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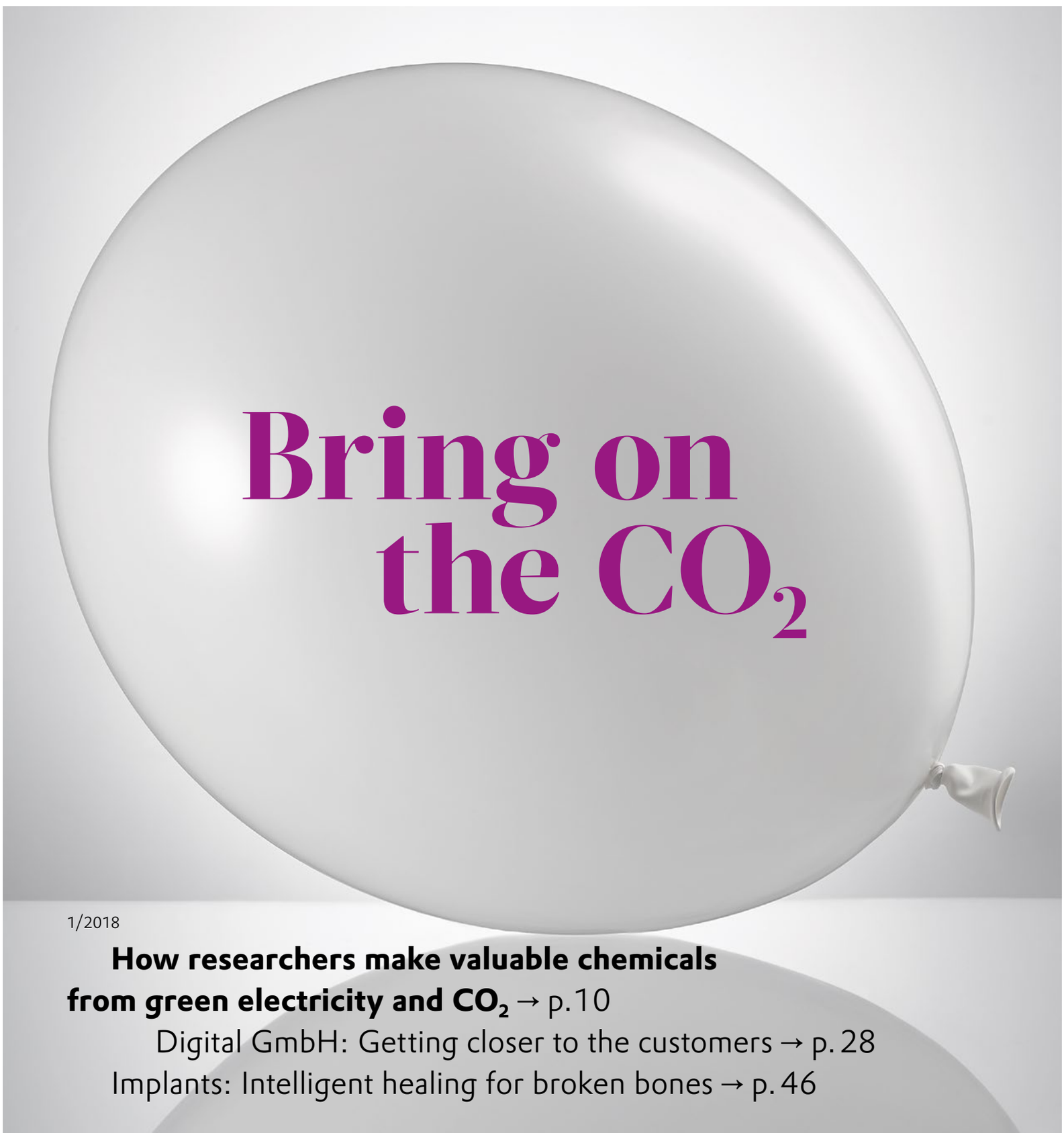
POWER TO CREATE

ELEMENTS

Research. Knowledge. The future.



Bring on the CO_2

1/2018

Georg Joachim Rheticus

Astronomer and mathematician

Georg Joachim Rheticus (* February 16, 1514 in Feldkirch; † December 4, 1574 in Kaschau) was an astronomer and a mathematician. Rheticus was one of the first scholars to disseminate the heliocentric theory of Nicolaus Copernicus, according to which the sun—in contrast to the Christian doctrine of that era—does not orbit the Earth. He studied with Copernicus, an astronomer and physician, for two years as his sole student, encouraging him to complete his work and publish it. In 1551 Rheticus published the most significant of his own works, the *Canon doctrinae triangulorum*, which included many trigonometric tables.

Feldkirch: city in Vorarlberg (Austria)
Kaschau: now Košice (Slovakia)
Nicolaus Copernicus: astronomer, 1473–1543

→ You can read more about the Rheticus project on page 10 ff.

DEAR READERS,

In the new Evonik magazine ELEMENTS, we are conducting an experiment. We'll present the same kind of science journalism you're already familiar with from the old ELEMENTS, but now we'll be putting it into a social, economic, and political context. We will continue to report on the latest research and innovation from Evonik—and we'll also ask questions about its social relevance. What kind of impact will this innovation have on my life? Who will benefit from it? And where will it be used in the future?

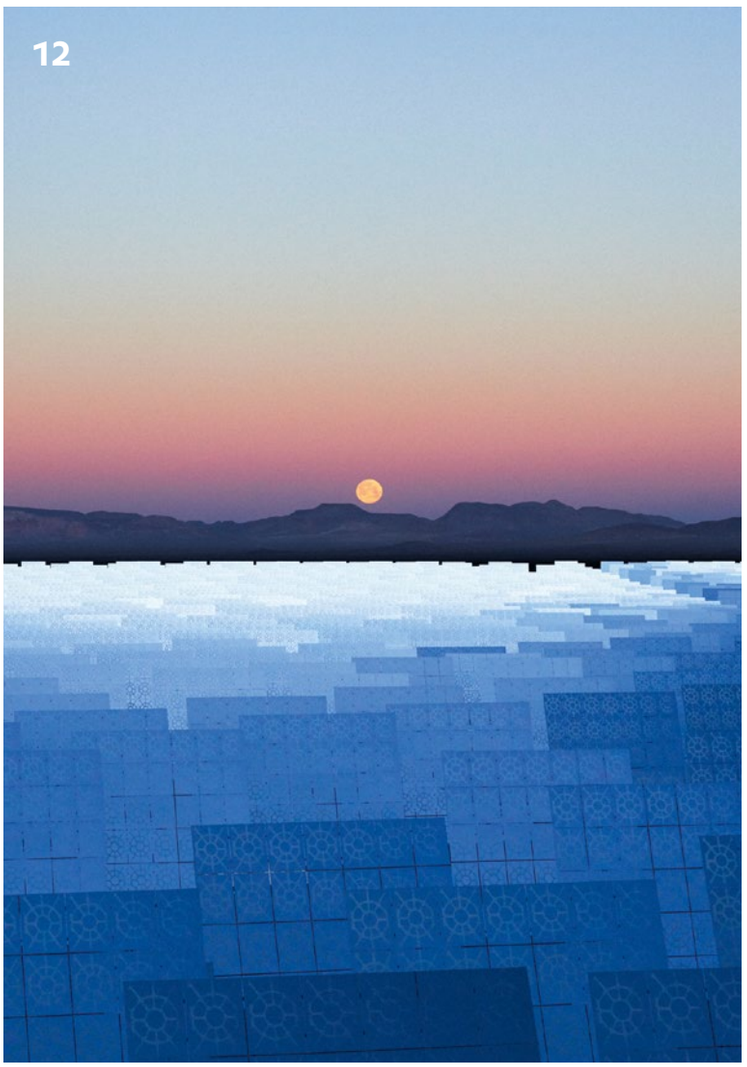
We won't be the only ones answering these questions. We'll also be getting input from the experts. In this issue, they will include Professor Ferdi Schüth, the Vice President of the Max Planck Society; Professor Walter Leitner from RWTH Aachen University; and Jens Monsees, the Corporate Vice President Digital Strategy at BMW. They embody expertise, strong opinions, and diversity. And they share our determination to make the world a little bit better day by day through research and innovation.

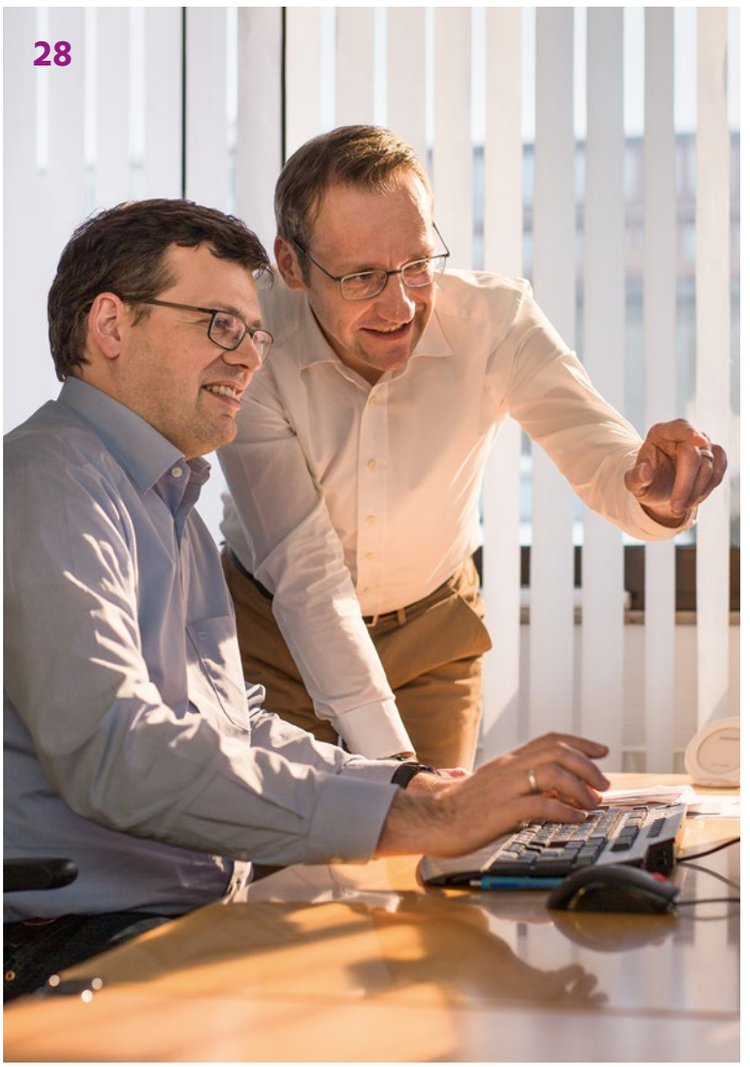
Apropos the world, Evonik is a German company with headquarters in the middle of North Rhine-Westphalia, but it operates in more than 100 countries throughout the world. We're interested in all of these countries. In each new issue of ELEMENTS, we will therefore focus on a different "Evonik country" and investigate the diverse relationships between the company, the region, and the people who live there. Our first photo journey will take you to Brazil. Also in this issue, Evonik CEO Christian Kullmann comments on US tax policy and issues a warning against trade wars. Finally, Professor Stephan Rosswog even goes one step further afield. He talks about his decades-long search for gold in outer space.

The new ELEMENTS will be published four times a year, in German and English, in a print version and digitally on the Internet. If after reading this issue you would like to continue receiving ELEMENTS, you can order your free subscription here: http://elements.evonik.com

I wish you pleasant and instructive reading, and I look forward to receiving your suggestions and comments at: elements@evonik.com

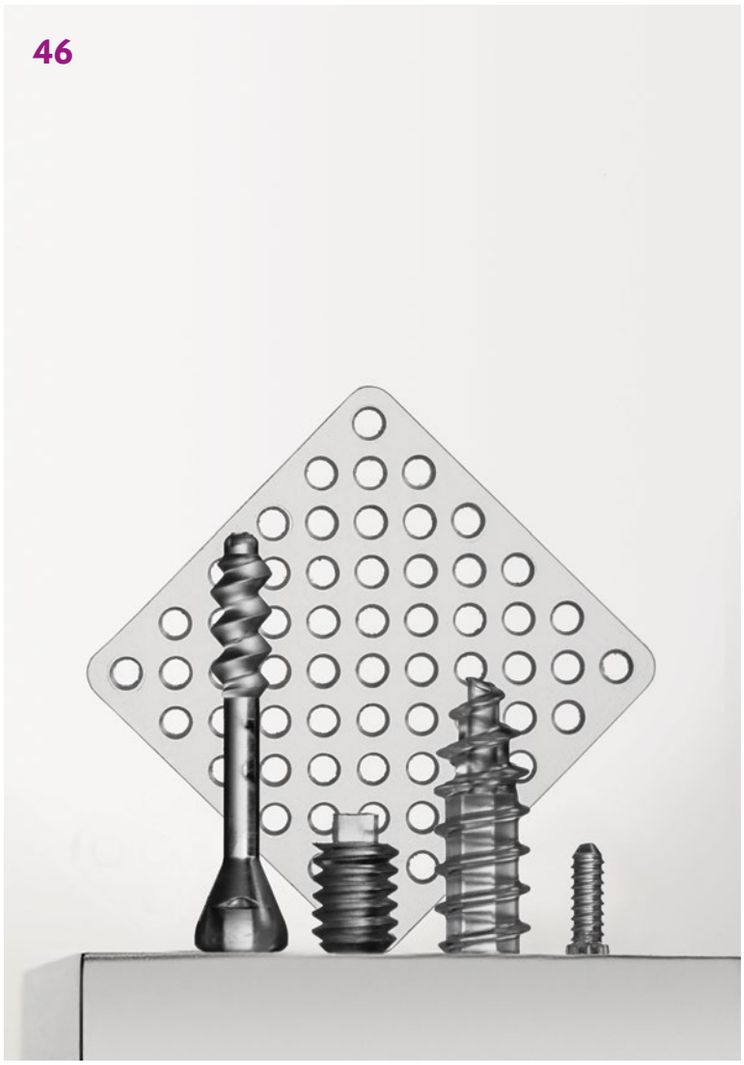
Matthias Ruch
Editor in Chief of ELEMENTS





BRING ON THE CO_2

CREATING VALUE WITH BITS AND BYTES



POLYMERS FOR BUILDING BONES

ELEMENTARY

1 “We try to prove that we’re getting things wrong”

Source: Wired

ASTRO TELLER is known as the “Captain of Moonshots” at X (formerly known as Google X). In the research lab of Alphabet, Google’s parent company, the developers have come up with a self-driving car, augmented reality goggles, and many other inventions in the “moonshot” category. Teller and his team aim to do nothing less than change the world. To make sure its researchers don’t get frustrated by the many setbacks they inevitably suffer on the road to a better tomorrow, X has a policy of celebrating defeats. For projects that flop, developers receive bonuses or even promotions. And at a festival analogous to Mexico’s Day of the Dead, they celebrate a Day of the Dead Projects with stage shows. On the next day they think about how to do better. It’s another kind of “error culture.”

“This robot works hand in hand with humans”

2

Source: ABB

YuMi is the world’s first genuinely collaborative dual-arm robot. He has been designed to work in close proximity to humans. Each of his two arms has seven degrees of freedom that enable it to move within the narrowest of spaces with a flexibility similar to that of human limbs. Moreover, thanks to diverse security features YuMi does not need a protective cage. “He works hand in hand with humans,” says Per Vegard Nerseth, Head of Robotics at the Swiss technology company ABB. The company also uses YuMi on its own production line at the ABB plant in the Czech Republic.

“We are revolutionizing the way we move around in the world’s major cities”

Source: Lilium

THE AIR TAXI from Lilium Aviation is the world’s first electric aircraft that can take off vertically like a helicopter—and then fly forwards like an airplane. The air taxi takes advantage of uplift under the wings, thus significantly saving energy. Lilium Aviation is a startup that was founded in 2015 by Daniel Wiegand together with three colleagues in Munich. Wiegand wants to achieve nothing short of a revolution in urban transportation. The first air taxis will soon be rising into the sky. These battery-driven aircraft will fly at speeds up to 300 kilometers per hour and be CO_2-neutral. Wiegand envisions being able to fly from Manhattan to JFK Airport in New York in only five minutes. For road traffic, that trip takes 75 minutes.

