3/2022

EVONIK
Leading Beyond Chemistry

ELEMENTS

Research. Knowledge. The future.

Delightful Dung

High-performance membranes help to produce high-purity gases from dung and waste → p. 10

Trojan horse: Active ingredient transport systems for cosmetics → p. 24

The right stuff: How Evonik is tackling the chip shortage → p. 32

Natural gas

A naturally occurring combustible mixture of gases

Natural gas is a fossil fuel that is extracted from the earth's interior. It consists of more than 90 percent of methane. A natural energy carrier for households and industry, it was created millions of years ago by the accumulation of dead biomass on the sea floor. Kerogen, the starting material for natural gas, is formed from this biomass. Biogas is a more sustainable and resource-conserving source of energy. Like natural gas, it is combustible, consists mainly of methane, and is obtained from the fermentation of biomass. The CO_2 it contains can be reduced to methane by archaea in a process called methanogenesis and released into the air.

Kerogen An insoluble long-chain hydrocarbon molecule contained in biomass. It is formed in environments characterized by low levels of oxygen, high pressure, and high temperatures

Fermentation The microbiological decomposition of organic materials in the absence of oxygen and under conditions of high humidity

Archaea Primordial bacteria that live under extreme conditions such as high temperatures or high humidity. They can be found in standing water, volcanic regions, and the stomachs of animals and human beings, for example

Methanogenesis A way of obtaining energy; used exclusively by archaea. In this process, CO_2 is reduced to methane

DEAR READERS,

The age-old dream of the alchemists was to turn simple ingredients into gold. But that dream was abandoned long ago. What remains is the basic concept of chemistry: processing simple raw materials into high-quality products. Manure and slurry are most definitely simple starting materials. In an Alpine valley, they are being used to generate valuable gases, thanks to innovative separation technology from Evonik.

Even modern science can’t turn manure into gold—but pure methane and high-quality CO_2 are more precious today than ever before, especially in Europe. As our cover story shows, biogas could help to safeguard the supply worldwide—and solve a waste disposal problem.

The dream of eternal youth is even older than the dream of gold. Here too, there’s no scientific recipe for achieving it. But there are substances that mitigate aging processes in human skin, for example. It’s vital to ensure these substances reach the places where they do their work. Delivery systems from Evonik make this possible—in some cases with the help of tiny particles of gold.

Today the scarcity of semiconductors is a nightmare for companies. Many countries are categorizing microchips as a strategic commodity and supporting the expansion of national production capabilities. In the process, manufacturers of high-end microchips are achieving new levels of purity. Evonik is part of this development, because the necessary level of quality can be reached only with solutions from the specialty chemicals industry.

On a personal note: Starting with this issue it will be my pleasure to present our innovation magazine to you as its new Editor in Chief—the successor of Matthias Ruch. If you have any questions, recommendations or criticisms, please write to me at elements@evonik.com

I wish you a thought-provoking read and new insights.

