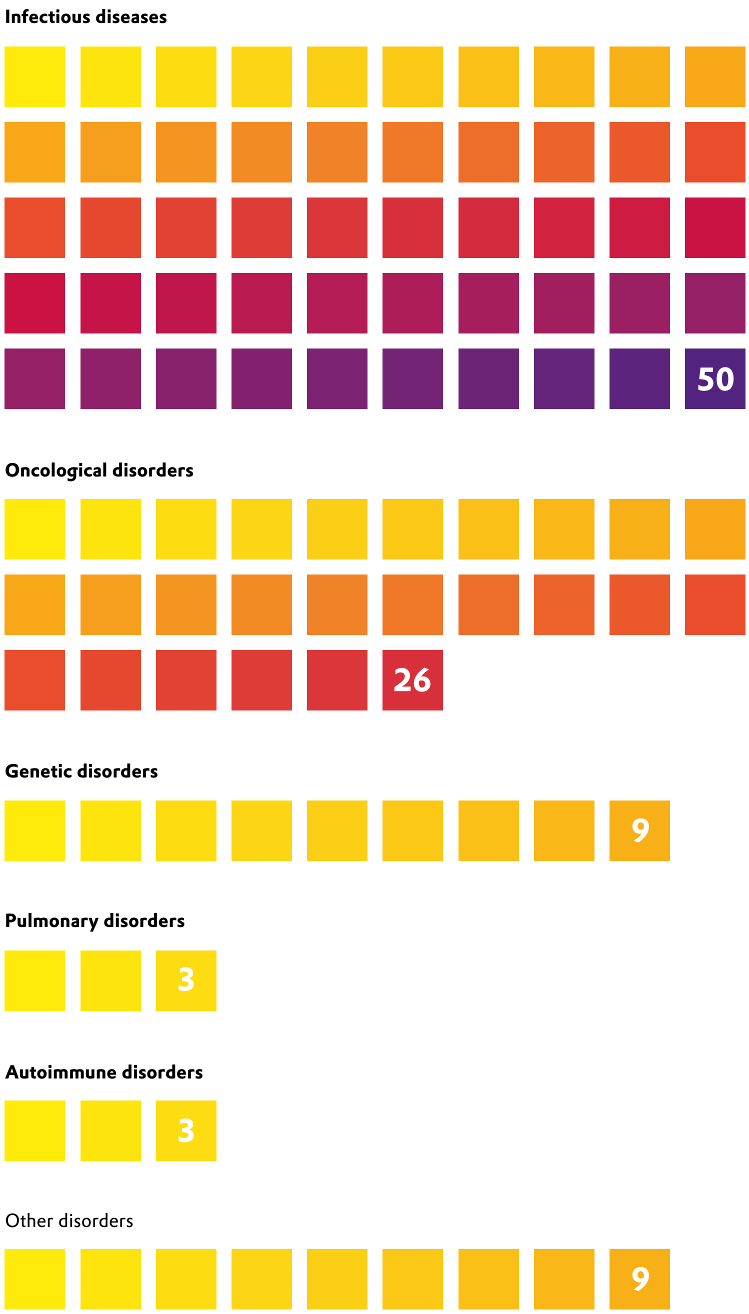
Tim Schröder is a science journalist who lives in Oldenburg. During his visit to the Evonik laboratories he was once again astonished to see how leading-edge research sometimes starts with a simple idea

PROGRAMMED FOR GROWTH

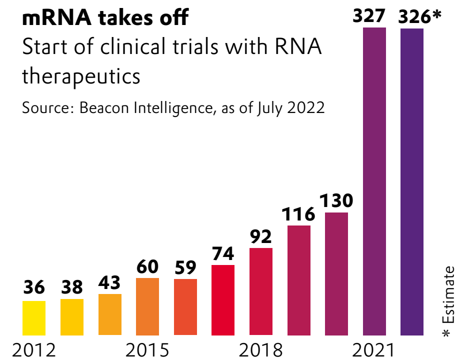
mRNA technologies are revolutionizing medicine. Which diseases are they aimed at? How quickly are the new therapies coming along? And how do the innovative active ingredients enter the body? A numerical overview