4

“How does it feel to be a robot? I was never anything else”

Source: The New York Times

BINA48 is a machine that can learn. She is a speaking robot head that was developed by Terasem Movement Inc. The company’s American founder, Martine Rothblatt, is one of the most dazzling personalities in the US tech community. She’s a lawyer, space expert, inventor, and the CEO of the biotechnology company United Therapeutics. And she earns up to US$38 million annually, which makes her one of the best-paid women entrepreneurs in the world. BINA48 was based on the model of her partner, Bina. She is a “social robot” who was designed to interact with human beings, and she even has a sense of humor.

Chemicals from Sun, Wind, and CO_2

Can specialty chemicals be produced from carbon dioxide, water, and renewable energy? In the same way that plants generate glucose through photosynthesis? Siemens and Evonik are exploring these questions in the Rheticus project. If they succeed in creating this artificial photosynthesis, it would be possible to produce chemicals sustainably. This technology would also be used for energy storage, and it could react to power fluctuations and help to stabilize the electricity grid.

This issue presents several aspects of the Rheticus project—its scientific dimensions as well as its social implications. That's because Rheticus also represents a new conceptual approach to energy policy. The aim is to find a better balance between the environment-friendly generation of electricity and its economically viable consumption—and to design the social framework in such a way that everyone ultimately benefits.

ELECTRIFIED CHEMISTRY

Converting carbon dioxide with the help of electricity and bacteria into valuable specialty chemicals: In the next few years, researchers from Evonik and Siemens want to use an initial pilot plant to show how this process can be utilized on an industrial scale

TEXT **BERND KALTWASSER**

Sunlight, carbon dioxide (CO_2), and water are all that green plants need for photosynthesis, the most important process for building biomass; over time, this produces a mighty tree from a tiny plant. It seems simple enough on the surface—but when chemists and engineers try to emulate what seems to work so easily in nature, they have so far been faced with almost insuperable problems. In the Rheticus project, Siemens and Evonik now plan to show that artificial photosynthesis is feasible using renewable energy: From carbon dioxide, water, and energy, valuable specialty chemicals are obtained by a combination of chemical and biological steps.

As long ago as the 1970s serious efforts were being made to implement the concept of artificial photosynthesis. But despite many small successes in certain areas, the big breakthrough that would allow the process to be used cost-effectively and over a broad front has so far failed to materialize. Now Rheticus could change all that. In the year 2021 the first test plant will go on stream at Evonik's Marl site in North Rhine-Westphalia to produce chemicals like butanol and hexanol, both of which are starting materials for specialty polymers and dietary supplements, for example.

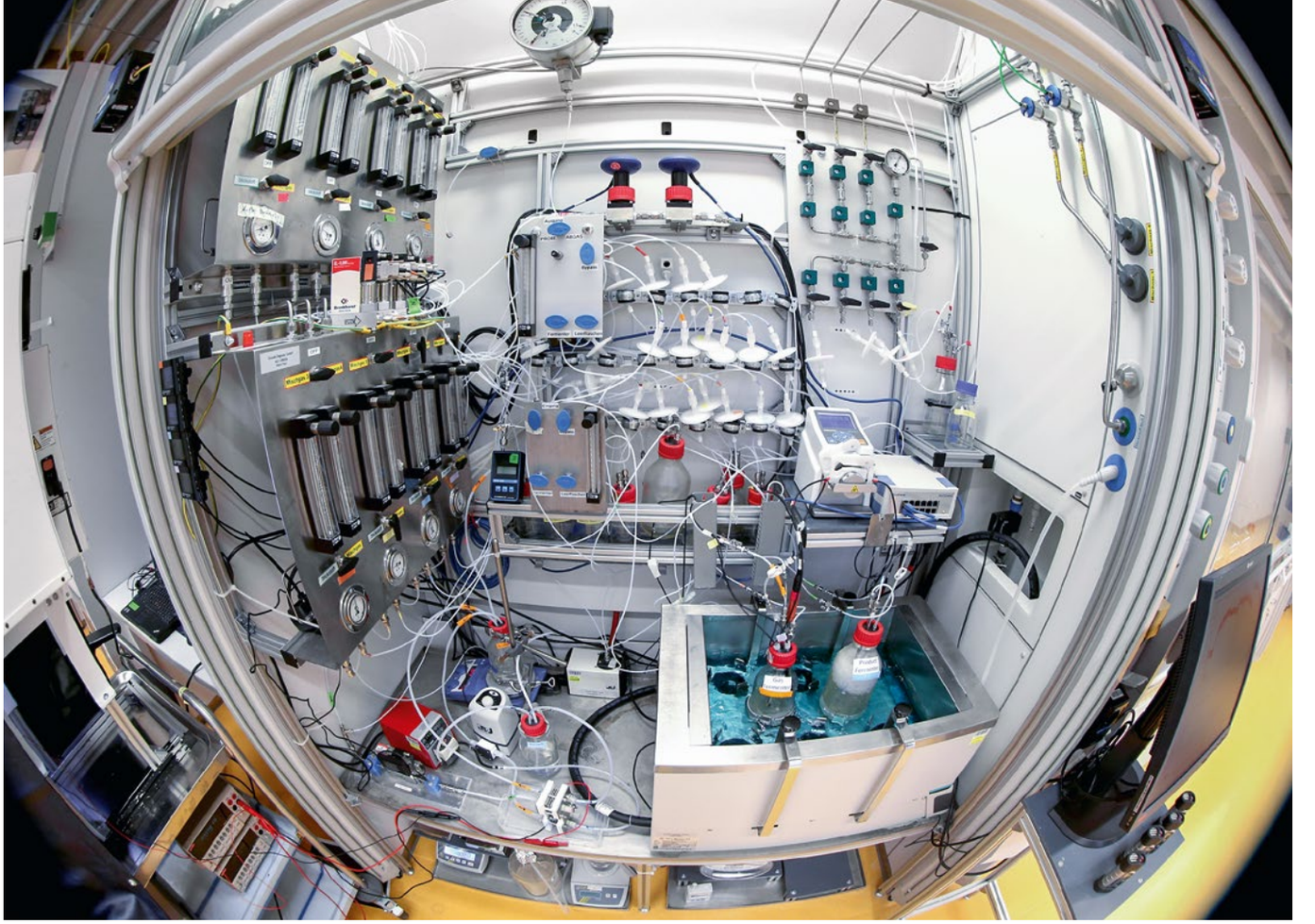
Rheticus is linked to the Kopernikus initiative for the energy transition in Germany, which seeks new solutions for a restructuring of the energy system. During the first funding phase of Kopernikus—in which Evonik and Siemens are also participating—the focus is on basic research; Rheticus, on the other hand, aims to rapidly put the technology into practice. The German Federal Ministry of Education and Research is supporting Rheticus to the tune of €2.8 million and the two industrial groups are investing roughly the same amount.

With this project, Siemens and Evonik are providing an answer to one of the central questions of the energy transition: How can volatile renewable energy be meaningfully used and intelligently stored?

Rheticus illustrates the power inherent in merging the energy and chemical sectors. Using power-to-X concepts—which describe how power can be used to produce chemicals, gases, and fuels—electrical energy that cannot be stored is converted into a form that can be stored over extended periods. In this way the chemical industry can contribute to what is known as sector coupling, in which power from renewable energies can be utilized as efficiently as possible—for example, to power electric vehicles in the transport sector, for methane production in heat supply, or in the chemical industry to produce specialty chemicals. With Rheticus, power is used to produce energy-rich organic compounds that are then directly used as specialty chemicals to add value.

RHETICUS SMOOTHS THE WAY IN INDUSTRIAL APPLICATION

The two processes that Rheticus links together have been known for a long time—and yet are quite new. Electrolysis, for example, has been used since the late 19th century for the industrial production of chlorine and sodium and potassium hydroxide solutions. In Rheticus, however, Siemens is pioneering the use of a CO_2 electrolyzer in industrial application. In this device, water is oxidized to oxygen (O_2) at the positive terminal (a titanium anode coated with iridium oxide) and hydrogen (H_2) is also produced. CO_2 is circulated



In a fermentation process—here on a laboratory scale—special bacteria convert synthesis gas containing CO into valuable chemicals

around the negative terminal, a silver cathode, where part of the gas is reduced by the electric current to carbon monoxide (CO). The resulting product is a synthesis gas, a mixture of CO_2, CO, and H_2. The ratio of the components is determined mainly by the flow rate of the incoming CO_2.

For the subsequent bacterial fermentation, the synthesis gas must be as free from oxygen as possible. This is because two different bacterial strains are used in Rheticus that are inhibited or even killed off by oxygen. Life scientists therefore describe these Clostridia as obligate anaerobes. In industrial biotechnology they are true exotics. The decision of the experts at Creavis, Evonik's strategic research unit, to use these bacteria is no coincidence. In contrast to commonly used microorganisms, such as *Escherichia coli*, they bring an invaluable advantage to Rheticus: The two Clostridia species used produce the alcohols hexanol and butanol naturally. This simplifies strain development. Moreover, if the wild-type strains are also used for production, plants can be more simply designed—without the additional safety measures that are required for handling genetically modified microorganisms. Clostridia grow in the absence of oxygen, which also helps maintain the cleanliness of the plant: Microorganisms in the ambient air do not thrive, and cannot survive, in this atmosphere that is so hostile to them.

Because the conditions for optimal growth for the two Clostridia strains are different, a system with two fermenters has been provided for the pilot plant. In the first bioreactor the incoming synthesis gas is metabolized by *Clostridium autoethanogenum* to acetate and ethanol. Both of these molecules then serve as starting materials in the second fermenter for the bacterium *Clostridium kluyveri* to produce butyrate and hexanoate. In the final step, these two compounds are reduced, again by *C. autoethanogenum*, to butanol and hexanol. →

"In the Rheticus project we're developing a platform for manufacturing chemical products in a much **more cost-effective and environment-friendly** way than the processes we're using today"

GÜNTER SCHMID

Dr. Günter Schmid
is the technical project responsible of the Rheticus project at Siemens Corporate Technology

MODULARITY TO ENSURE FLEXIBILITY

One special feature of the Rheticus platform is its modular structure. The electrolyzer and fermenters have been designed as independent units. This allows the plant size to be scaled as desired and adapted for local conditions. The possibility of developing further modules also offers unprecedented flexibility in relation to raw-material sources and the products produced. In conjunction with *C. autoethanogenum* the bacterial species *Pelobacter propionicus*, also an obligate anaerobe, could metabolize, for example, CO_2 and ethanol to acetate and propionate. Oleaginous yeasts would be able to convert the substances formed from *C. autoethanogenum* into lipids. These are just two examples illustrating the potential of artificial photosynthesis, which would possibly allow numerous chemicals and fuels to be produced much more advantageously and with greater environmental compatibility than has so far been the case. Furthermore, the Rheticus platform also serves as an energy store and can respond to power fluctuations.

The electrolyzer and fermenter units are designed so that they can operate continuously but need not always run at full capacity. Solutions based on this system could therefore make it possible one day to provide the extremely important balancing energy that must be available within seconds for stabilizing the grid.

Siemens develops and is already selling H_2 electrolyzers that meet these stringent demands; in principle it could do the same for the CO_2 electrolyzers used in the Rheticus project. There are no serious concerns that fluctuating power supply could cause problems for the bacteria: In nature, after all, they have successfully coped with changing conditions for millions of years.

SCALING UP TO INDUSTRIAL SCALE IS POSSIBLE

A way in which a relatively small plant could be designed for industrial use is described in a recent issue of the scientific journal *Nature Catalysis* (doi:10.1038/s41929-017-0005-1). According to this, a plant that could produce 10,000 metric tons of hexanol and butanol within a year would consume about 25.5 megawatts. Depending on location, weather conditions,

and the type of photovoltaic modules installed, this corresponds approximately in Germany to the annual energy output of solar modules with an area of 0.15 square kilometers. By way of comparison, according to estimates by the Fraunhofer Institute for Solar Energy Systems, all the photovoltaic modules installed in Germany up to the start of 2018, with a total power rating of 40 gigawatts, cover an area of about 300 square kilometers.

About 25,000 metric tons of CO_2 are needed annually to produce 10,000 metric tons of hexanol and butanol. This gas is abundantly available, as the German Federal Environment Agency has found that about 45 million metric tons of CO_2 emissions arise annually from industrial processes in Germany. Rheticus is therefore preparing the way for utilizing what is by far the most important greenhouse gas as a raw material, and thus preventing it from entering the atmosphere in the first place.

The researchers have also worked out in this publication how the scale-up could be effected. To process 25,000 metric tons of CO_2 the electrolyzer would have to be scaled up by a factor of 270,000—by, for example, increasing the electrode surface from 10 square centimeters to 1 square meter and operating 270 cells in parallel. This is not unrealistic: Both have already been implemented in other electrolyzers.

For the fermentation in the laboratory, the researchers use two one-liter bioreactors. To produce 10,000 metric tons of alcohols annually, the production rate would have to be increased by a factor of 21.6 million—by, for example, increasing the cell density in the fermenters by a factor of 30 and the volume of the tanks to 700,000 liters. These figures have also already been attained in other industrially used biotechnological processes.

CHEMISTRY FOLLOWS THE BEST AVAILABLE ENERGY FORM

Over the next two years about 20 Evonik and Siemens employees will be working hard to transfer Rheticus from the lab into a technical test plant on the 25-metric-ton scale. A few questions remain to be answered: How should the interfaces between electrolyzer and fermenter be designed? Will anaerobic Clostridia also pass the test on the industrial scale? Will it be possible to design a fully continuous process with the two Rheticus modules?

Despite these challenges, there has never been a better time than the present to contribute to the energy transition and create a new energy base for the chemical industry with a project like Rheticus. Looking back at the past, it is clear that in choosing its raw materials the chemical industry has always followed the best available energy form. A hundred years ago, coal chemistry was in its element, followed a few decades later by the golden age of petrochemistry. Thanks not least to the development of renewable energies, the availability of electrical energy over the last few years has been improving steadily and this trend is expected to continue. Electrical power is therefore of interest even for the energy-intensive processes of the chemical industry. An increasing number of experts expect an electrification of the chemical industry in the future. Rheticus shows one way that this could be achieved, thus affording a glimpse into the future. —

Dr. Thomas Haas
is responsible for the Rheticus project at Creavis, Evonik's strategic innovation unit

"With the Rheticus platform we want to show that **artificial photosynthesis** is feasible"