Jörg Wagner
Editor in Chief

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

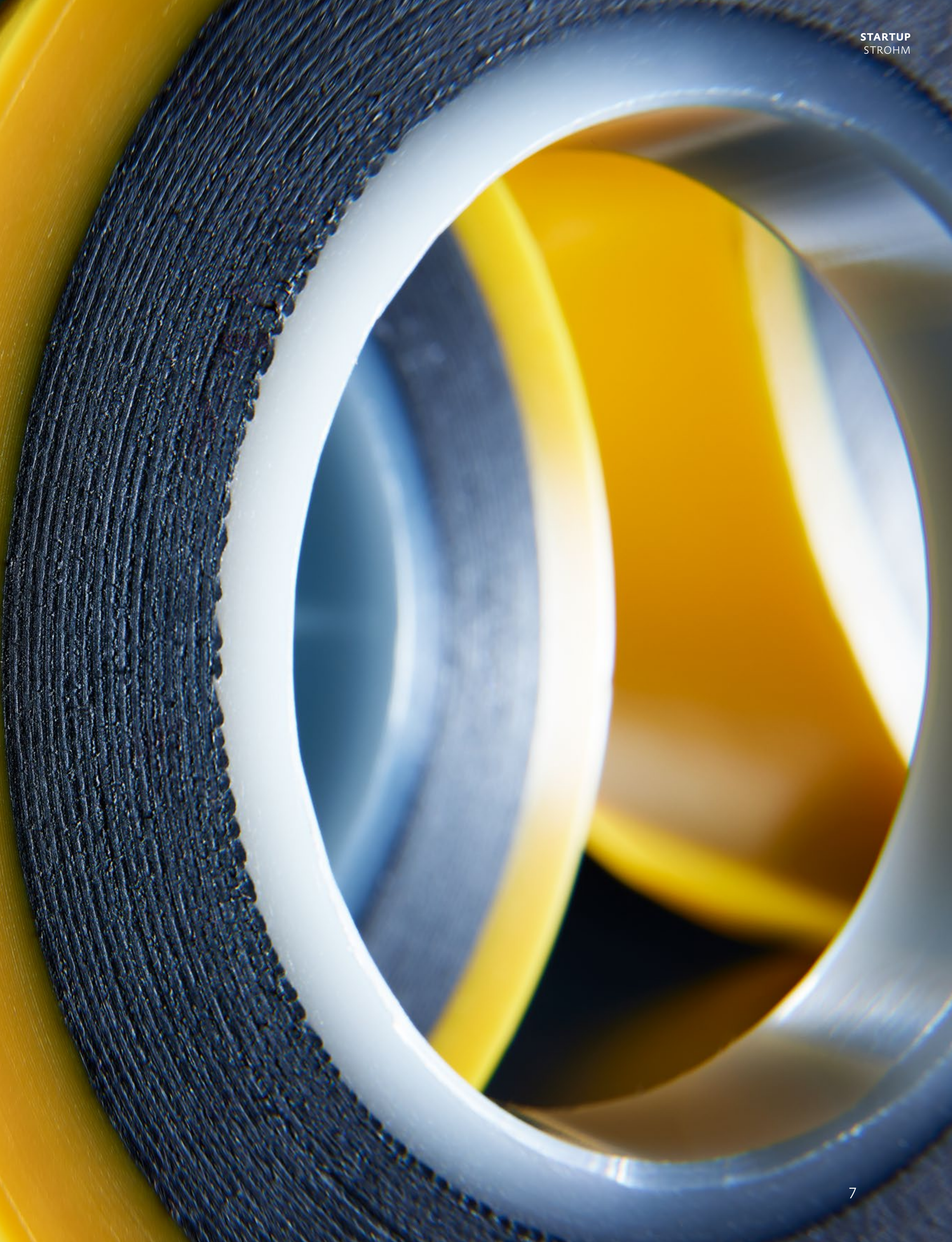
An ultramodern biogas plant in the Wipp Valley is solving a problem for Patrick Meyr and many other farmers in the South Tyrol region: What can they do with the climate-damaging slurry from their dairy cows?

Enzyme meets polymer: Infinitec combines the two into effective delivery systems for active ingredients

Sometimes science needs a hands-on approach. The physicist Ronny Brandenburg (left) and the chemist Ralf Jackstell are working on a new type of plasma reactor in Rostock

LIGHTWEIGHT PIPES

Environmentally friendly alternatives for fossil energy sources are a good thing. But these alternatives, such as green hydrogen, are even better when they can also be transported in an environmentally compatible way. The Dutch startup Strohm, with which Evonik has been cooperating since 2009, has come up with a solution to accomplish this: thermoplastic composite pipe technology (TCP). This technology makes it possible to manufacture multilayered pipes with a glass-fiber or carbon-fiber core and plastic in the inner liner and outer layers. Evonik supplies Strohm with a stabilizing tape made of carbon fiber and the polymer PA 12 for this purpose. The pipes have a diameter of only five to 20 centimeters and are very light and transportable on a drum, which greatly simplifies installation compared to the usual pipes made of steel. Other advantages of TCP are that the pipes are corrosion-free and are not subject to embrittlement. Moreover, they are produced exclusively with green electricity.