INFOGRAPHIC **MAXIMILIAN NERTINGER**

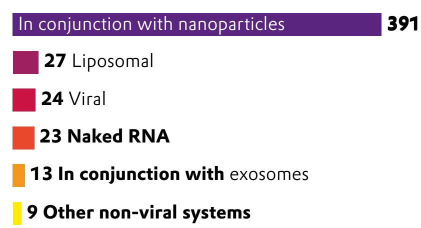
Beyond COVID-19
Areas of application of mRNA therapeutics and vaccines[1] in clinical development, in percent
Source: Roots Analysis, as of January 2023



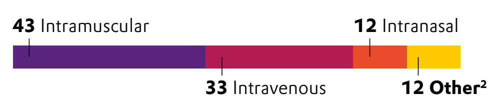
mRNA takes off
Start of clinical trials with RNA therapeutics
Source: Beacon Intelligence, as of July 2022



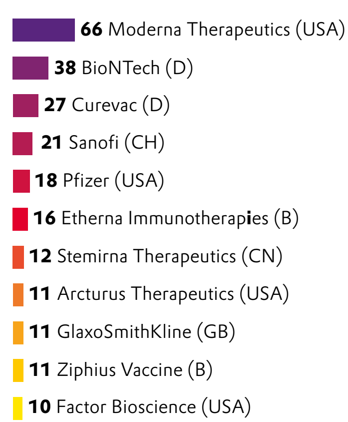
Nanoparticles in the lead
The most important transport systems for mRNA active ingredients by number of product developments
Source: Beacon Intelligence, as of January 2023



Under the skin
Routes of administration of mRNA therapeutics and vaccines[1], in percent
Source: Roots Analysis, as of January 2023



Sector pioneers
The most important developers of mRNA therapeutics by number of product developments
Source: Beacon Intelligence, as of July 2022



[1] Therapeutics for which the status information is available
[2] Including intradermal, subcutaneous, and external

Phages inject their genetic information into a bacterium, so that it will produce more phages—before it dies

RETURN OF THE BACTERIA EATERS

How can harmful bacteria be combated when antibiotics are powerless? The bacteria-eating viruses known as phages have the potential to save countless human lives. This therapy has actually been well known for a long time, but the knowledge was lost in the West after World War II. It could become very important for a healthy future

TEXT **BJÖRN THEIS**

The Red Army found itself confronting two enemies in 1942. One of them was the German Wehrmacht, which during its retreat from Stalingrad was ravaging the Red Army; the other was an invisible enemy that was causing a growing number of casualties. Cholera was spreading among the Russian soldiers and the civilian population. In order to get the situation under control, the leadership in Moscow sent Zinaida Vissarionovna Yermolyeva, one of the USSR's leading microbiologists, to Stalingrad. Because the city was cut off from medical supply lines, Yermolyeva devised a plan to make use of the natural predators of the cholera bacterium. She set up a production facility for bacteriophages and thus created enough anti-cholera suspension to treat 50,000 people a day. After just a few days, the epidemic in the city had been stopped.

In the decades since then, the fact that phages can be extremely effective in the struggle against bacteria has been forgotten in many places. However, in recent years researchers have once again been focusing more intensely on phage-based therapy. Bacteriophages—or phages for short—are viruses that select highly specific bacteria as hosts for their own multiplication process. For example, a phage that attacks cholera bacteria can infect only these bacteria, not human or animal cells. As a result, phages can be handled safely. Like all viruses, they dock onto their target bacterium, inject their genetic information, and reprogram it to produce additional phages after the infection—until no host bacteria are left.