THOMAS HAAS

Two Steps to Green Chemistry

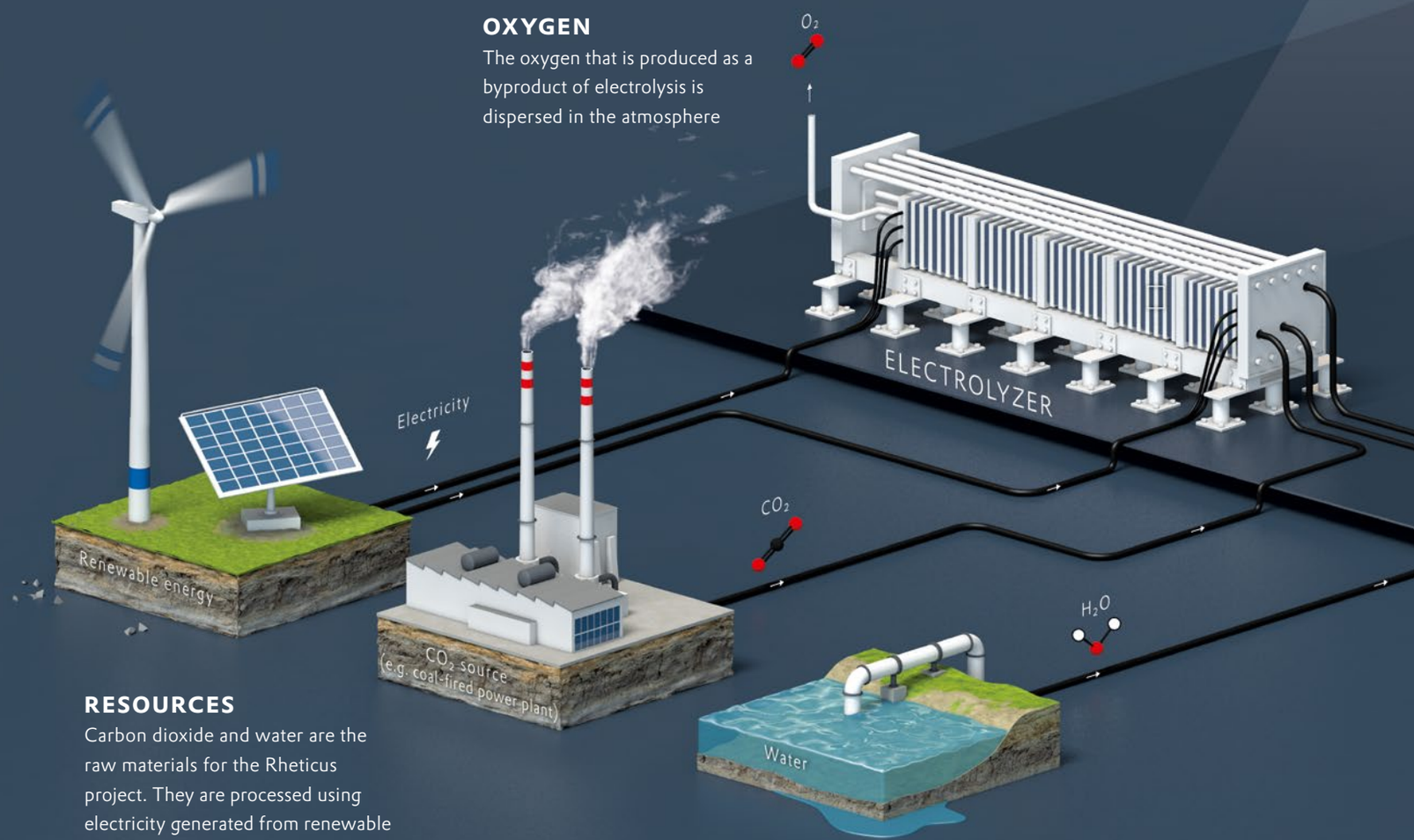
Evonik and Siemens are developing a sustainable process for producing specialty chemicals with the help of carbon dioxide, water, and electricity from renewable sources. A combination of chemical electrolysis and microbial fermentation can be used to produce valuable substances such as butanol and hexanol

INFOGRAPHIC **MAXIMILIAN NERTINGER**

KEY

- Carbon dioxide (CO_2)
- Water (H_2O)
- Oxygen (O_2)
- Carbon monoxide (CO)
- Hydrogen (H_2)

OXYGEN
The oxygen that is produced as a byproduct of electrolysis is dispersed in the atmosphere



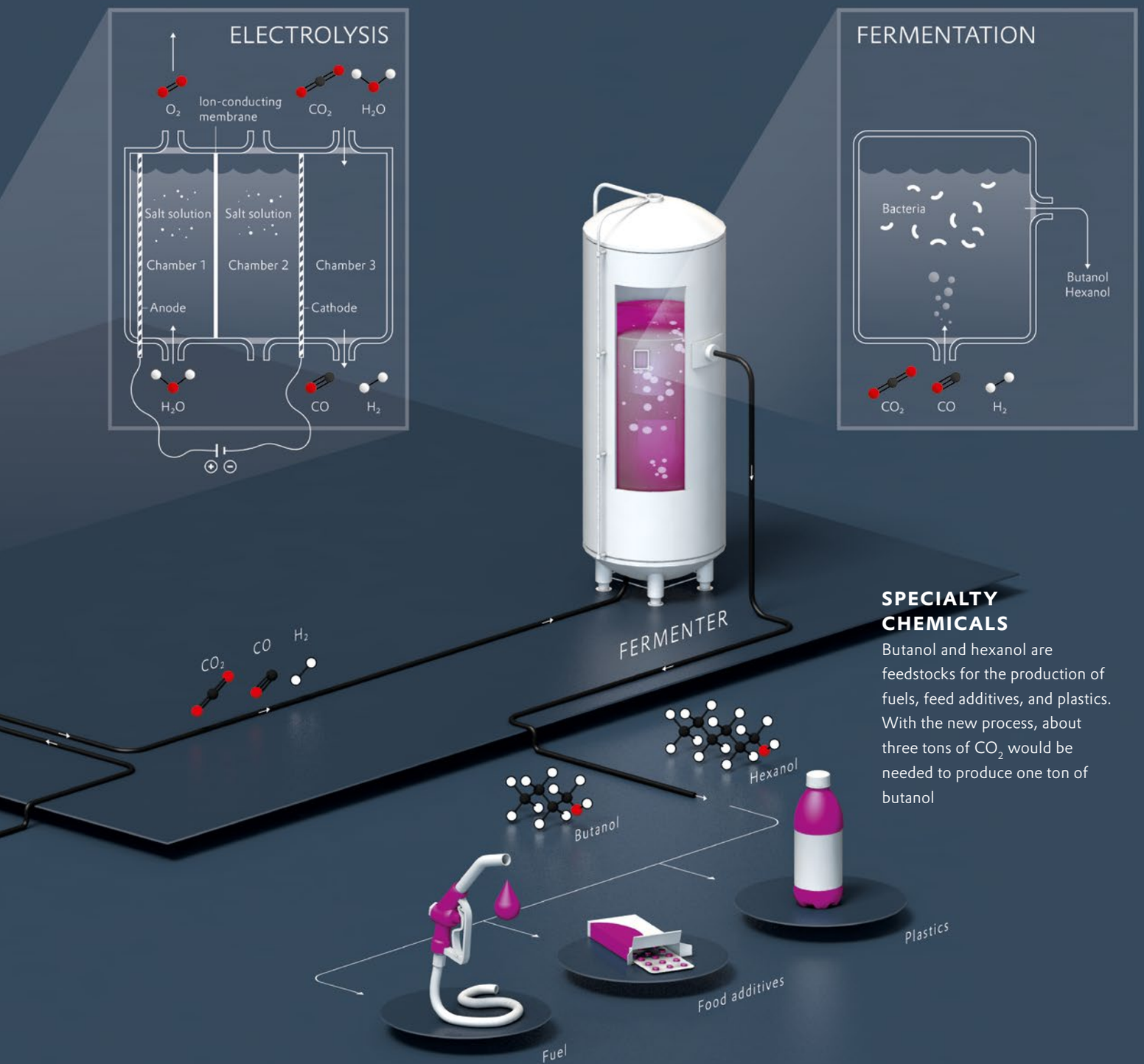
RESOURCES
Carbon dioxide and water are the raw materials for the Rheticus project. They are processed using electricity generated from renewable sources

1 ELECTROLYSIS

Inside the electrolysis cell, water is separated into hydrogen and oxygen at the anode. At the cathode, carbon dioxide is reduced to carbon monoxide. The result is synthesis gas, a mixture of CO_2, CO, and H_2

2 FERMENTATION

Inside the fermenter, bacteria metabolize the synthesis gas under the exclusion of oxygen. The alcohols butanol and hexanol are thus produced in several steps



SPECIALTY CHEMICALS

Butanol and hexanol are feedstocks for the production of fuels, feed additives, and plastics. With the new process, about three tons of CO_2 would be needed to produce one ton of butanol

“We’re Harvesting Renewable Forms of Energy”

Professor Walter Leitner is the speaker of the Power-to-X consortium of the Kopernikus initiative. The project deals with the storage and use of electrical energy from renewable sources by means of conversion into fuels and chemical products

INTERVIEW **JÖRG WAGNER**
PHOTOGRAPHY **HENNING ROSS**

Prof. Dr. Walter Leitner
holds the Chair of Technical Chemistry and Petrochemistry at RWTH Aachen University and is the Director of Molecular Catalysis at the Max Planck Institute for Chemical Energy Conversion

Mr. Leitner, research on CO_2 utilization has been going on for a long time. In the past, many projects ran aground because they were only able to produce small amounts of materials. Is that also true of the Rheticus project?

Of course we're looking for solutions on an industrial scale. That's the purpose of the Power-to-X projects. One key criterion of success has to be whether or not we can ultimately, as the goal of our vision, create carbon-neutral production processes for fuels and for complex chemical products. In this endeavor, smaller volumes are also important and valuable, because they make the business case—in other words, the calculation of a business model—easier.

Could the production of chemicals be completely decentralized in the future? In the same way as the generation of renewable energy?

Decentralization is a really major topic, and it's being extensively discussed in our group. Petrochemistry largely operates via large chemical facilities and takes advantage of economies of scale—but that could change. The production of chemicals could shift to places where you wouldn't expect it, such as biogas and wind power facilities. This is not a trivial issue. Is it easier to bring electric power to the consumer or to bring the consumer to the energy production facility? Logistics and social acceptance both play a role here. In order to answer this question, concepts such as Rheticus, which make modular facilities possible, are valuable.

How strongly do political decisions influence the success of such projects? After all, energy policy in particular is constantly being modified and repaired.

The fundamental vision of an "interlinking of sectors"—in other words, the integrated use of carbon-free power generation and alternative carbon sources—is independent of political frameworks, and it's a central component of sustainable chemical production. However, business cases change in tandem with the prices of raw materials and energy, and energy prices are of course also influenced by political decisions. People basically should not reduce the Power-to-X projects to a means of cushioning the effects of spikes in the power supply. Value should be created no matter what is done in this regard. In the course of the energy transition as a whole, we may have focused too strongly on the expansion of renewable energy generation alone. In particular, Power-to-X projects can help to restore a better balance between the environment-friendly generation of energy and its economically viable consumption.

Kopernikus

In the Kopernikus projects for the energy transition, scientists, industry, and users are working together to develop new energy systems and energy concepts to the point of large-scale industrial application. Kopernikus is the biggest research initiative of the German Federal Ministry of Education and Research concerning the energy transition. The ministry is providing €400 million between 2015 and 2025 for the following four topic areas:

- **New power grid structures (ENSURE)**
  Goal: reducing the costs of restructuring the power grid by combining centrally and decentrally generated electricity
- **Power-to-X (storage of excess electricity)**
  Goal: storing more than 90 percent of the renewable energy that is not used immediately, in the form of chemical base materials, gas or fuel
- **Industrial processes (SynErgie)**
  Goal: adapting energy-intensive production processes to a fluctuating energy supply
- **Systems integration (ENavi)**
  Goal: forging ahead with the energy transition in a sustainable manner with the greatest possible degree of social acceptance

The Power-to-X consortium alone unites 46 partners—research institutes, industrial companies, and social institutions. Why do you need such a complex organization?

We want to form a national platform for this topic and to bring together the areas of expertise that are scattered throughout Germany. We have a broad spectrum of stakeholders that represent specific interests and, most importantly, can also bring in existing infrastructures and research activities. These stakeholders represent the entire spectrum of the value chain, ranging from renewable energy generation to chemical products and engines—in the latter case, if they are fuel producers.

Does that mean you are now doing more coordination than actual development work?

No, because we're not starting out at Square One. Thanks to the experiences of our participants, we can expand existing networks and take advantage of existing areas of expertise. As a result, we don't have to spend the first two years getting different groups to talk to one another. That's very important, because it means our lead time was kept to a minimum. At Power-to-X we quickly created six very clearly structured research clusters. These clusters have an interdisciplinary structure, but they are always focused on a common goal through the bracket of a certain technology. That made it much easier for us to get started. →

"Power-to-X projects can help to restore a better balance between the environment-friendly generation of energy and its economically viable consumption"

WALTER LEITNER

What exactly is new about Power-to-X?

Mainly the interlinking of sectors that I mentioned before—in other words, the fact that we are bringing together very different industrial sectors against the background of the technologies we want to develop. These sectors range from energy generation to the chemical sector, the processing industry in the area of emerging chemical products, and the automotive sector. In addition, there's a new dimension in play here: the use of renewable forms of energy as an input for the conversion of materials. We're doing more than "only" producing methane in order to store energy. Or, to put it in other words, we're harvesting renewable forms of energy! And we're also doing this in complex chemical molecules for various value chains, not only in simple compounds for storing energy.

How is Power-to-X organized?

The first three clusters are examining how chemical base materials—for example, carbon monoxide and hydrogen—are produced from electrical energy. These "power molecules" are then the focus of the next three clusters, which are examining how to use them to create chemical products with a higher added value. From a chemist's perspective, one could say that we're first doing the electrolysis part, followed by the catalysis part.

That's the chemistry aspect. What about social acceptance of the projects? Social institutions are of course involved in the Kopernikus initiative. How have the discussions developed so far?

They've been very intense. And harmony hasn't always reigned. ...But the debates are very constructive. For all of the projects, there's a trio of sustainability issues: economy, ecology, AND social acceptance. For example, it's helpful to jointly consider at an early stage what community participation models might look like in a decentralized chemical production network. Municipalities can also participate, just as they would in the case of a wind turbine. However, this is still only a vision of the future. However, we are continuing this debate in parallel to our technical research. The goal is participation. The term "acceptance" doesn't really go far enough.

But basically there's nothing to criticize about the concept of Power-to-X, is there?

Well, there are some open questions. For example, there's the question of whether we utilize "excess electricity" or build specific facilities such as wind turbines to supply the chemical production plants with energy. Another question is how high the product risk is for the decentralized production of chemicals. In a chemical park everything is safeguarded, but at a site somewhere out in the country it isn't. We're dealing here with the discrepancy between local environmental protection, on the one hand, and global climate protection, on the other.

You've already spent many years doing research in the area of sustainable chemical production. Now this gigantic research offensive is falling into your lap, so to speak. Has Kopernikus been a godsend for you personally?

Of course I'm absolutely thrilled by the dynamism that is now streaming into this field! But the project didn't really come to us out of the blue. In order to get it, we had to do some work in the coordination group, together with Prof. Kurt Wagemann from Dechema and Prof. Rüdiger Eichel from the Jülich Research Center. ...The chemical conversion of fossil raw materials has made wonderful things possible for us—lengthening life expectancy, feeding ever larger numbers of people, raising standards of living—but it has also had an impact on the environment, especially in terms of CO2 emissions. We are now being given the opportunity to shrink our carbon footprint, while at the same time making better chemical products. That's a wonderful thing.

Kopernikus will run until 2027. What's your desired result for the projects?

I want us to take at least three technologies to the point where they can take, or have already taken, the step into real industrial production. Rheticus is already developing in the right direction by leaps and bounds. —

Environmental Pioneers and Nuclear Power Users

In Germany, 2018 began with a historic energy-related event: On the morning of New Year's Day, green electricity* covered all of the country's power needs for the first time. Here are some examples of how the energy transition is progressing in other countries

* Source: Bundesnetzagentur

RUSSIA

Unexploited potential

Russia has some of the world's biggest deposits of natural gas, petroleum, and coal. As a result, investments in renewable energies appear to be less cost-effective. The country is instead focusing on the further exploitation of fossil fuels. Russia's huge potential of hydroelectric, solar, and wind power remains unexploited.

MEDITERRANEAN COUNTRIES

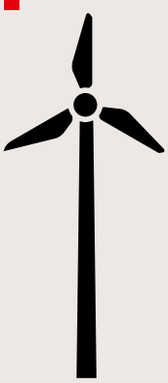
More green energy

The future-oriented Mediterranean Energy Transition scenario envisions a general reduction of electricity consumption and increased coverage from renewable energies. In fact, solar and wind power's share of the energy mix could triple to 27 percent by 2040. The scenario incorporates data from 25 countries from the northern and southern Mediterranean, ranging from Portugal and Albania to Morocco and Israel.

IRAN

Green electricity for domestic use, oil for export

Environmental and economic considerations are driving Iran's development. The more the country can cover its energy needs with renewables, the more oil it can sell abroad. In order to exploit Iran's ideal conditions for renewable energies, investors from Norway, Denmark, the UK, Germany, and Italy are planning to build large solar and wind energy facilities there.



CHINA

Renewable nuclear power

China has already reached its solar energy targets for 2020. It also plans to further expand wind power. However, the country's energy hunger cannot be sated by these means alone, so China also counts nuclear power among its renewable sources of energy. It currently has 38 reactors in operation while 20 more are under construction.