Sunlight prevents scratches

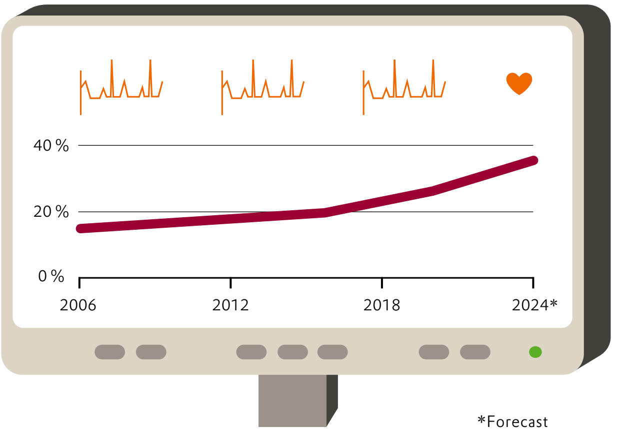
Heat unlocks the self-healing powers of a special coating

It's annoying when the paint job of a car gets scratched. And it's not just because it impairs the vehicle's appearance, as scratches can enable moisture to get through the paint job and cause rust to form. A research team led by Dr. Jin Chul Kim at the Korea Research Institute of Chemical Technology (KRICT) has now found a way to make scratches disappear before the car owner even notices them—in less than 30 minutes and simply with the help of the sun. This is made possible by a novel coating resin that has a polymer network of dynamic chemical bonds. If damage causes the bonds to dissolve, they will resume their original order when stimulated by heat. This is achieved using urea and an organic photothermal dye in the coating. Urea causes the polymer structures to repeatedly decompose and rearrange, while the dye ensures that the compounds in the coating react to heat. When sunlight hits a scratched paint job, the surface temperature rises, triggering the self-healing process of the broken chemical bonds so that they seemingly recombine on their own. The coating is transparent and can be easily mixed with a variety of paints.

THAT'S BETTER

Researching and healing

Biotechnologically produced drugs' share of global pharmaceutical sales



*Forecast

Source: Statista 2022 & Evaluate

The development of the mRNA vaccine against COVID-19 made the potential of biotechnology particularly clear. The steady increase in biotechnologically produced preparations' share of global drug sales is a hopeful sign of medical progress and an advance in the fight against serious illnesses such as cancer or diabetes. Specialty chemicals help in the development and use of these preparations, for example in the form of delivery systems for mRNA vaccines.

1

MINUTE

That's the maximum amount of time it takes for a novel aluminum-sulfur battery to fully charge. This innovation from researchers in the USA could be a cost-effective and resource-saving alternative to lithium-ion batteries. According to its developers, it is particularly suitable for small stationary storage systems such as wallboxes.

GLASS FIBER ...

... combined with plastic creates a durable, lightweight material that can be used to make wind turbine rotor blades, for example. However, glass-fiber-reinforced plastic is difficult to recycle. A new composite resin aims to change that. For this resin, researchers from the USA combined glass fibers with a plant-based polymer and a synthetic one. This mixture can be dissolved and recycled into numerous products, including new rotors, diapers—and even gummy bears.

Powdered energy

Scientists use boron nitride to store hydrogen

In the search for sources of alternative energy and fuel, researchers around the world are pinning their hopes on hydrogen. However, an immense amount of energy is needed to store hydrogen, no matter whether it's in a gaseous or a liquid state. Australian researchers under Dr. Srikanth Mateti at Deakin University have now made a discovery that could allow hydrogen to be safely stored and transported in powder form. They found the key by accident in boron nitride, a boron-nitrogen compound. Using a mechanochemical method, the team was able to trap gaseous hydrogen in powdered boron nitride. If the powder was later heated, the gas was released again. The technology requires only low pressure and low temperatures and produces no waste or by-products. In addition, the boron nitride powder can be reused several times for the same process. Further tests are set to follow in order to validate the process and transfer it to an industrial scale.

PEOPLE & VISIONS

"Our devices are so light that they float like lotus leaves"

THE PERSON
Virgil Andrei studied chemistry at Humboldt University in Berlin. Later, the native Romanian moved to the United Kingdom, where he earned a doctorate in artificial leaves at Cambridge University. He is currently a research fellow at the university's St. John's College. Recently Andrei spent six months in the USA researching the production of multicarbon products made from CO_2 and water. The researcher, who has always been interested in renewable energy, sees his experience abroad as an asset: "It inspired me and shapes and my idea of sustainable research," he says.