TWO RESEARCHERS, ONE DISCOVERY

Phages received their name in 1917 from the French microbiologist Félix Hubert d'Hérelle, who had discovered them simultaneously with the English microbiologist Frederick Twort. Both of them observed the formation of holes in films of bacteria, within which the bacteria died off and stopped spreading. D'Hérelle suspected that special microbes were responsible for this phenomenon, and he named them phages, deriving this term from the Greek word "phagein" (to eat). He could not see these microbes. That only became possible when the transmission electron microscope was invented in 1931. Nonetheless, d'Hérelle immediately began to develop phage-based therapies against bubonic plague and cholera. His efforts were successful. The following two decades saw the rapid spread of commercially available phage-based products in France, the UK, Germany, Italy, and the USA—until the 1940s, when antibiotics entered the market. By contrast to the selective phages, antibiotics destroyed all bacteria with a high degree of effectiveness. As a result, research involving phages stopped almost completely in the West. Only in the USSR did it continue to develop.

THE WEST IS RACING TO CATCH UP

In Russia, Georgia, and Poland, phage-based products have been used and freely available for decades, but in most Western countries their use is not permitted. However, there are signs that a reevaluation is taking place. An important reason for this is the rapid spread of bacteria that are resistant to antibiotics. Approximately 1.2 million people have died from infections caused by antibiotic-resistant bacteria since 2019. According to some estimates, this figure could increase to ten million by 2050. In order to tackle these resistant bacteria with phage-based therapies, research is urgently needed. The cornerstones have been laid: The first National Forum on Phages convened in Germany in 2017, and the Leibniz Institute's German Collection of Microorganisms and Cell Cultures (DSMZ) has started to create a collection of potentially therapeutic phages. In the USA, some phage-based products have already been approved for use in the food production industry, for example in order to prevent *listeria* infections. In the West, the race to catch up with other countries' production of functional phages has begun.

That's a good reason for the Foresight team at Creavis to evaluate this topic in depth in the new Foresight focus project "GameChanger 2040." That's because phages could be suitable for some areas of application as sustainable and cost-effective alternatives to antibiotics.

Björn Theis heads the Foresight department at Evonik's innovation unit Creavis

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Phosphorus

"We are closing regional cycles"

Tim Bunthoff is a project engineer at the Gelsenkirchen-based infrastructure company Gelsenwasser, where he is head of the department responsible for sewage sludge recovery

LOG **ANNALENA BICKERT**
PHOTOGRAPHY **HENNING ROSS**

The American biochemist and science-fiction writer Isaac Asimov once described phosphorus as "life's bottleneck." In my view, this sums up the properties of the element. It is the precondition for all life on earth, because phosphorus compounds play a crucial role in biological growth and energy metabolism. That's why phosphorus is important for the food and feed industry. The element is one of the most abundant on earth, but it is unevenly distributed. Major deposits can be found in Morocco, China, and Russia. Because significant deposits are lacking within the European Union, the European Commission has classified phosphorus as a critical raw material.

Beginning in 2029, Germany will legally require phosphorus to be recovered from sewage sludge at municipal wastewater treatment plants. For this purpose, the sewage sludge is first thermally treated, i.e. dried and incinerated. The phosphorus is then found concentrated in the ash. In the future, this ash will be further treated by the Gelsenwasser Group in one of the world's first phosphorus recovery plants. In our favored process, hydrochloric acid is used to separate the ash into its harmful and valuable portions. This removes heavy metals from the material cycle and generates high-quality products. Our main product—calcium phosphate—is something like the mother of all phosphates. It is highly pure and can be used instead of imported phosphorus as a starting material for a variety of products, such as particularly clean fertilizers.

Our recycling concept requires little transportation and helps to reduce pollutant emissions and close regional nutrient cycles. This is an important step toward circular value creation. In this way, we can obtain clean phosphorus and conserve natural resources, thus significantly reducing the environmental impact.

Masthead

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“The art of progress is…

…to preserve order amid change and to preserve change amid order,” wrote the British philosopher and mathematician Alfred North Whitehead in his book *Process and Reality* in 1929. Whitehead was convinced that flowing transitions, rather than abrupt breaks, exist between all things.

From this perspective, the green transformation of the chemical industry cannot happen overnight. In order to succeed, it must move forward step by step. As a result, tried and tested processes can be continued while raw materials and energy from non-fossil sources are used. That benefits the climate and strengthens innovative capacity.