NORWAY

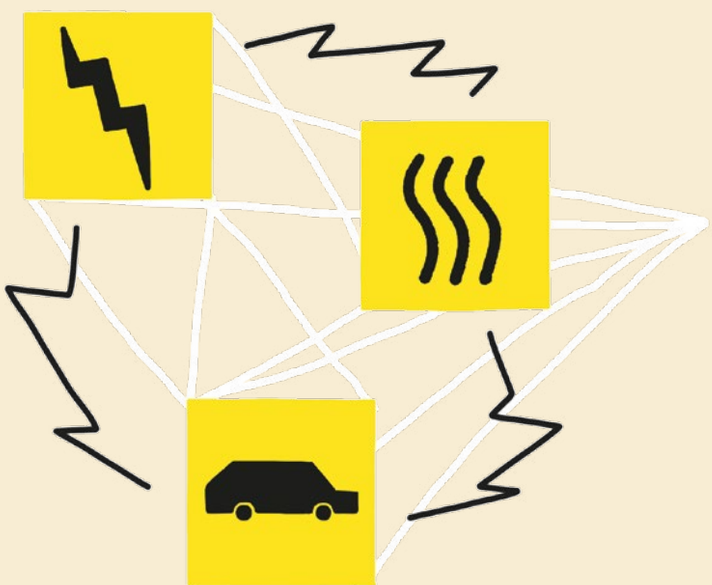
A climate policy pioneer

Hydroelectric power supplies more than 95 percent of the energy in the country of fjords. The promotion of electric mobility and a ban on the sale of cars with combustion engines starting in 2025 are strengthening Norway's role as a climate policy pioneer. At the same time, the country is benefiting from its huge reserves of natural gas, which make it Europe's second-largest supplier of natural gas, after Russia. In 2017, more than 40 percent of the gas exports were shipped to Germany.

HOW TO CONNECT SECTORS

If the energy transition is to succeed, the electricity, mobility, and heating sectors must move closer together. Here the chemical industry is playing an important role

TEXT **FERDI SCHÜTH**
TRANSLATED BY **TRANSFORM GMBH ON BEHALF OF EVONIK INDUSTRIES**
ILLUSTRATION **STEFAN MOSEBACH**



"The separation of the energy sectors cannot be sustained"

The German federal government has set itself the goal of reducing greenhouse gas emissions by 80 to 95 percent by 2050, compared to 1990 levels. In order to reach this goal, the use of fossil-based energy resources must be reduced to practically zero and, conversely, the proportion of renewable energies must be massively increased. With the exception of biomass and solar thermal energy, renewable energy sources are mainly available in the form of electric energy generated by wind turbines and photovoltaic systems.

Our energy system has traditionally been divided into three sectors: mobility, heating, and electricity. These sectors are supplied by a variety of energy sources. Mobility is primarily supplied by oil; heating primarily by natural gas, but also by oil, coal, renewable energies, and electricity; and electricity by coal as well as renewable energies, nuclear energy, and natural gas. The heating and mobility sectors are not greatly electrified today, but when they start to rely much more on electrical energy in the future, it will no longer be possible to sustain the traditional separation of the three sectors.

CUSHIONING FLUCTUATIONS IN SUPPLY

However, these sectors also offer the possibility of using flexible loads to cushion the fluctuations in supply that naturally occur when the sun and the wind are used as energy sources. So far, this cushioning has been done to a small extent through electric night storage heating systems, which transform surplus electrical energy from nuclear and lignite-fired power plants into low-temperature heating at night. In the future there will be a stronger focus on similar systems, such as those that charge electric vehicles with renewable energy during periods when there is an energy surplus. As a result, electric energy is becoming a link for connecting sectors that generally used to be separate.

The important role that this link between the sectors will play in the success of the energy transition was recently emphasized by a position paper and analysis that was part of the Academies' Project "Energy Systems of the Future."* This study concludes that the direct use of electric energy in the mobility and heating sectors will be considerable—and that it will also be the least expensive, as a rule. Conversely, synthetic fuels for vehicles and heating will play a significant role in a future energy system that will largely depend on renewable sources.

CHALLENGES FOR CHEMISTRY

This prediction involves an economic sector that has not been mentioned before in this connection: the chemical sector. The chemical industry is a relatively insignificant consumer of oil, which is its key raw material.

It consumes less than ten percent of the total oil produced. The decreasing use of oil as a source of energy poses two challenges to the chemical industry—but at the same time, these challenges could help it to open up new areas of business. Firstly, in the future oil as a raw material may not be available for many production processes in the same amounts or at the same levels of quality and prices as in the past. As a result, the chemical industry will have to find other production routes. Secondly, the increasing incorporation of electrical energy into chemical production processes will make available an additional component of value creation: the function of balancing loads in an energy system that is largely based on a fluctuating supply of electrical energy.

HYDROGEN PRODUCTION

Electrolysis is probably the most important process that can link the electricity system with the chemical sector. In all of the relevant scenarios, the production of hydrogen is a crucial element. In the abovementioned Academies' Project study of the energy transition, the authors conclude that a water electrolysis capacity of 15 to 30 gigawatts would be suitable for a system that is largely based on renewable sources of energy. This would correspond to about one third of Germany's current average electrical load!

In addition, hydrogen could be used in various value chains of the chemical industry, and carbon from CO_2 would definitely also be incorporated into the products. For example, hydrogen could be used to produce synthesis gas, which is needed to manufacture many chemical products. However, the costs of such a production process would be much higher than those of conventional methods. The prices of the conventional fuels produced with this chemical process would thus be considerably higher than the current market prices. As a result, it's especially important to initially develop such synthesis processes for high-priced or completely new products, because the additional cost of using electrical energy to make these products would be relatively insignificant. Such processes could be used for the market entry phase, and cost reductions could be achieved later on through economies of scale. That would make it a realistic alternative to expand the production of really large-scale fuels for vehicles and heating, such as Fischer-Tropsch fuels, methanol or oligomethylene ether.

* F. Ausfelder et al., *Sektorkopplung – Untersuchungen und Überlegungen zur Entwicklung eines integrierten Energiesystems*, publication series "Energiesysteme der Zukunft," Munich 2017

"The Rheticus approach is highly interdisciplinary"

PIONEERING TECHNOLOGY

The Rheticus project has the potential to eventually produce a pioneering technology of this kind. In this project, two especially interesting aspects come together. For one thing, the Rheticus approach does not begin with the generation of the hydrogen from which synthesis gas has to be produced. The synthesis gas is produced directly. In addition, the Rheticus concept aims to produce not relatively inexpensive fuels such as methanol and gasoline but much higher-value products such as butanol and hexanol.

These two factors, taken together, could lead to an interesting process that is not only convincing in economic terms but also could fulfill a desirable systemic function in the linkage between the electricity and chemical sectors. In addition, butanol is a promising fuel molecule that could create a direct link with the mobility sector as well.

AN INTERDISCIPLINARY APPROACH

Another striking aspect of the Rheticus project is its highly interdisciplinary nature. It draws on expertise from the fields of electrical engineering, chemistry, and biotechnology. This is a general characteristic of projects that aim to link various sectors. As a rule, they are so complex and cross-disciplinary that they can only be pursued through a collaborative approach—by scientists and technologists from a variety of disciplines, academic research, and industry. This is the only way to successfully mobilize the combined innovation potential of all of these fields in order to realize the energy transition through a strengthened linkage of the sectors. —

Prof. Dr. Ferdi Schüth is the Director of the Max Planck Institute for Coal Research in Mülheim an der Ruhr and the Scientific Vice President of the Max Planck Society

2017 Was a Good Year

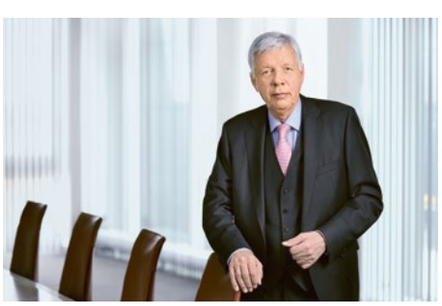
Evonik posted strong growth and plans to boost sales and earnings further this year

Evonik's earnings in 2017 successfully reached the level that had been forecast. The adjusted EBITDA of €2.36 billion was near the top of the predicted range of €2.2 billion to €2.4 billion. Sales rose by 13 percent to €14.4 billion. The factors contributing to this increase included organic growth and the inclusion of the acquired specialty additives business of Air Products and the silica business of Huber.

"2017 was a good year for Evonik," said CEO Christian Kullmann. "We've made progress in the implementation of our strategy, and we will continue to systematically pursue this path in 2018." On May 23, the Executive Board and the Supervisory Board will recommend that the Annual Shareholders' Meeting approve a dividend of €1.15 per share. Compared to the closing price at the end of 2017, the dividend yield would amount to 3.7 percent. This means that Evonik has one of the highest dividend yields of any chemical company. The Group expects that its sales and operating results will increase in 2018 and that its adjusted EBITDA will amount to between €2.4 billion and €2.6 billion.

Sales by segment

Werner Müller named honorary chairman



The Evonik Supervisory Board has unanimously named Dr. Werner Müller its honorary chairman. The appointment came at the recommendation of the Executive Board. In a statement, the Supervisory Board expressly praised Müller for his outstanding service to the company. "Werner Müller founded and managed Evonik. Moreover, he played a key role in making the Group what it is today," said Christian Kullmann, Chairman of the Executive Board. "Without him, Evonik wouldn't exist." Müller was the Chairman of the Executive Board when Evonik Industries AG was founded in September 2007. He has chaired the Supervisory Board since September 2012. At the end of February, Müller announced that he would step down from his position after the Annual Shareholders' Meeting on May 23, due to health reasons.

New plant to be built in Marl

Evonik plans to build a new manufacturing complex for polyamide 12 (PA 12) at its location in Marl, North Rhine-Westphalia. The plant will greatly increase the Group's total production capacity for PA 12 so that it can continue to meet the strong demand for this product. Due to its high stability and flexibility, high temperature resistance, and low weight, this high-performance plastic is used as a substitute for steel in many applications, such as automobile production, lightweight engineering, and oil and gas pipelines. PA 12 is also used in the medical sector and in 3D printing. The PA 12 market is growing by more than 5 percent worldwide. Growth is even in the double-digit range for uses in 3D printing.

Award-winning innovations

Dr. Harald Schwager, Deputy Chairman of the Evonik Executive Board, and Chief Innovation Officer Dr. Ulrich Küsthardt recently presented two teams of employees with the company's in-house Innovation Award 2017. One of the teams has developed a probiotic additive for poultry feed that promotes gut health in chickens; the other team has come up with a new technique that can use special C4 flows for chemical production—a first for the industry. Each of the teams can look forward to €30,000 in prize money.

A total of six teams made it into the final round, where they explained their projects to the judges, who consisted of around 300 top managers and researchers from the Group. "The products and processes that were presented today show that we are on the right track in boosting the Group's growth with innovations," said Schwager at the awards ceremony.

The probiotic GutCare®, a special strain of the bacterium *Bacillus subtilis,* improves the health and productivity of chickens and at the same reduces the use of antibiotics. The product was launched on the US market in early 2017 and is now also available in China, India, and Bangladesh.

The second winning team successfully developed FCC-C4, a new source of raw materials for the manufacture of C4-based products such as the antiknock agent MTBE and the plasticizer DINP (diisononyl phthalate).

Greater driving safety

The Preh company has developed a touch interface that is easy to use due to its tactile aids. It is currently being used in the four-zone climate control system of the 5 and 7 Series BMWs. The tactile aids are made possible by a covering consisting of the thermoplastic PLEXIMID® TT50. This polymethyl methacrylamide (PMMI) from Evonik is highly dimensionally stable under heat and is especially well suited for this application due to its temperature stability and the hardness of its surface.

Partnership with Lilly extended

In late 2017, Evonik and Eli Lilly and Company extended their long-term supply agreement, according to which Evonik will continue to supply Lilly with important pharmaceutical active ingredients and precursor products for drugs. The ingredients are produced at the plant in Tippecanoe (Indiana, USA), which Evonik acquired from Lilly in January 2010. Since then, Evonik has been manufacturing pharmaceutical active ingredients at the plant for more than 20 customers. With a production capacity of 170 cubic meters for pharmaceutical active ingredients, the plant is one of the biggest facilities of its kind in the world.

New membrane production

Evonik has put another membrane production facility into operation at its location in Schörfling (Austria). The new hollow fiber spinning plant manufactures membrane modules especially for the efficient production of nitrogen and for process gases. The new hollow fiber spinning plant doubles the existing production capacity for SEPURAN® membranes. Evonik invested around €50 million in the expansion of this Austrian location. SEPURAN® membranes can very efficiently separate gases such as methane, nitrogen, and hydrogen from gas mixtures.

Launch of the new membrane production facility

Opel relies on PLEXIGLAS®

The automaker Opel is using a customized PLEXIGLAS® molding compound from Evonik to make the striking taillights of its new Crossland X family SUV. The component's double curve, which is typical of the Opel brand, makes the lights look homogeneously red when they are lit. However, they are also easy to see when they are switched off. This effect is produced by optical waveguides made of PLEXIGLAS® 8N 3V219, which were now combined with light-scattering red additives for the first time. The optical properties of the brand-name polymethyl methacrylate from Evonik ensures that the light is evenly scattered and very well transmitted. This enabled the taillights to be made even thinner, resulting in a bigger trunk.

Partnership for ThreAMINO®

Evonik and Fufeng Group have concluded a cooperation agreement for the production of ThreAMINO® (L-threonine) for animal feed. It will enable Evonik to supply amino acids to customers all over the world. Fufeng Group, which has its headquarters in Junan, operates several large industrial facilities in China's northern provinces and is the world's largest producer of starch-based food and feed additives.
L-threonine, which Evonik sells under the brand name ThreAMINO®, is an essential amino acid. Because animals cannot produce it on their own, it has to be given to them in their feed. An optimal threonine content improves feed intake, weight gain, and the feed's nutritional value.

Perfect balance for SUV tires

Green tires conserve resources. A case in point is Evonik's silica/silane technology, which can reduce fuel consumption by up to eight percent. Evonik has now developed a new kind of silica, ULTRASIL® 7800 GR, whose tailored surface enables the material to meet the extremely high demands of SUV tires and all-weather tires. As a result, large tires and tires that are subjected to heavy use (such as all-weather tires) can now have a perfect balance between maximum grip and minimum rolling resistance.
ULTRASIL® 7800 GR will be produced in the USA because that country has the world's largest market for SUVs. Evonik is responding to the growing demand for silica in tires by building a new production plant in South Carolina in the southeastern United States. The new facility will begin producing silica in mid-2018.

CIO Award for Process Engineer

Dr. Frank Stenger
heads a specialist group for reaction technology at the process engineering unit. Among other things, the group is working on modular facilities and innovative reaction concepts

Frank Stenger from the process engineering unit at Evonik's Technology & Infrastructure Segment has received the Chief Innovation Officer (CIO) Award 2017. The company presents the award annually to honor the outstanding achievements of a single researcher. The man who won the award this year is a well-known team player. Stenger is a "Best Project Networker" who has managed nine publicly funded research projects for Evonik over the past ten years. These projects have been implemented in cooperation with 71 partners. The projects had a total volume of €50.6 million, which is a record for the company. Projects such as F^3 Factory, ENPRO, and ROMEO focused on the improvement of production processes and facilities. "We need a broad network in order to take part in successful consortia and find the right partners for our projects," says Stenger. In line with this approach, he has been working for many years on various committees at specialist associations such as DECHEMA and ProcessNet. "Over the years, I have created a network that also extends across Europe. That was an important door-opener for the EU-funded ROMEO project," says Stenger.
Partnerships of this kind are extremely valuable for Evonik. The Group has received around €130 million in funding for 195 research projects since 2007. The benefits that can't be expressed in monetary terms are even more valuable. They include new contacts to innovative partners, an enhanced reputation and visibility, and increased knowledge and expertise.

Venture capital for young digital companies

Through its venture capital unit, Evonik is involved in the Digital Growth Fund I of the Digital+Partners growth investment company, which is based in Munich. The fund supplies venture capital to rapidly growing young industrial tech and fintech companies that have proven and successful B2B business models. The regional focus is on Germany, Austria, and Switzerland. Plans call for the fund to have an investment volume of €300 million. "Our strategic involvement in the Digital Growth Fund I puts us in contact with young technology companies that are of interest to us. These contacts will help us to successfully shape the digitalization process at Evonik," says Dr. Henrik Hahn, Chief Digital Officer at Evonik.