THE VISION
Together with an interdisciplinary team, Virgil Andrei has created a leaf-like device that generates sustainable fuels from water and sunlight. It's made of perovskite and metal oxide light absorbers, which are placed on flexible plastic and metal films. "Our devices are so light that they float like lotus leaves," says Andrei. He and his team now aim to produce their leaves on a square-meter scale and use them to provide fuels in a decentralized manner. They would be particularly suitable for remote communities or in refueling stations for ships.

GOOD QUESTION

Mr. Nyström, will we soon throw batteries into wastepaper baskets?

That's quite possible. Electronic waste is a major problem, and batteries are especially toxic. That's why we're researching sustainable materials, inks, and additive manufacturing techniques to print biodegradable paper batteries. To do this, the anode and the cathode are printed with special inks on a small piece of paper that is saturated with salt. The salt dissolves on contact with water. The saltwater solution that is produced serves as an electrolyte and activates the paper battery. Our technology has the potential to replace conventional rechargeable batteries in low-power applications. Areas that could benefit include environmental sensing, logistics monitoring, and healthcare. And our batteries won't pollute the environment at the end of their service life.

Gustav Nyström heads the Cellulose and Wood Materials Laboratory at the Swiss Federal Laboratories for Materials Science and Technology (EMPA) and is a lecturer at ETH Zurich.


BIOGAS
WIPPTAL

Biogas has been produced in the Wipp Valley in the South Tyrol since 2017. The biomethane extracted from it is liquefied and used as fuel for the trucks of several local transport companies

VALLEY OF HOPE

Trash, manure, and wastewater have lots of potential. The biogas extracted from them with the help of high-performance membranes from Evonik provides energy carriers and valuable raw materials for industry. A plant in the South Tyrol shows on a small scale how a problem can become a profitable solution for everyone involved

TEXT **CHRISTOPH BAUER**

The Mayr family's farm lies picturesquely on the outskirts of Pfitsch, a small town in the Wipp Valley (Wipptal) in the South Tyrol region. To the south you can see lush green meadows and cornfields; to the north is Höllenkragen Mountain, which is 1,600 meters high. Right behind the main farmhouse with its traditional wooden balcony, curious little calves look through a stall door. A barely perceptible whiff of cows hovers over the scenery.

It's hard to believe that no fewer than 300 cows are standing in the four stables of the Mayr farm. Each of them, when full-grown, can produce not only 32 liters of milk daily but also about 50 liters of slurry and four kilograms of manure. At the moment, Patrick Mayr and his children are feeding the cows with corn silage. The stables are roomy with high roofs, and scrupulously clean. But the Mayr farmyard does not have a correspondingly huge dunghill or a gigantic pit of slurry. The cows' droppings are picked up from the farm on a regular basis. →

The huge amounts of animal waste that are generated pose a huge challenge to the farms in this idyllic mountain world. "We used to deliver manure and slurry to the fruit and wine growers, but they could only use the manure in the fall and the slurry in the spring," says Mayr. Besides, increasingly strict European Union regulations set certain limits, because too much slurry on too small an area of land poses a threat to the groundwater. The farmers face a choice: either keeping fewer cows or finding a solution for the disposal of their cow droppings.

The farmer Patrick Mayr is glad that the biogas plant takes the slurry from his 300 cows. Liquefied biomethane is stored there in refrigerated tanks (right)

BIOFUEL FOR TRUCKS

In the Wipp Valley, gray semitrailers and ocher-yellow tank trucks drive from farm to farm. They collect manure and slurry and take it to a brand-new facility in Pfitsch that uses SEPURAN® Green, a high-performance membrane from Evonik, to produce carbon dioxide (CO_2) and biomethane (CH_4). Before the plant gates stands a pump where the vehicles of the cooperative's members can refuel with liquid biomethane (bio-LNG, or liquefied natural gas). Each of the big tanks holds 400 liters. "We've calculated that this amount of bio-LNG is roughly equal to the manure and slurry produced by one cow over a year," says Manfred Gius, the CEO of Biogas Wipptal.

In Pfitsch, the local farmers are demonstrating how many of the problems of modern agriculture can be solved simultaneously. The demands for action are being intensified by the overfertilization of the fields and the neighbors' complaints about the smell of the slurry—but that's not all. The methane contained in the slurry and the manure is an especially damaging greenhouse gas. Admittedly, the proportion of CH_4 in anthropogenic greenhouse gas emissions is only about three percent, but methane is responsible for 0.5°C of the global warming that has taken place so far, which totals approximately 1.1°C. The largest proportion of worldwide methane emissions is due to human activities. Three sectors are especially serious sources: agriculture is responsible for about 40 percent of the total, the energy industry for about 37 percent, and the waste management industry for about 19 percent. If the biogas produced by all of these sectors were systematically processed, it could replace a large proportion of natural gas production—and generate lots of other useful materials. Dr. Götz Baumgarten, who played a major role in the development of SEPURAN® membranes at Evonik, is seeing growing worldwide interest in the production of biogas. “At the moment, North America is intensely active in areas focusing on waste materials,” he says. “But the regions along the equator also have a lot of potential, because of the fast growth of their local vegetation.”

WHERE SHOULD THE WASTE GO?

The plant in the South Tyrol demonstrates on a small scale how biogas can be utilized efficiently. The membrane it uses separates out biomethane in a concentration of about 97 percent. The CO_2 contained in biogas is actually so pure after treatment that it can be used in food production—for example, as the carbonic acid in beverages. At the same time, the dairy farmers are reducing their farms’ pollution of the atmosphere by 30 to 40 percent.

By using the treatment plant, the region’s farmers are not only preserving the earth’s climate but also safeguarding their own livelihood. For a large number of these farmers, many of whom also have another job, reducing their livestock or paying for waste removal would have meant economic ruin. That’s why in 2008 they came up with the idea of using the manure to produce biogas for generating electricity. More than 40 farmers backed this concept. But not all of the valley’s inhabitants were thrilled by it. People worried that the plant might produce bad odors or that meadows would be repurposed for raising energy crops. It took eight years before the biogas plant’s site was ready for construction and all the permits were on the table. However, the price of a kilowatt-hour of electricity had decreased so much since the project was launched that the whole enterprise was no longer worthwhile.

But in 2018 the Italian government passed a law to promote biomethane for heavy-duty transportation—and the farmers in the South Tyrol switched their plans from electricity to fuel. They found the technology they needed for their production about 250 kilometers northeast of Pfitsch in the town of Schörfling am Attersee in Austria. This is where Evonik has since 2011 produced high-performance membranes that convert biogas into ultrapure biomethane and natural carbon dioxide.

The membranes, which are sold under the product name of SEPURAN®, look like macaroni with regard to their shape and color. In recent years the company’s solutions for biogas have been followed by modules that can separate out hydrogen, helium, nitrogen or oxygen. The tiny tubes made of high performance polymers are packed and fixed by the thousands in stainless steel pipes. The biogas is precleaned and then forced through these modules. Because their molecules have different sizes, →

A tank truck regularly picks up the slurry from the farms in the region and delivers it to the biogas plant carbon dioxide and water vapor escape sideways through the membrane, whereas the methane reaches the other end of the membrane in high purity. "Our membranes have proved to be very robust," says Baumgarten, the expert from Evonik. "Even the first plants are still running without any problems."

However, he adds, huge progress has been made in terms of capacity and efficiency in the past eleven years. SEPURAN® Green membranes were originally designed for smaller amounts of material. Today they are also used in large biogas plants that are being constructed all over the world by a network of partner companies. Baumgarten reckons that the membranes will last for the entire lifetime of a biogas plant. "We're doing practically zero replacement business," he says.

In Pfitsch, the farmers recruited potential buyers of the methane produced at their plant as investors: the logistics companies Fercam and TransBozen as well as the local authorized dealer of the truck producer Iveco, all of which use the liquid form of the gas as fuel for their trucks. The companies became shareholders and financial backers of the new design of the plant, which is managed by Manfred Gius. As an engineer, Gius had previously headed pipeline and gas plant construction projects in several countries. Besides, he's a South Tyrol native. "I know quite a bit about gas plant construction," says Gius, who is now the company's CEO. "But as far as I know, this concept is unique, at least in Europe." He's referring to the fact that the South Tyrolean farmers wanted not only to produce biomethane and bio-CO_2 but also to utilize manure and slurry down to the last crumb and drop in ways that make environmental and economic sense. By now, 60 farmers hold shares in Biogas Wipptal and 130 farmers are sending their manure and slurry there to be processed.