Additional production line for ACRYLITE®

In spring 2018 Evonik will begin the construction of an additional facility for compounding the brand-name PMMA ACRYLITE® at its location in Osceola, Arkansas (USA). With this measure, the Methacrylates Business Line will almost double the location's production capacity for this special molding compound. The new compounding line is scheduled to be completed and put into operation in the first quarter of 2019. Evonik is thus the only PMMA manufacturer in the world to have a fully integrated MMA/PMMA network and associated compounding operations in the Americas, Europe, and Asia. As a result, the company can offer all specialty molding compounds in the three regions from its own local production facilities.

Acquisition of solid additives

Evonik recently signed a contract for the acquisition of 3M's compounding business with highly concentrated additives. This move expands the specialty chemicals company's growth opportunities in the highly profitable business with specialty additives. The acquisition encompasses the Accurel® product range that is manufactured in Obernburg, Germany, as well as the 3M location there.
This compounding technology for highly concentrated additives enables manufacturers of plastics to introduce large amounts of additives into a polymer matrix by means of a solid polymer carrier. It will enable Evonik to open up new areas of application in the packaging industry, for example.

Investment in a hydrogen peroxide startup

Testing of the HPNow generator in Israel

Through its venture capital unit, Evonik has acquired a stake in the startup HPNow ApS. It now has a minority interest in this company, which is based in Copenhagen (Denmark). HPNow has developed a technology that uses a fully automatic system to turn water, air, and electricity into hydrogen peroxide (H_2O_2). In the future, this technology will make it possible to directly produce H_2O_2 in small amounts at the intended location as needed. It will enable customers to use hydrogen peroxide in places where transport and storage problems have previously limited its application—in various agricultural sectors, for example. "HPNow can help the electrochemical production of H_2O_2 to achieve a breakthrough," says Dr. Bernhard Mohr, Head of Venture Capital at Evonik. Evonik is one of the world's biggest manufacturers of hydrogen peroxide, with an annual capacity of more than 950,000 tons and 13 production facilities.

Donald Trump's tax reform is putting the rest of the world under pressure to act. But copying the US model would be the wrong response from Europe

by Christian Kullmann

Christian Kullmann
is the Chairman of the Executive Board of Evonik Industries. The Group posts more than 20 percent of its sales in the USA

No one is obligated to like Donald Trump or to approve of his political measures. His isolationist ideas, unilateral US initiatives, and tariff barriers are not blueprints that can be used to solve the global problems of our time. But in spite of the backward-looking ideology that shows through in Trump's program, we have to take his political actions seriously. And that obligation, of course, has consequences for the whole world.

With his tax policy, the US president has achieved his first major political success on the domestic front. Trump is a businessman, and he has done something that makes many businesspeople happy: He has drastically cut taxes. For companies all over the country, federal taxes have been lowered from 35 to 21 percent. If we add the varying tax rates in the individual states, US businesses will have a total tax rate of 25 percent on average. That's 13 percentage points less than before.

Opinions may differ as to why this tax cut is coming in the midst of an economic boom and about its long-term consequences, as it has massively increased the USA's debt burden. But Trump is defining the rules, and the world is reacting because it's being forced to react. China, the world's second-largest economy, immediately raised the possibility of lowering its taxes on investments. Other countries will follow its lead.

Is this the beginning of a golden age for companies? Absolutely not. In the first place, it's questionable how long the lower tax rates can be sustained by the US economy. The upward spiral of national debt cannot continue indefinitely. The US government, like other governments, is responsible for future generations. Secondly, it's true that low tax rates directly favor corporate investments. However, ultimately local market opportunities are the factor that determines lasting success. Favorable fiscal conditions are hardly a good basis for strategic growth plans, because they can quickly change as a result of the national budget situation and the composition of the government.

Finally, negative side effects of Trump's drastic measures can already be seen. The president is vehemently proclaiming import taxes on foreign products. Such plans simply ignore the fact that for large regions of the world free trade is a strong engine of prosperity. Thanks to years of increasing convergence, the tariffs on the transatlantic trade in goods now average two percent. That has especially benefited trade between North America and Germany. Only a few exceptional products still reflect the protectionism of bygone eras. But now we can expect a return to tariffs of 25 percent on US imports of steel, for example.

How should Europe, and Germany in particular, react to that? To put it plainly, neither the creation of new tariff barriers at the EU's outer borders nor Germany's entry into an international tax-dumping competition would be the right answer. The European Union depends on free trade, and it therefore should not respond to bad politics with bad countermeasures. In Germany, the focus on consolidating state finances after decades of lacking accountability has only just gained genuine political importance. This policy should not now be carelessly sacrificed; instead, it should continue to serve our long-term interests.

Rather than engaging in a race to the bottom with the USA and Asia regarding corporate taxes, Europe should harmonize the tax rates within the EU. At the moment, EU states that have close political ties are still competing with each other through their fiscal policies. Today, 25 years after the founding of the European single market, the tax landscape within Europe still looks like the patchwork of small countries of the prewar era. Many cross-border companies would benefit from a harmonization of corporate taxes at the EU level, if only because of the elimination of the related administrative costs.

This harmonization should not be oriented toward Irish dumping-level tax rates nor toward the highest bidders. Under President Macron, France is leading the way by lowering its corporate tax rate from 33 to 25 percent, thus moving in the direction of the European average. This is an exemplary response to the "going it alone" approach on the other side of the Atlantic. We need to forge ahead with the integration of the European economic region, while at the same time strengthening the competitiveness of the businesses within it.

THE DIGITAL PACEMAKERS

Digitalization is revolutionizing entire sectors of the economy, including the chemical industry. What does this mean for Evonik? To get some answers, we visited the new Evonik subsidiary Digital GmbH in Essen, which is one of the driving forces of this transformation

TEXT **CHRISTA FRIEDL**
PHOTOGRAPHY **HENNING ROSS**

If you want to find out how people tick, ask them about their role models. All of the employees at Evonik Digital GmbH have put up posters of their role models in the company kitchenette. Captain Future is there next to Catwoman, and Mr. Spock rubs shoulders with Tesla founder Elon Musk. The role models include superheroes, science fiction characters, and visionaries who are pushing the envelope, taking on challenges, and changing the world with their ideas.

The process engineer Henrik Hahn, 49, doesn't look like Captain Future or Mr. Spock. He is Evonik's first Chief Digital Officer and the men and women who work at this subsidiary form his team. Together, they want to discover the Group's digital potential and use their ideas to set standards for the chemical sector. Rather surprisingly, they are doing this in a former savings bank.

This unadorned building is located on an ordinary street, with an old pub just around the corner. Are Hahn and his team really trying to shape Evonik's digital future here? "We needed a spatial concept that would foster innovation and communication and generate a real startup feeling," Hahn explains. The people who work here don't use their last names or insist on their academic titles. They work in open-plan offices instead of separate rooms and wear jeans instead of suits. "This too is Evonik," says Hahn.

Evonik is basing the development of its digital strategy on the following question: Does the way we currently manufacture products, do research, and communicate safeguard our future and our profitability? "It certainly doesn't happen automatically," says the chemist Catharina Müller-Buschbaum, who heads Digital GmbH jointly with Hahn. "The rules of the digital world are changing rapidly. Communication is becoming ever faster, more direct, and more transparent, and the boundaries between companies are becoming more porous."

A speedboat for all digital issues

"Digitalization has been an important topic at Evonik for years," says Hahn. Production is a case in point. For a long time now, smart tools have been ensuring that processes run efficiently and even tiny deviations in plant operations are detected early on. "What's new is that we now have a speedboat for all digital issues: Evonik Digital GmbH." In their team, Hahn and Müller-Buschbaum have brought together 25 experts from a variety of disciplines, including business administrators, technicians, scientists, humanities scholars, and social scientists.

The subsidiary, which was founded in 2017, receives input from the operating units and develops new ideas and business models until they can be transferred to daily operations. "Technology is driving digitalization," says Hahn. "Our task is to find out how we can optimally exploit it for our customers' benefit." The parent company provides the required funds. Evonik will spend around €100 million on digitalization activities by 2020. The most important questions here are: Which new business models will Evonik be able to develop in the digital world? How will these models benefit customers? How are digital methods and tools transforming research and development? And how can the company help its employees prepare themselves for a digital work environment? →

"THE RULES OF THE DIGITAL WORLD ARE CHANGING RAPIDLY"

CATHARINA MÜLLER-BUSCHBAUM

Take research, for example: In our globalized and digitalized world, research and development have become more important than ever before. But innovation cycles are becoming shorter and shorter. Companies that want to keep up have to achieve quick results that win over customers and markets. To do this, Evonik Digital tests agile working methods that focus on flexibility and fast adaptability. One example of these methods is the "design sprint," which was originally developed by Google.

Preventing false starts

"Design sprints enable us to quickly find out what our customers want and whether a particular idea has a market," explains the mechanical engineer Jörn Kiwitt, who transfers development methods from the digital world to the chemical industry. "We take our cues directly from the users in order to expand our range of methods for innovation processes."

Whereas the search for new additives or optimized synthesis processes typically takes several years, a digital sprint leads to the creation of an initial innovation concept within a single working week. On Monday, a small team sets the sprint's target, which consists of a question that needs to be answered. Possible solutions are drawn up on Tuesday. One of these solutions is selected on Wednesday and then implemented in the form of a storyboard—a line of arguments for the customer. On Thursday, the team tries to turn this solution into a kind of prototype, which can consist of a chemical substance, a sales channel or a service concept. On Friday, the prototype is presented to potential customers in the form of a short video, for example. This prototype is not a finished product, only a mockup for testing the customers' reactions.

This response determines whether, and how, the idea will be transformed into an actual product. "Design sprints enable us to work in a concentrated way and generate a high level of motivation, and they are very satisfying for everyone involved," says Kiwitt. Most importantly, they shorten innovation cycles, reduce costs, and prevent the development of products that are inappropriate for the market. Hahn and his team have conducted several such sprints to date—not only for the subsidiary's own topics, but also in cooperation with specialist teams from the Group. The results so far have been entirely positive. In one such sprint, Evonik Digital worked together with the winning team of the in-house Ideation Jam 2017 to create a three-minute video for a new additive that enables concrete to repair cracks itself. The additive has met with an enthusiastic response from potential target customers such as concrete producers and construction companies. The results are helping to transform the idea into a marketable product.

Interdisciplinary dialogue: The mechanical engineer Jörn Kiwitt and the business administrator Jenny Taheri

"DESIGN SPRINTS ENABLE US TO QUICKLY FIND OUT WHAT OUR CUSTOMERS WANT AND WHETHER A PARTICULAR IDEA HAS A MARKET" JÖRN KIWITT

A design sprint was also used to develop an idea for a chemical logistics system. This platform concept, which comprehensively combines information about goods orders and shipments with the status information of the various transportation systems, could lead to fewer empty runs and shorter waiting times in logistics operations. "It could boost efficiency by more than 20 percent," says Hahn. To make this possible, the information has to be provided transparently in real time. This means, for example, that the user always knows where every truck and shipment is located. Since March, Evonik Digital has been testing the concept at a shipping company in cooperation with colleagues from the logistics department, a business line, and the IT Data Lab.

Chemicals at a mouse click

The changes brought about by digitalization are especially drastic when it comes to commerce, where it is not restricted to the business with end consumers. It also opens up new opportunities for B2B enterprises such as Evonik to find out what customers really want and to offer them solutions that are tailored to their requirements. Specialists at Digital GmbH and the Functional Solutions Business Line are now gathering initial experience with a digital sales channel called ChemEasy. The name says it all: It takes only a few clicks to set the parameters (e.g. amounts, payment methods, delivery details) and complete the transaction.

For the past year or so, Functional Solutions has been using this channel to sell a variety of products, including catalysts for the production of biodiesel in Germany and seven other European countries. The initial customer response has been positive, and the team is now thinking about the next step. Over the long term, ChemEasy could become a platform where entire sectors, such as those of biodiesel producers or paper manufacturers, would be able to procure all of the chemicals they need from a variety of suppliers. Evonik plans to expand this digital sales channel throughout Europe this year and also launch it in the USA, Singapore, and Brazil.

Learning from the end consumer

Hahn and his team also want to learn from experiences with the end consumer business. "Analyzing the buying behavior of private customers enables us to draw valuable conclusions for our B2B business," says the project manager Philipp Tomuschat. "After all, every B2B buyer is also an end consumer." To gain such experiences themselves, the digitalization experts have created their own online sales channel for private customers: the MEDOX® project. It sells the dietary supplement MEDOX®, which is made from Scandinavian blueberries and red currants from New Zealand. The capsules contain plant-based substances that demonstrably have a positive effect on blood vessels, the cardiovascular system, and the metabolism of sugar.

Since the end of 2017 Evonik Digital has been selling the capsules in Germany exclusively through its new MEDOX® shop. This opens up a big playground for experiments concerning the wishes and needs of end consumers in direct digital sales. "We can precisely determine how large data volumes are recorded, structured, and usefully evaluated," says Tomuschat. "Once we have evaluated this data, we transfer our experiences to the business with industrial customers."

From product development to logistics and sales, Hahn and his team have many starting points where they can take action. Moreover, the effects that the digital transformation will have on the chemical industry are slowly becoming evident. "At Evonik, we have been dealing with chemicals for more than a hundred years. By contrast, our excursion into the digital age has only just begun," says Hahn. "But that's not a drawback. It's a big opportunity."

Partnerships

In order to promote digitalization at the Group, Evonik is forming partnerships at various levels. For example, a strategic partnership with IBM gives Evonik access to cognitive, cloud-based solutions such as blockchains and the Internet of Things. In a collaboration between Evonik and the University of Duisburg-Essen, the two partners are jointly enhancing customized training concepts for practical use in industry. In addition, Evonik is involved in the Digital Growth Fund I of the growth investor Digital+Partners, which provides venture capital to rapidly growing young industrial-tech and fin-tech companies.

"WE ARE VERY CLOSE TO OUR CORE BUSINESS"

INTERVIEW **KARIN ASSMANN**
PHOTOGRAPHY **HENNING ROSS**

Dr. Henrik Hahn is the Chief Digital Officer of Evonik, manages the operations of Evonik Digital GmbH together with Dr. Catharina Müller-Buschbaum, and is the Chairman of the Digitalization working group of the German Association of the Chemical Industry (VCI). In this interview, he explains the role that digitalization is playing in the chemical industry

Mr. Hahn, when it comes to digitalization the chemical industry is not exactly regarded as a pioneer. Is that also your view?

No and yes. In the area of production plant operation, I believe we are clearly a pioneer in the processing industry. The chemical industry has long been using process control systems—comprehensive digital package solutions for intelligently managing and visualizing plants. It also uses process simulation, which speeds up and simplifies the development and optimization of technical processes. But when it comes to comprehensively connecting customers and suppliers with our operations, making consistent digital customer experiences possible, and using established digital marketing tools—in these areas, other industries are ahead of us.

Has the chemical industry simply failed to respond to this trend?

I wouldn't say that. Digitalization isn't a revolution that happens overnight. It's an evolutionary process. And the chemical industry is in a comfortable situation: Our customers appreciate us because of the added value we reliably create. But will things stay this way? I doubt it. We are part of an industrial network consisting of customers, suppliers, and competitors, and digitalization is changing our interactions within this network. The sharing of information is becoming simpler, faster, and more direct. In the future, the focus won't be only on what we produce but also on how we interact with our customers. And that will have an impact on our processes.

Can you give us an example?

One practical example would be logistics services. More and more producers are connecting with their customers and thus gaining direct access to their business software. They are processing orders via digital channels and platforms, and as a result they can plan their carriers' capacity utilization much more effectively. Customers that don't use this option and prefer to use fax machines, phones, and e-mails are slowing down their own operations. They can no longer cooperate efficiently with many providers of logistics services.

What conclusion do you draw from that?

We have to make sure we adapt our own processes to this development. And by that I mean not only production but all of our business processes, from human resources to research, application technology, and finance. That also includes the use of artificial intelligence, although I prefer to use the term "augmented intelligence." At the same time, we should forge ahead with our own digital integration within our industrial network, create new digital channels, and develop new digital platforms. Above all, we have to get our customers enthusiastic about our offers in this regard. One example of that is the PLEXIGLAS® online shop for our business customers in the UK.

Enthusiastic about what?

Take a look at the end consumers. They don't buy products from an online shop because the transactional processes behind it are so wonderfully efficient. They shop there because it's convenient and because it's fun if the shop is well-organized. I think that our shopping behavior in the private sphere will spill over into industrial purchasing—that one day our customers will even expect to be able to buy our products online without having to take our business hours into account. And that will make the customer experience increasingly important.

What makes you so sure of that?

Let me give you a small example. At the beginning of last November we opened a store on the B2B platform Alibaba. There we offer silica, anti-foaming agents, and PLEXIGLAS®. Through this store we want to primarily address small and midsized companies in China that we might not reach otherwise. We received our first order even before we had officially announced we would be represented on Alibaba—even though nobody could have known about our store at that time. The customer had found us nonetheless while surfing through the platform.

How can we make online shopping for chemicals an "experience"?

We have to examine the customer's entire journey, from simply receiving information to purchasing a product. How does the customer make this journey, and what does he experience along the way? All the digital tools he uses must be designed to make him enjoy using them. They must make the customer's virtual journey through the company as easy as possible. If that happens, he'll enjoy coming back. Incidentally, this approach fits in well with the concept of specialty chemicals.

Which is more important: the digitalization of a company's internal processes, the company's integration into the industrial network, or the customer experience?

We shouldn't prioritize prioritization. Digitalization is an organizational task. Obviously, we address efficiency in the production process because we want it to basically be easily measurable and because it brings quick returns, as a rule. But efficiency can be tricky. Focusing on efficiency can be a distraction. It may cause us to neglect areas that are just as important or avoid dealing with certain issues at all. That's because it's much harder to measure the value of digital tools in internal business processes, such as those in human resources departments.

What about new business models?

At first glance, people are tempted by innovative business models that are as disruptive as possible; business model innovation is also a very popular buzzword. But these models require a great deal of patience. In the chemical industry we can't completely shift over to a digital business model—unlike the insurance sector, for example. Ultimately, molecules are the factor that makes new and more effective products possible for our customers.

Are you saying that there are limits to what can be digitalized in the chemical industry?

That's not what I meant. But there will always have to be someone who produces chemicals. The question is: Will our role be reduced to that of a manufacturer in the long term, or will we succeed in providing the customer experience as well? In other words, will we have to hand over part of the value creation process to vendors or online shop operators because they have better digital tools? Finally, it's also a question of asserting our innovation prerogative. Companies that are in contact with their customers know what the market needs and can react appropriately in the area of research and development.

What's your solution?

We want to not only keep the value creation process inside the company but also expand it. That includes entering into partnerships in order to boost digitalization—with renowned technology companies and science partners as well as startups and digital agencies that are not yet very well known. This is where we have successfully laid the groundwork for a digital ecosystem for the Group.

You and your team have moved out of the Evonik headquarters. Aren't you running the risk of operating at too great a distance from the Group?

No, not at all. We are a corporate unit within the Group. As a result, we have addressed many themes that the operating units have already anticipated or that we initiated together with them. Our operations are very close to our core business, but we're also able to look beyond our current horizons.

What aspects do you think will change at Evonik in the next ten years as a result of digitalization?

E-commerce will become much more important than it is today, not only because of its high degree of transaction efficiency but also because we'll be able to use it to attract new customers. We will also have a higher degree of automation due to assistance programs and robots. But above all, we will realize that human beings are indispensable. People will still be needed, because the machines and algorithms must be organized and controlled. And in order to do that we'll need more than just technology and data. At Evonik, human beings are the focus of digitalization—and we express that fact through our #HumanWork philosophy. Incidentally, I believe that we are pioneers in this area as well.

"Google Can't Work Miracles"

INTERVIEW **MATTHIAS RUCH, MICHAEL HOPP**
PHOTOGRAPHY **STEFAN HOBMAIER**

Jens Monsees worked at Google for seven years; today he is in charge of digital strategy at BMW. What opportunities does digitalization offer to German industry? And where do we stand in international comparisons? A talk about customer wishes, driving pleasure, and Larry Page's toothbrush test

Mr. Monsees, you are responsible for digitalization at BMW. What does digitalization mean for the auto industry?
At the moment, the connection between digitalization and the auto industry is often discussed in negative terms. People talk about the risks digitalization poses to jobs and employment and the alleged danger of German automakers being robbed of their business. That's how the situation looks to outsiders, but not to us. By contrast, we believe that digitalization offers our industry huge potential and gigantic opportunities.

What kinds of opportunities?
Our mission is to create added value for our customers. After all, we're not pursuing digitalization for its own sake. We're looking for benefits and added value for our customers. If we successfully deliver that to our customers, digitalization will offer us new areas of business.

Can you give us an example?
The traditional product development process works as follows: We do research and development, and through it we create new products. This is followed by marketing and sales models, and finally we expect customers to buy the product. That's how it used to be, everything very linear. Today, thanks to data analytics and the Internet of Things, we have the ability to understand what customers really need and want at a much earlier point in time. We're not the ones who try to figure out what our customers might reasonably need. Instead, data-supported analyses and artificial intelligence offer us the basis for better understanding customer needs. On this basis we can develop our products and services, deriving them directly from the customer. This means a paradigm shift, completely different processes, and a different mentality.

The further development of cars seems to be increasingly driven by software. Modern cars drive and park themselves almost independently, continuously communicate gigantic amounts of data, and almost seem to be computers on wheels. Doesn't that cause you some concern?
In the area of digitalization we are focusing on the opportunities rather than on concerns and misgivings. We believe that the privacy and safety of our customers are especially important. Why should this development be causing me concern?

Well, online commerce on the Internet is a threat to the very existence of many traditional →

"We're not pursuing digitalization for its own sake. We're looking for added value for our customers"

JENS MONSEES

Jens Monsees
As the Corporate Vice President Digital Strategy, Monsees is responsible for the digital transformation of BMW. He has a degree in business administration with a specialization in marketing and innovation management, and he has already worked for BMW before. He subsequently worked as an automotive specialist at Google

retailers. The business models of banks and insurance companies are also changing. And according to some gloomy scenarios for the auto industry, the automakers will one day be degraded to the status of suppliers for the software corporations.

I don't share this fear, but the idea behind it has to be taken seriously. When I get into my car today, I take along my Spotify and all of my digital services. They come from other suppliers, not directly from BMW. If we put our main focus on the customer, all of these elements have to be compatible and they have to function smoothly.

And what happens if you don't?

If many companies are competing over a single customer, a third party might come along later on from Silicon Valley or China and say, if you don't close these gaps and don't offer a really customer-friendly product, we're going to take away your business. That has already happened in the travel industry and in commerce.

How do you plan to prevent this from happening in the auto industry?

First of all, by reorganizing our entire business from the standpoint of the customer. And secondly, by abandoning the idea that we can develop the best customer solution for every need inside our own company. We are concluding partnerships and working together to bake a big beautiful cake for the customers, which will then belong to several companies.

So you'll be sharing the customers and sharing the business. Will this strategy still enable you to grow?

All of us will grow together.

Or will these partnerships ultimately mean that less of the big automotive cake will be left over for you?

No, we'll be getting more. Absolutely. After all, the cake is getting bigger all the time.

And how will it be distributed? In the future, how will you decide what you will do yourself and where you'll have to depend on partnerships?

We have to fill the interface to the customer with innovative and digital services ourselves. We have to do this better and integrate it more deeply than companies like Google and Apple. That's the way to do it. At my former employer, Google, Larry Page always called this the toothbrush test. Everybody needs a toothbrush and uses it twice a day. If I invent a product or a service that helps to fill a need in a similar way, it will be possible to monetize it.

"Germany should be much more self-confident and really think in terms of opportunities—after all, we are a country of engineers"

JENS MONSEES

Dividing up the big cake: In the course of the digital transformation, companies should not be afraid of entering into partnerships. Jens Monsees, the head of digital strategy at BMW, is convinced of that

And are we able to do that in Germany?

Are we? Absolutely! Germany is a country of engineers.

But the best software engineers are obviously located elsewhere.

I worked at Google for seven years, and I assure you that they can't work miracles. However, there is a crucial cultural difference. When an engineer in Germany achieves a 98 percent solution for a problem, he talks about the two percent that is still missing. When an American achieves a 60 percent solution, he calls it awesome, great, and wonderful.

What can we learn from that?

I think we should work with much more self-confidence and really think in terms of opportunities. From my experiences in the USA, I know that Google and Amazon are also copying many aspects of German industrial companies—for example, our absolute process orientation and our almost perfectionistic attention to detail. And planning things, very complicated things, very well.

At the same time, Americans joke a little about German "overengineering."

If it's really a case of overengineering, that's not good. But just take a look at a logistics center at Amazon. They are also striving for efficiency, precision, and the smooth interaction of huge gear trains. I think that the IT industry is learning a lot from the German production industry.

Is that what we mean by Industry 4.0?

Exactly. And from my point of view, this theme is really being defined by Europeans and Germans. On the other hand, of course at companies like Apple we also have the flexible approach, agile working, and the absolute orientation toward customer utility. All of these are good things, and they are now being adopted very quickly by the automobile industry in order to fill its own gaps.

If it's true that we know and can do all of these things, why is it that all of the globally successful companies such as Google, Amazon, and Facebook come from the USA and not from Germany?

I've been thinking about that question for a long time. I think one of the reasons is that the USA and also China, where these huge ecosystems have arisen and where the very successful companies have grown up, have gigantic domestic markets. As a result, they can start out by conquering their domestic markets without entering into big partnerships or being adapted for other cultures and languages. In this way they already grow to be very big before they go out into the world. One example of that is the online retailer Alibaba from China, which is now coming to Europe and the USA.

Matthias Ruch (left) and Michael Hopp with Jens Monsees at BMW headquarters in Munich

The German market is rather small compared to the USA and China…

…and that's why we can't monolithically develop things such as autonomous driving for ourselves alone and simply build them digitally. That being the case, why can't we build a platform together with other manufacturers and develop this area together?

Even beyond Germany?

Take Airbus as an example, in competition with Boeing. In that case the Europeans didn't talk about the individual pieces of the cake. Instead, they worked together to build up something big. Through collaboration across national boundaries, they reached critical mass.

In the auto industry you are now trying to reach critical mass together with Mercedes and Audi.

…in order to accumulate enough data. Digital systems are always critical masses: The more people are in the system and the more they use my services, the better can I individualize them and the more I learn about these people's needs. Nowadays that's called an ecosystem. I have to create a center of gravity that might not lie entirely within my own industry. It can also be a neutral area in the middle, around which the auto industry will then grow.

In the end, the vehicles, which used to be your core products, will be interchangeable.

The BMW Group always promises to deliver a premium product. That's why at BMW the steering wheel will also stay on board, and along with it the driving pleasure. At the same time, we want to use differentiated driving strategies to give our customers the option of participating in a video conference during a drive instead of driving themselves. In the end, digitalization primarily offers customers many new opportunities.

A “*land of the future*”—that was how the author Stefan Zweig rhapsodized about Brazil. He wasn’t the first one to pin his hopes on this country—and he won’t be the last

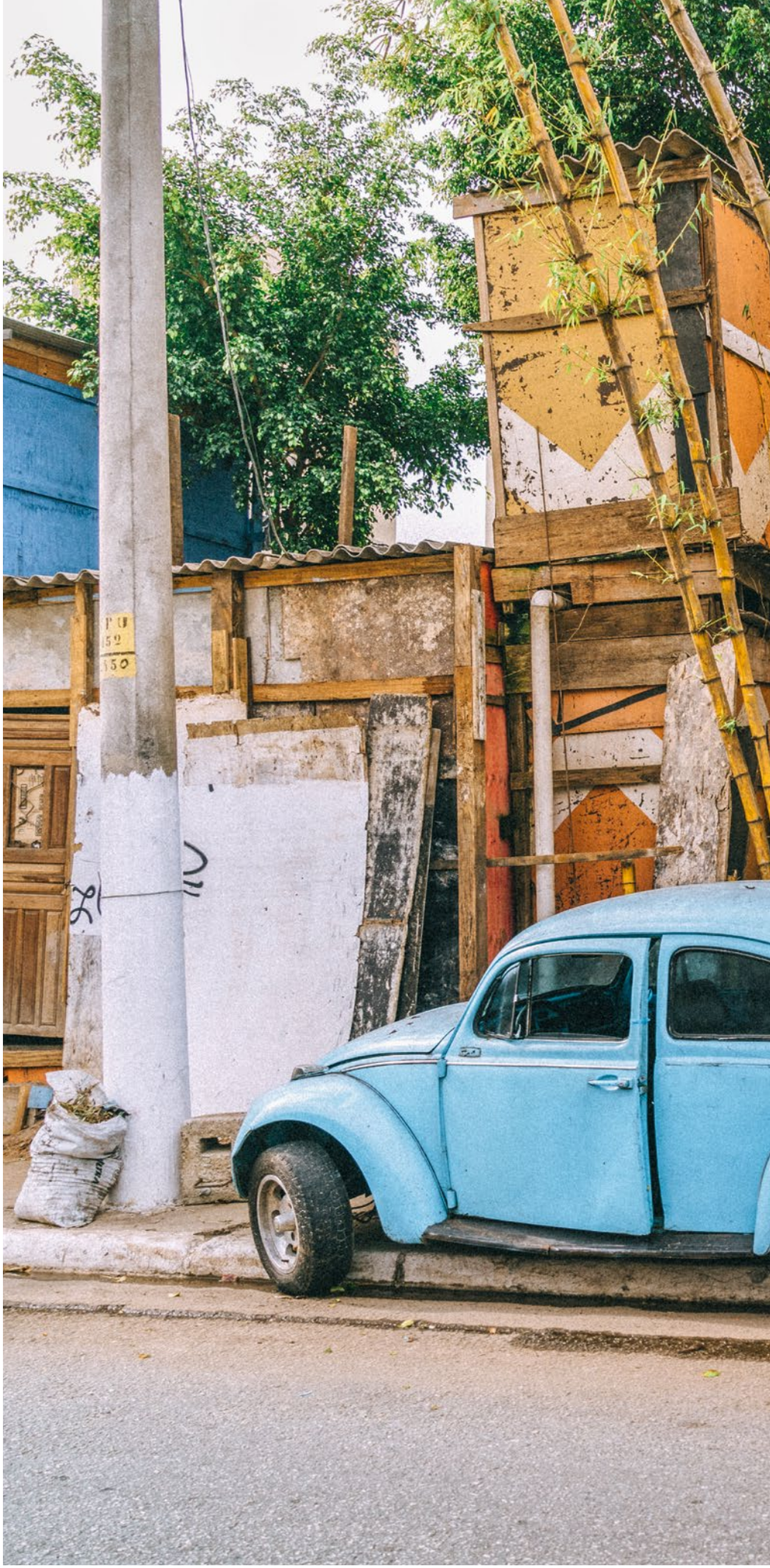
For Evonik, the country symbolized by Sugarloaf Mountain is an important international location and the gateway to South America

TEXT **TOM RADEMACHER**

Brazil is the world’s fifth-biggest country, with the fifth-largest population. In the past 40 years, Brazilians’ life expectancy has increased by 15 years and the country’s per capita gross domestic product has grown by 450 percent. Brazil is a land of superlatives that offers many opportunities—but also many challenges

Brazil's beaches and promenades resemble catwalks. In international comparisons, it's the fourth-largest market for cosmetics and body care products. Brazilians, especially Brazilian women, invest considerable time and money in looking attractive. In its laboratory in Brazil, Evonik has developed cosmetic formulations that include specialized skin care products for soothing the skin before and after tattooing

No other country in the world produces more sugarcane. Brazil also leads the global rankings of exporters for meat, coffee, and soybeans. Evonik supports agriculture with products including Biolys®, a biotechnologically produced amino acid that improves animal feed



Cars in Brazil:
In Brazil, the VW beetle is called the Fusca. Over three million of them had been made in Brazil by 1996, when production there ceased. Even though there are considerably more bicycles than cars in Brazil (70 million versus 43 million), cars are regarded as status symbols. The automotive market collapsed dramatically during the economic crisis starting in 2014, but recovered in 2017. Evonik operates a plant near São Paulo for producing silicas, which are primarily used for producing high-quality automobile tires with reduced rolling resistance


И: 358
FIFO'S

Since the boom years in the early 2000s, 30 million Brazilians have climbed up into the middle class. The people in this group are active consumers and are also very communicative. In 2016, the country had 1,189 mobile lines per 1,000 inhabitants

FOCUS
NUTRITION & CARE

Evonik conducts most of its South American business in Brazil. The Nutrition & Care Segment is especially well represented here, at seven locations in all. There Evonik produces, among other things, active ingredients and auxiliary materials for cosmetics and consumer goods. A recent addition is the production of silicas, which are used in almost all consumer durables, ranging from toothpaste to high-gloss paint.