BACTERIA DO THE WORK

The manure that is brought in trucks from the farms to the plant initially lands in a storage bunker that holds 1,200 cubic meters. There it is chopped up in a fully automatic process, liquefied with slurry, and pumped into fermenters, where a natural bacterial strain anaerobically breaks down the organic digestive waste, thus producing biomethane. The four pre- and post-fermenters with their striking yellow domes have a total capacity of 32,000 cubic meters.

The manure rots for 30 days in the pre-fermenters, emitting about 85 percent of the biomethane in the process. During the next 30 days the remaining 15 percent is emitted in the post-fermenters. Reverse osmosis is used to extract the water from most of the slurry in the fermentation residue. This process was developed by a US company. A vibrating membrane prevents the system from clogging. Through this method, 50,000 cubic meters of pure water of drinking-water quality is recovered annually and channeled into the Pfitscherbach stream that runs past the plant complex.

> **"The manure and slurry produced by one cow in a year is enough for one tank of bio-LNG"**
>
> MANFRED GIUS, CEO OF BIOGAS WIPPTAL

A gripper automatically transports the cow manure from the delivery area into the plant (top). What remains at the end of the process is odorless pressed pellets of fertilizer (right)

Part of the residue from the fermenters, together with its residual moisture, is sold to fruit and vegetable farmers, who use it specifically for the growth phases of their plants. Because this fertilizer does not soak away as rapidly as slurry, it can be applied in smaller amounts and does not pose as great a problem for the groundwater. The rest of the residue is dried, pressed into odorless pellets, packed into recyclable paper bags, and marketed as long-term fertilizer. The farmers who bring their manure to the plant receive the fertilizer free of charge. “The travel agents and hotel owners are thrilled that the smell of manure and slurry is no longer wafting over the meadows,” says Gius.

The biomethane is liquefied at a temperature of -150°C and stored under continuous quality control in three cylindrical white tanks at the edge of the plant complex. The participating companies can either fill up their trucks’ tanks directly from a fuel pump or take away the biomethane via trucks with trailers and sell it.

WORLDWIDE INTEREST

Italy is, after Germany, the second-biggest biogas market in the European Union. Demand has also increased significantly in countries such as France and Denmark. Most of these countries use biogas to produce electricity and heat, which are either used decentrally or fed into distribution networks. However, the production of biomethane as a fuel, for the heating market, and as a basic chemical product is growing in importance—largely because of the steep increase in the price of natural gas (see the interview starting on page 20). In 2021 processed biogas already accounted for 25 percent of Denmark’s domestic gas supply. The Danish government aims to use biomethane primarily in industry, for energy production, and as a basic chemical feedstock. For example, the biogas plant that has operated on the island of Funen since 2020 uses Evonik’s SEPURAN® Green membranes to produce biomethane from silage, manure, and slurry.

Recently there has been a commitment to biogas in the USA as well. The Inflation Reduction Act (IRA) that was passed by Congress in mid-2022 includes a climate protection package amounting to $369 million. Its aim is to reduce greenhouse gas emissions by 40 percent by 2030. Meanwhile, in the USA, biogas has been legally recognized as a renewable energy source in the same category as wind and solar power. Many companies with large vehicle fleets, such as the online mail-order firm Amazon, the logistics services provider UPS, and the Walmart retail chain, are taking advantage of this law →

“Our membranes have proved to be very robust”

GÖTZ BAUMGARTEN, HEAD OF MEMBRANE DEVELOPMENT AT EVONIK

Modules containing Evonik membranes separate the precleaned biogas into biomethane and natural carbon dioxide

and planning to use biomethane to make their CO_2 footprint a few sizes smaller. California grants tax breaks to fuels that fulfill the “low carbon fuel standard,” no matter in which US state the biomethane was fed into the grid.

Fair Oaks Farms in Indiana is one of the big biogas producers in the USA. Here milk is produced, as on the farms in the South Tyrol but on a completely different scale. Approximately 35,000 dairy cows are kept here in several facilities. Here too, SEPURAN® Green membranes are used for processing biogas.