Evonik locations

1 Cascavel
2 Rio Grande
3 Itajaí
4 Castro
5 Americana
6 São Paulo
7 Guarulhos
8 Barra do Riacho
9 Mucuri

Evonik has

516

employees at

9

locations in Brazil

RESOMER® polylactic acids are completely resorbed into the body

HEALING BONES WITH POLYMERS

Broken bones, torn tendons, and damaged intervertebral discs are painful and impair quality of life. Evonik's Medical Devices Project House develops materials that support healing and can spare patients further surgery. The first products are now being launched on the market

TEXT
KARIN ASSMANN

Perfect lightweight structure and high resilience: Bones combine maximum strength with minimal weight

Soccer players live dangerously. According to the German insurance association GDV, every fourth injury in this game is a fracture. To get the injured players back on their feet fast, surgeons often use screws, plates, wires, and pins to set the bone fragments and stabilize them until healing is complete. The fracture site gradually ossifies, the bone tissue regenerates, and the implants become superfluous. "Metal implants are usually removed after 12 to 24 months; for the patient this means more surgery, followed by extra time for recovery," says Dr. Andreas Karau, who is responsible for Biomaterials in Evonik's Health Care Business Line.

But metal is not the ideal material for treating fractures, because metal implants are much less elastic than bone. They therefore bear the mechanical forces exerted at the fracture site particularly well—too well, in fact, as Karau explains: "Bones need constant mechanical loading to regenerate and to maintain their density and strength. The absence of physiological stress can slow down the healing process." In the case of implants that remain in the body long-term, this may even lead to the shielded bone degenerating in the course of time. "This is known in medicine as the stress shielding effect. To prevent this, metal implants are often removed after a few months when the fracture has healed," says Karau.

A better approach is to make implants from a material that would allow mechanical stress to be exerted on the affected bone instead of intercepting it. This is where polymer-based devices have the edge: They are considerably more elastic than metals, and hence prevent the stress shielding effect. Evonik's experts have even taken the idea a step further: Implants made from RESOMER® biodegradable polymer offer the additional advantage of being resorbed by the body as the bone heals. Ideally, a bioresorbable polymer would be chosen in such a way that the strength of the implant is reduced as healing progresses and the load-bearing capacity of the fracture site increases. This eliminates the need for a subsequent intervention to remove the implant—which reduces the burden on the patient, the risk of infection, and, not least, the cost of treatment.

Evonik initiated systematic development of improved materials for orthopedic surgery in the Medical Devices Project House in Birmingham (USA) in 2014. This site was selected because the USA is the largest regional market for medical devices, with a share exceeding 40 percent; the size of the global medical devices market is currently €300 billion and is growing annually by about six percent. "We develop new solutions that help avoid additional surgery or accelerate the healing process," says Balaji Prabhu, head of the project house. →

Invertebral disc prostheses made of VESTAKEEP® restore the natural height of a disk segment

"We were able to customize implants by using printable biopolymers"

ANDREAS KARAU

For example, torn tendons are held in place with screws and pins made of RESOMER®

POLYMERS GAINING GROUND

Polymers, however, make up only about ten percent of the total implant market. "For many applications, such as artificial hip and knee joints or the stabilization of load-bearing bones, the available plastics that are approved for medical devices are simply not strong enough," says Prabhu. By contrast, polymeric materials are gaining ground in the treatment of fractures of the hands, feet, jaw, or skull, and for reconstruction of tendons in the shoulder, knee, or spine: A good 50 percent of implants in this area are made of polymers.

Evonik has been active in this market for many years and offers a wide range of polymer materials, including the RESOMER® brand of biodegradable polymers based on polylactic acids. Medical device manufacturers use these to produce screws, pins, and small plates that are degraded in the body after a specified period. Evonik also offers the polyetheretherketone VESTAKEEP®, which is used to make implants for the spine, mouth, jaw, and skull; such applications require both biocompatibility and good mechanical properties.

But the potential of these polymer materials in medical technology is far from exhausted. "If biopolymers could be processed by 3D printing, it would be possible to customize implants for each individual patient and operation," says Karau.

Around 25 researchers are working in the project house to realize this vision. "Most of them were freshly recruited, because it takes very specific expertise in a variety of different fields to develop new solutions and bring them to market readiness," says Karau. Some researchers, for example, have gained experience working for high-profile manufacturers of medical devices or in academia, while others have worked on the development of aerospace engineering materials. "So we're optimally positioned," adds Prabhu.

FIRST PRODUCT READY FOR MARKET LAUNCH

The Health Care Business Line is in the process of launching a product developed by the project house; this is a composite of RESOMER® polylactic acid and a synthetic hydroxyapatite filler. Hydroxyapatite, which makes up 70 percent of human bone, is the most common biomineral in the human body. "By combining RESOMER® and hydroxyapatite we can offer a composite whose mechanical properties are very similar to natural bone. Implants made from this material support bone regeneration and prevent the stress shielding effect," says Karau.

The properties of the two materials complement each other perfectly. RESOMER® provides biodegradability: It is completely degraded in the body to carbon dioxide and water, causes no inflammatory reaction, and is non-toxic. And it has yet another important advantage: "We can control the rate of degradation of the composite very precisely by varying the composition, chain length, and degree of crystallinity of the polylactic acids," says Prabhu. The biodegradable polymer can break down within a few weeks or over several months, depending on how long the bone and surrounding tissue require for regeneration.

Hydroxyapatite, an extremely hard material, performs two functions in the composite: It improves the mechanical strength of the polymers, and it promotes the healing process, known as osseointegration, in which bone cells are laid down on the surface of the implant. The biomineral is incorporated into the regenerating bone while the RESOMER® is slowly degraded. "At the same time, the hydroxyapatite serves as a buffer. During the degradation of RESOMER®, the pH of the surrounding tissue may fall slightly. Hydroxyapatite stabilizes the pH, thus improving osseointegration," says Prabhu.

However, a suitable pre-compounded composite for this purpose has not so far been available on the market. "Manufacturers of medical devices either had to compound the material (mix the individual raw materials to produce the composite) themselves, or commission a service provider to do so. And this processing step is not trivial," says Karau. The processing conditions, above all, are critical: Non-ideal conditions result

Balaji Prabhu,
Head of the Medical Devices Project House

in inhomogeneous dispersion of the hydroxyapatite in the polymer or cause a degradation reaction of the polymer.

But the Project House has cracked the problem: "We can now manage this step on the commercial scale," says Karau. The Business Line can now offer composite materials of different compositions that manufacturers of medical devices can process directly by injection molding to produce the required part, without the need for an intermediate step. "Feedback from selected partners who have already received samples of the material has been overwhelmingly positive. The new product has sparked considerable interest," says Karau.

A CAGE FOR THE SPINAL COLUMN

A second focus of the Project House is VESTAKEEP®. "In chemical terms this is a biocompatible polyetheretherketone," says Evonik expert Marc Knebel, who is responsible for Medical Devices & Systems in the High Performance Polymers Business Line. "It is used in orthopedic implants that will remain in the mouth, jaw, skull, and, in particular, the spine over the long term."

A typical VESTAKEEP® product is an intervertebral disc implant. These look like small cages with a central cavity that is important for correct functioning; that's why they are also known as spine cages. For a slipped disc, doctors may advise removing the disc and replacing it with an implant of this type to restore the natural distance between the vertebrae," says Knebel. "Over time the bone material then grows into the cage, bridging neighboring vertebrae."

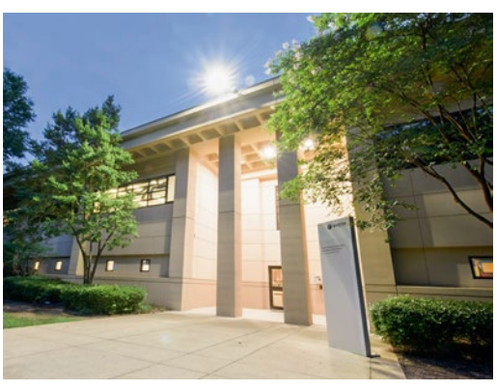
As Knebel explains, VESTAKEEP® is particularly suitable here due to the properties of the material: "The elasticity of VESTAKEEP® is comparable to that of bone, so that implants of this material prevent stress shielding of adjacent vertebrae."

However, a challenge with spine cages is that they may migrate, or subside, in the post-implantation phase. "Until ossification is sufficiently well advanced, the ridged surface of the implant ensures adequate stability through its clamping action," says Knebel. The VESTAKEEP® experts have even devised a trick to accelerate the healing process: A composite of VESTAKEEP® and the biomineral hydroxyapatite is expected to facilitate the growth of bone cells on the implant surface, allowing the vertebral bodies to fuse faster.

Here again, the temperature that is required in the production process presents a major obstacle, since it must be above 400 °C. The solution is a modified hydroxyapatite that is easily processed →

Initial successes with 3D printing: The project house has successfully produced molded parts made of RESOMER® powder through selective laser sintering

On the test bench: An injection molding prototype made of the newly developed composite material consisting of RESOMER® and hydroxylapatite



The Medical Devices Project House in Birmingham (Alabama, USA)

NEW COMPETENCE CENTER

Like all of Evonik's project houses, the Medical Devices Project House was a temporary organization. When it ended as scheduled on March 31, 2018, the Health Care Business Line (as the major user) took over its operation as a competence center that is also available to other business lines. The competence center will provide application technology support for the sales and marketing of the new products. It will also initiate projects and partnerships with customers and will continue working on existing projects.

3 QUESTIONS FOR PROF. DR. DOMINIK MEYER

Implants made of various polymers are also used at the Balgrist University Hospital in Zurich. The deputy chief physician of the orthopedics department talks about his experiences with plastic implants

What motivated you to use implants made of plastic?
Most of these materials have already been used since the 1980s. Their quality has improved quite a bit since then, and as a result they are a very good alternative in many areas today. In the case of screws, it's often important to ensure that they can be resorbed by the body. They disappear within three to six months and make it unnecessary to operate again on the patient. This is where bioresorbable plastics demonstrate their strengths.

What other advantages do the plastic alternatives offer?
Implants made of plastic are very useful if the patient requires radiation therapy, for example, because the radiation is scattered less widely. The use of plastic is also advisable for MRTs.

What has to happen so that plastics can be used even more often in the future?
In some cases, the strength could be increased. Plastic is a good material for the skull or the hand. But bioresorbable plastics in particular are not yet suited for high levels of strain such as those sustained by the thigh bone, for example.

at high temperatures and ensures very good bone growth. The process is currently being ramped up to commercial scale, and the launch of the new composite is slated for 2019. Its name, VESTAKEEP® Osteoconductive, indicates the ability of the composite to act as a scaffold and facilitate natural bone growth.

PRINTED IMPLANTS

Evonik's researchers in Birmingham are also pursuing the idea of developing printable RESOMER® polymers for medical technology. Should a patient with, for instance, skull or facial trauma require an implant, computed tomography can be employed to determine its exact form. Software then sends the data to a printer that fabricates the implant. A patient-specific implant is thus available within a matter of hours and the patient can undergo surgery.

However, this remains a vision. "Currently, the surgeon selects the most appropriate implant from a number of standard sizes: Individually fabricated polymer implants for individual patients are not available," says Prabhu. This is a serious drawback, but no implantable polymer materials have been available so far that give consistently high print quality and also meet the stringent regulatory and property requirements for medical technology. For example, polylactic acids now available on the market for industrial 3D printing contain additives that make the material printable in the first place, but these very additives prohibit its use in medical devices.

"We're working on making our biodegradable RESOMER® polymers usable for 3D printing in medical devices," says Dr. Thomas Riermeier, head of the Pharma Polymers & Services Product Line at Health Care. The aim is to bring to market materials with the appropriate documentation for the most common printing processes: powders for selective laser sintering (SLS) and filaments for fused deposition modeling (FDM).

With FDM, a filament of the polymer is fed to an extruder in the 3D printer, heated to melting point, and extruded through a nozzle. The component is built up layer by layer. "It's vital that the filament has a stable geometry suitable for the purpose and does not change chemically when melted. And it must deliver reproducible results, even on printers from different manufacturers," says Riermeier about the requirements of the material.

With SLS, by contrast, a laser moves over a powder bed, sintering only certain defined areas of the uppermost particle layer on the surface of a powder bed. These areas solidify upon cooling. After each layer is completed, the powder bed is lowered, a new layer of material is applied, and the process is repeated until the complete part has been produced, layer by layer. "For optimal results the polymer powder should have a suitable particle diameter and good flowability. This latter requirement is especially challenging for us: While free-flowing additives are commonly used in industrial applications, this is of course impossible in medical devices because they are not approved for this purpose," says Riermeier.

The project house researchers have already achieved some success with both printing methods. They have developed processes that produce RESOMER® powder and RESOMER® filaments of the right type. The first test parts have been printed to investigate how the material behaves during printing and to assess the properties of the printed component. The next step will be to provide manufacturers of medical devices with research samples, enabling them to carry out their own printing tests.

But there are regulatory hurdles to be overcome before the first printed implants can be deployed in healthcare environments. Who will print the device—the hospital, the printer manufacturer, or a service provider? How will consistent quality be assured? Who approves a freshly manufactured implant? "Our aim is to be ready with the appropriate products as soon as these issues have been resolved," says Riermeier. On the basis of the results achieved so far, the chances are good that this goal will be achieved.

Brilliant Bones

Tubular bones are superb examples of lightweight construction. They are extremely resistant to tensile, compressive, and torsional forces. However, they break if they are overloaded. Then therapy and medical technology are needed

Lightweight

10%

of a human being's body weight is due to bones. Muscles account for up to **50%**.

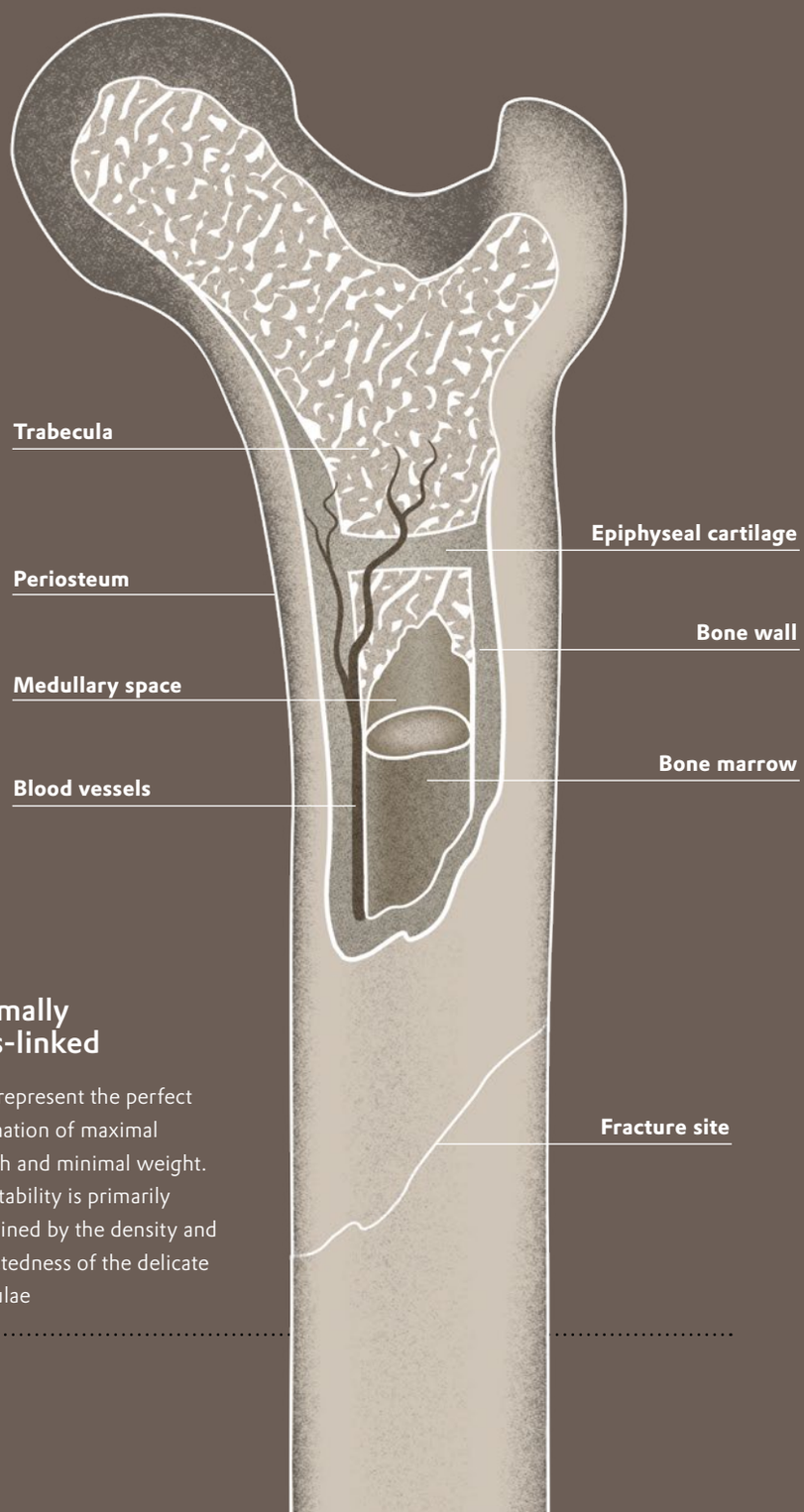
Flexible

20 times

her body weight is cushioned by a gymnast's skeleton when she lands on the mat after a somersault. Upon impact, her thighbones may bend by as much as two millimeters

Optimally cross-linked

Bones represent the perfect combination of maximal strength and minimal weight. Their stability is primarily determined by the density and connectedness of the delicate trabeculae



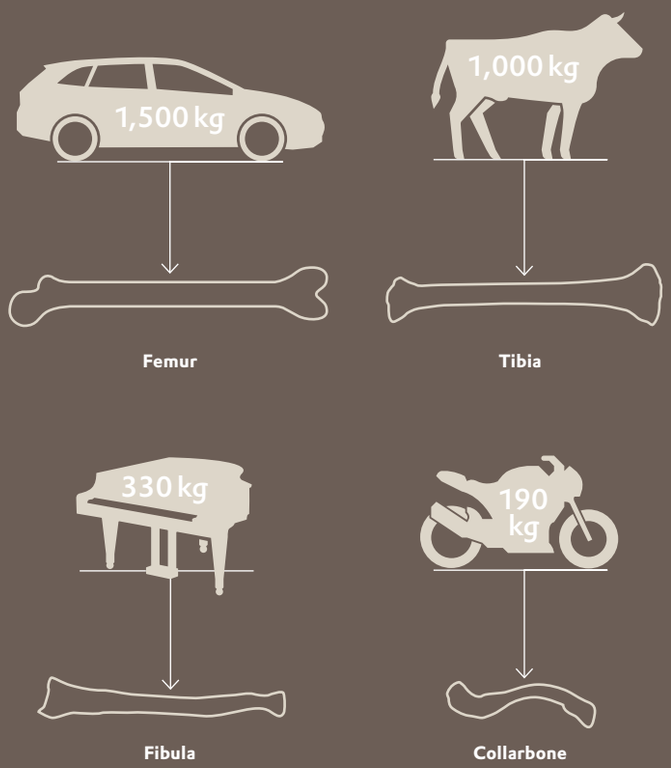
Effective mix of materials

Bone strength is dependent on the bone's mineral content. The elasticity the bone requires comes from the collagenic bone matrix

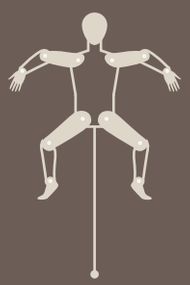
A 20% water
B 25% organic components (bone matrix)
C 55% inorganic components (minerals, primarily calcium hydroxyapatite)

Resilient

A comparison of various human bones' load-bearing capacity:



Bones need…



…movement:
primarily dynamic exercises with power input that alternately stress and relax the body

…calcium and Vitamin D:
through healthy, balanced nutrition and sunlight

Adaptable

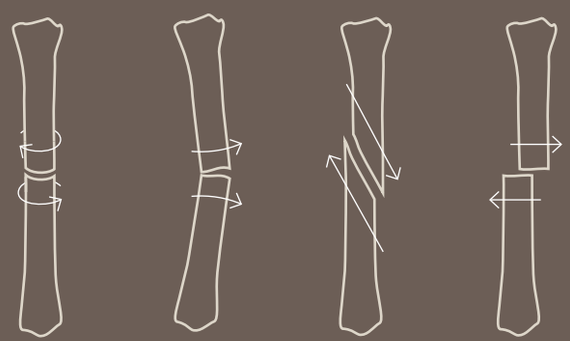
8% to 10%

of bony tissue is formed and broken down within one year. This enables the bone to adapt to changing stress situations and grow as a whole

Atrophy of the bones

Until the age of about 30, the bone formation processes are predominant. With advancing age, more and more bone mass is broken down. A disproportionate decrease of bone density is known as osteoporosis

Pressure from all directions



Bones are subject to tensile, compressive, shearing, and torsional forces. A bone breaks if it is overloaded. That is most likely to happen if the bone is twisted

Osteoporosis risk

8.9 million

bone fractures

are caused by osteoporosis worldwide every year

EXTREME EXTREMITIES

The prosthesis of the future might be controlled via motor impulses from the neural pathways just as well as a hand, for example. The futurologists at Evonik have taken a look at where current developments might lead

TEXT **BJÖRN THEIS**

Children with prostheses should not be excluded by their peers; instead, they should become the main focus of interest when children are playing together

In the Star Wars film "The Empire Strikes Back," the hero, Luke Skywalker, loses his right hand in a duel with Darth Vader. Skywalker survives the duel, and at the end of the film we see him fine-tuning his prosthetic hand. From then on, he swings his lightsaber expertly and without any impairments whatsoever against the forces of evil.

In real life, the loss of an extremity still means a severe decline of an individual's quality of life. The prostheses that are currently available can only inadequately replace the lost limb's function, and in many cases they are a social handicap for the wearer. New design approaches and technologies are gradually coming up with promising ways to improve this situation.

These modern prostheses often seem playful. For example, the product designer Carlos Arturo Torres has designed a prosthetic arm for children in cooperation with the Lego Future Lab, the toy manufacturer's experimental research and development department. Torres would like to ensure that children with prostheses are not excluded by their peers but instead become the focal point when children are playing together. That's why the prosthesis he developed, called Iko, ends not in a hand but in a Lego connector. The connector can be used to build any Lego construction, whether it's an excavator shovel, a hand, or a Star Wars spaceship. The prostheses created by the designer Sophie de Oliveira Barata →

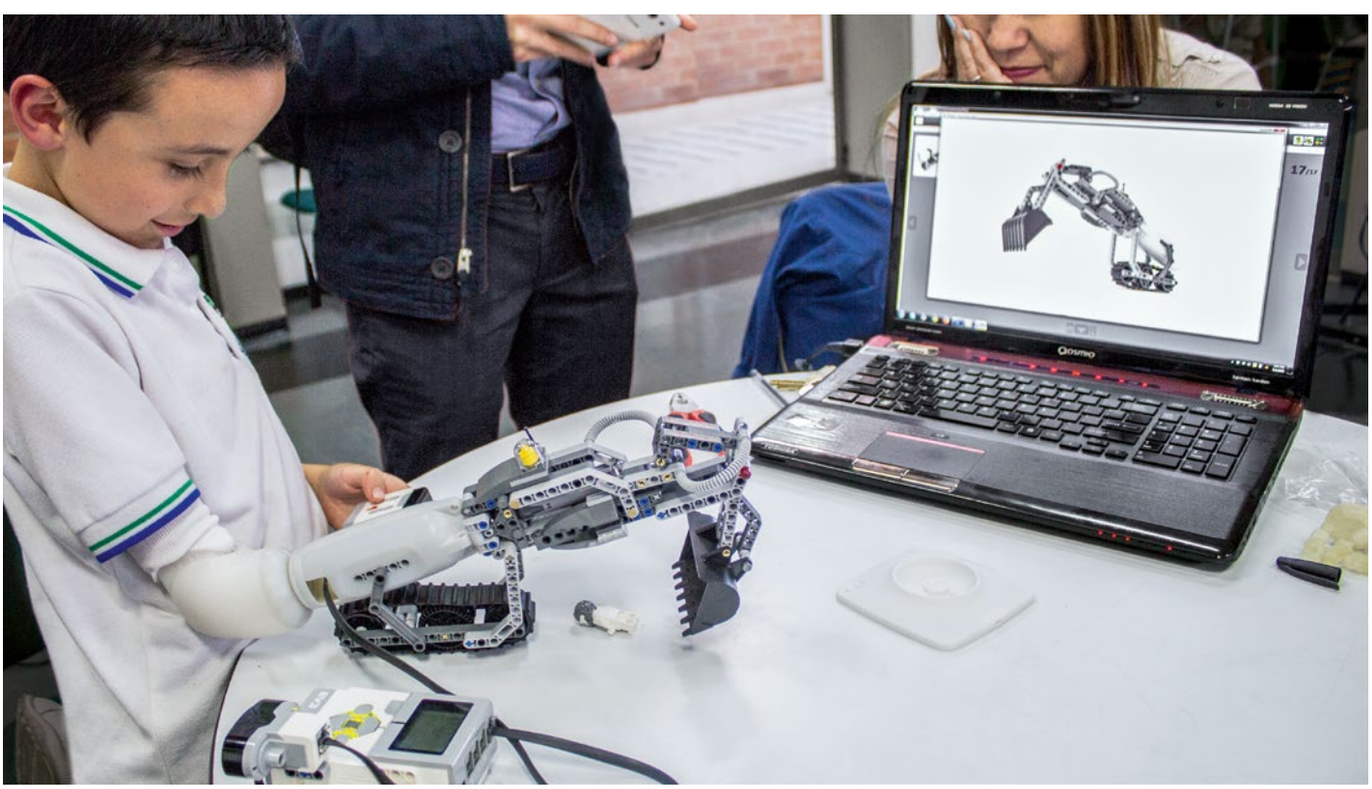
have been inspired by computer games and fetish fashion, and they remind one of humanoid robots.

However, in order to fulfill further promises of science fiction, a number of technical problems still have to be solved. One of the goals is to control the artificial extremities just as precisely as a real hand via motor impulses from the nerve paths. However, this kind of control becomes possible only if the microelectronics are connected with human nerves—using electrodes that are no larger than neurons. Conducting polymers seem to be promising materials for such neural electrodes, because they can transfer the charge of ions via the tissue to electrons in an electrode. In addition, they can be modified in order to improve their biocompatibility by means of special compounds called adhesion ligands or bioactive molecules.

Another challenge is that of tactile feedback: Only by touching an object can we know how firmly we can grip it without causing any damage. In order to equip prostheses with this kind of sensitivity, extremely tiny pressure sensors are needed. Piezoelectric polymers, which transform pressure and dynamic forces into electric signals, could be used for this purpose.

The more progress is made in the area of prosthetics, the greater becomes the need for new materials. The Corporate Foresight team at Creavis, Evonik's strategic innovation unit, is therefore examining prosthetics and its growth opportunities for Evonik within the framework of its GameChanger focus topic. And who knows? Prosthetic hands such as Luke Skywalker's may soon no longer be mere science fiction. —

The more progress is made in the area of prosthetics, the greater becomes the need for new materials



Young Dario from Colombia can fit a self-built excavation shovel or any other Lego component to his prosthetic arm

James Young's prosthetic arm was inspired by the computer game Metal Gear Solid. The young Briton lost an arm and a leg in an accident. His prosthesis consists mainly of carbon and is equipped with a USB connection and a screen that can display e-mails and the user's heart frequency, among other things. It was created by the London-based designer Sophie de Oliveira Barata

IN MY ELEMENT

79 196.97
Au
Gold

“Gold Was Created in Outer Space”

Stephan Rosswog is a professor of theoretical astrophysics at the University of Stockholm. In his childhood he was a huge fan of Carl Sagan’s TV show *Cosmos: Our Spacetime Universe*

TEXT **NADINE NÖSLER**
PHOTOGRAPHY **BASTIAN WERNER**

In my professional life I have often dealt with gold—not here on earth but in outer space. That’s because everything on earth, even we ourselves, originated in the stars. For example, the carbon atoms in our bodies were produced at some point in the interior of a star. The astrophysical origins of many elements are well understood, but the origins of the heaviest elements, such as gold and platinum, used to be a mystery. According to our reference books, the element gold is created in the course of a supernova—in other words, the explosion of a star. That used to sound plausible, but in my doctoral dissertation I examined a different theory: namely, that gold is created by the collision of two neutron stars. When two of these ultra-compact dead stars collide, material including a gigantic amount of neutrons is catapulted into space. After a series of many nuclear reactions, various elements are created, including gold. My initial computer simulations already showed that just enough material is generated in order to clearly indicate what processes are taking place in the universe. In physical terms, my theory was completely plausible. Nonetheless, many of my colleagues were skeptical. After all, no one had yet observed such a process “live.” Over a period of 19 years, I continued to refine my calculations and explain them in lectures. But people continued to be skeptical. On my parents’ 80th birthday, I received a phone call. My colleagues in the USA had observed the flash of light that we had predicted! I suddenly had my proof. It was an incredible feeling. After that, everything happened very fast. I had to interpret measurements, collaboratively publish papers with colleagues, and give interviews. I’ve also been invited to give presentations at many conferences. I think people will believe me now.

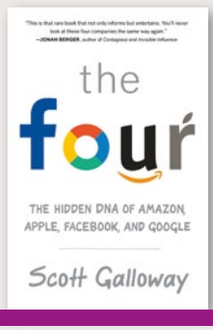
On artificial intelligence, the "Big Four" of the Internet age, and overlooked scientific concepts

TEXT **NIELS BOEING**

Intelligent machines

Artificial intelligence (AI) is one of today's major trends. But for the physicist Max Tegmark it's more than that: It's the third phase of life, which will be able to shape not only its thinking (software) but also its physical shape (hardware). Human beings can only change their thinking. Tegmark is convinced that a "machine intelligence" that is superior to human intelligence will exist in the future. He analyzes the consequences of this development in well thought-out, detailed scenarios, in which machine intelligence is either a "benevolent dictator" or an "enslaved god." Tegmark's book concludes with the "AI principles of Asilomar," which has already been signed by 1,400 researchers. In its tone and substance, his book is a genuine enrichment of the debate.

Max Tegmark
Life 3.0: Being Human in the Age of Artificial Intelligence
Alfred Knopf, New York 2017



Intelligent corporations

Four corporations dominate the digital economy: Amazon, Apple, Facebook, and Google. Their total value on the stock market almost equals the gross domestic product of France. This kind of dominance is without precedent in economic history, warns Scott Galloway, a professor of marketing in New York. In fact, he asks whether the Four are none other than the Four Horsemen of the Apocalypse. In his informative book, Galloway explains how the Four rose to power: Through clever ideas, risk-taking CEOs, and lots of capital, they have become platforms that no one can avoid. Could a new company bring down the hegemony of the Four? Galloway proposes eight criteria for such an enterprise—but he believes that no other company fulfills them.

Scott Galloway
The Four: The Hidden DNA of Amazon, Apple, Facebook, and Google
Penguin Random House LLC, New York 2017

Intelligent ideas

In 1976, Richard Dawkins came up with the concept of "memes"—ideas that prevail in the evolution of culture, in the same way that genes do in biological evolution. John Brockman, the curator of the influential online salon Edge.org, asked 200 researchers what scientific concepts have undeservedly not managed to become memes so far. In short essays, these authors present their candidates, which include the Menger sponge and relative deprivation. The concept of a "premortem" illustrates the relevance of these concepts. It's a proactive analysis of the factors that could drive a company into bankruptcy—a very special tool for adjusting a business strategy.

John Brockman (Ed.)
This Idea Is Brilliant: Lost, Overlooked, and Underappreciated Scientific Concepts Everyone Should Know
Harper Collins, New York 2018

Masthead

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Innovation is not about ideas,

…it's about solutions, says an American motto. At Evonik, research, creativity, and self-renewal lead to innovations that provide solutions for the future.

The new ELEMENTS showcases current research at Evonik: the people who devote their lives to it, the paths they're pursuing—and how their inventions are impacting society. In this issue you'll find concrete examples from the areas of "green" chemistry, medical technology, and digitalization

1/2018 **Bring on the CO_2**