LANDFILL WASTE AS AN ENERGY SOURCE

In addition to substrates from agriculture, trash is increasingly becoming a focus of the biogas industry in the USA. In Europe, trash has been separated for decades and residual waste has been combusted as a rule, but in the USA landfills are still common. And as the trash rots inside them, vast amounts of methane are formed. For several years now, the city of Dubuque in Iowa has been using methane from its landfill to provide heating for a total of 2,700 households. This energy source has tremendous potential, explains Martin Reiser from the Institute for Sanitary Engineering, Water Quality and Solid Waste Management at the University of Stuttgart. “About 150 to 200 cubic meters of landfill gas are formed by every ton of unseparated household trash,” he says. “And about 60 percent of this gas is methane.”

The fifth gas processing plant equipped with SEPURAN® Green membranes went into operation in Dubuque over a year ago. Partly thanks to its use of biogas, the city has reduced its greenhouse gas emissions by two thirds since 2016. If other municipalities were to follow this example, the effect on the earth’s atmosphere would be tremendous. Researchers at the SRON Netherlands Institute for Space Research discovered on the basis of new satellite data that landfills release even more methane than was previously assumed. They analyzed large landfills in Buenos Aires, Argentina; Delhi and Mumbai in India; and Lahore, Pakistan. The data showed that these cities produce between 1.4 and 2.6 times more greenhouse gas than suggested by previous data sets, and that landfills are the source of up to 50 percent of these emissions.

FIZZY DRINKS FROM BIOGAS

According to the German trade association Biogas, there is still unused potential in the processing and utilization of biogas. For example, biomethane and bio-CO_2 as well as other byproducts are used to generate electricity in many plants—and the carbon dioxide substantially reduces their efficiency. SEPURAN® Green membranes make it possible to separate the CO_2 and utilize it separately from biomethane. Natural CO_2 is in great demand as a raw material, for example as carbonic acid in the beverage industry, as well as for food packaging and as a growth accelerator in greenhouses.

In the town of Güstrow in Germany, a biogas plant is now being converted so that it can separate bio-CO_2 and liquefy it for further transport. The plant had been pro-

The biogas plant in Wipptal annually produces 4,000 tons of biomethane, about 7,000 tons of natural carbon dioxide, 30,000 tons of liquid fertilizer, and 5,000 tons of fertilizer in the form of pellets

ducing biomethane and feeding it into the 25-bar natural gas network since 2009. The 400,000 tons of substrate that the plant used annually consisted mainly of corn but also of whole-plant silage, grains, and grass silage. It produced more biomethane than any other plant in Germany. The construction company EnviTec Biogas acquired the plant in April 2021 and repurposed it.

The new operating model calls for reducing the input to 150,000 tons of substrate per year, but to mainly utilize agricultural residue. In the future, SEPURAN® Green modules will be used in northeastern Germany, as in the South Tyrol, to produce bio-LNG as well as liquid CO_2. Hannes Baumgartner, the managing director of the logistics company Fercam, which holds shares in Biogas Wipptal, says that liquid biomethane is the ideal fuel for trucks. “When it’s combusted, it produces significantly less pollutants and CO_2 than diesel. The use of bio-LNG will enable us to work almost CO_2-neutrally in the future,” he explains. According to Baumgartner, liquid gas is especially suitable for heavy-duty transportation over long distances because the gas vaporizes as it gets hotter. He adds that compressed gaseous biomethane has proved to be more suitable for shorter trips that involve many stops.

GROWING INTEREST

For the bio-LNG producers in the Wipp valley, selling is no problem. The shareholders use part of the fuel themselves. As for the rest, they are currently getting the best prices in Germany, because companies that use bio-LNG don’t need to buy CO_2 certificates. Evonik is also increasingly relying on bio-LNG, which it buys from Shell. This multinational energy company is currently investing in a biogas plant in the Rhineland that is expected to produce 100,000 tons of liquid gas per year. The production plant for SEPURAN® modules in Schörfling already obtains all of its energy from biomethane.

There is also potential for growth in the South Tyrol region. “We are a small company with only five employees,” says Gius, the CEO of Wipptal Biogas. “But in South Tyrol alone, theoretically nine more plants of this size could be operated using only manure and slurry.” Also, he says, there is still plenty of organic waste that could be used in addition to agricultural waste. “In any case, we don’t have to fall back on energy plants,” he concludes.

Christoph Bauer is a journalist who works at Evonik’s Communications department. In South Tyrol he learned that when it comes to climate protection, traditional farmers can be members of the avant garde

Separate ways

Methane and carbon dioxide are important starting materials for chemical processes. High-performance membranes allow them to be extracted in high purity from biogas, which is available in large quantities

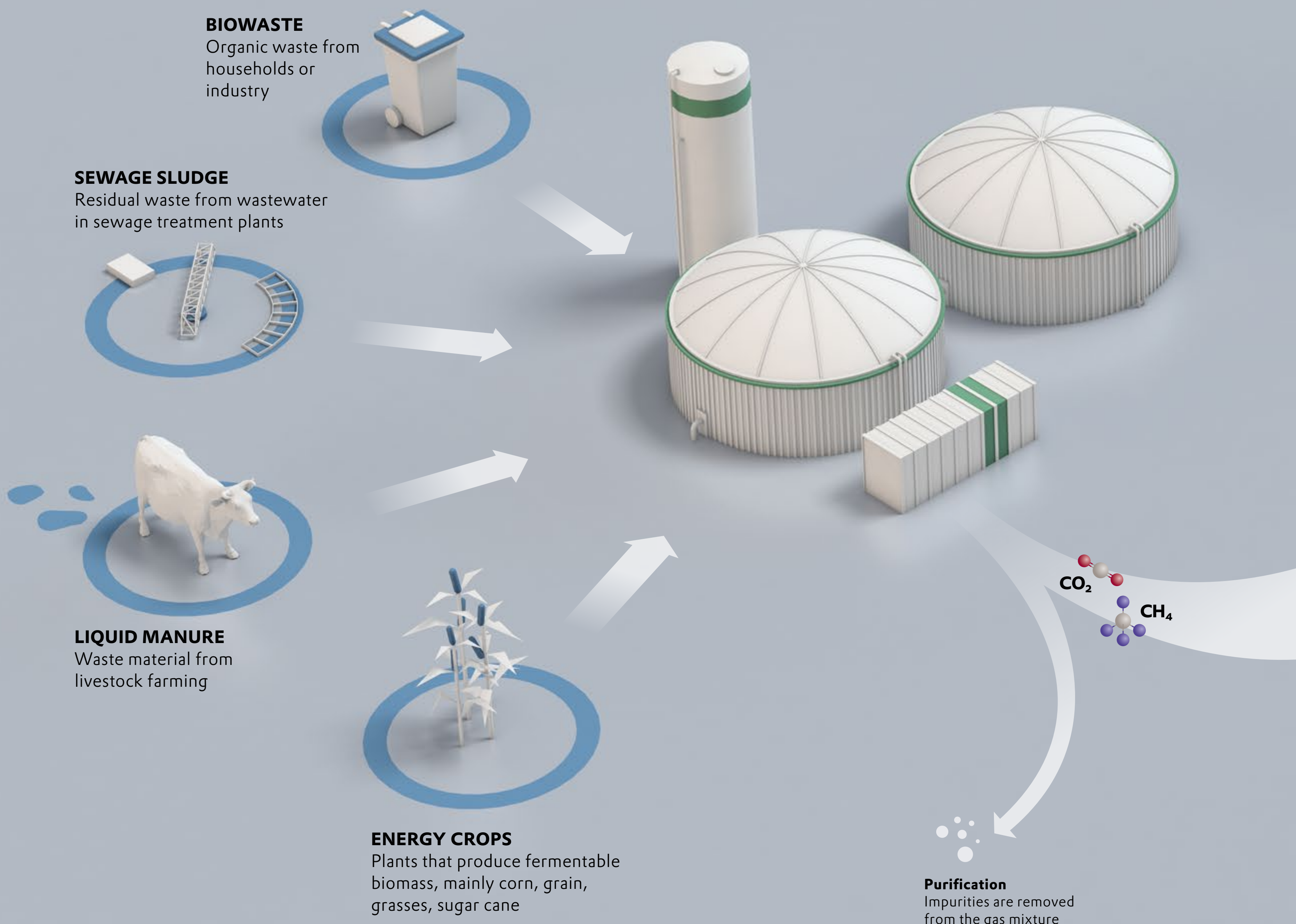
INFOGRAPHIC **MAXIMILIAN NERTINGER**

STARTING MATERIALS

The starting materials for biogas production come from different sources

BIOGAS FACILITY

Under the exclusion of oxygen, the starting materials are fermented here into a mixture of CO_2 and CH_4

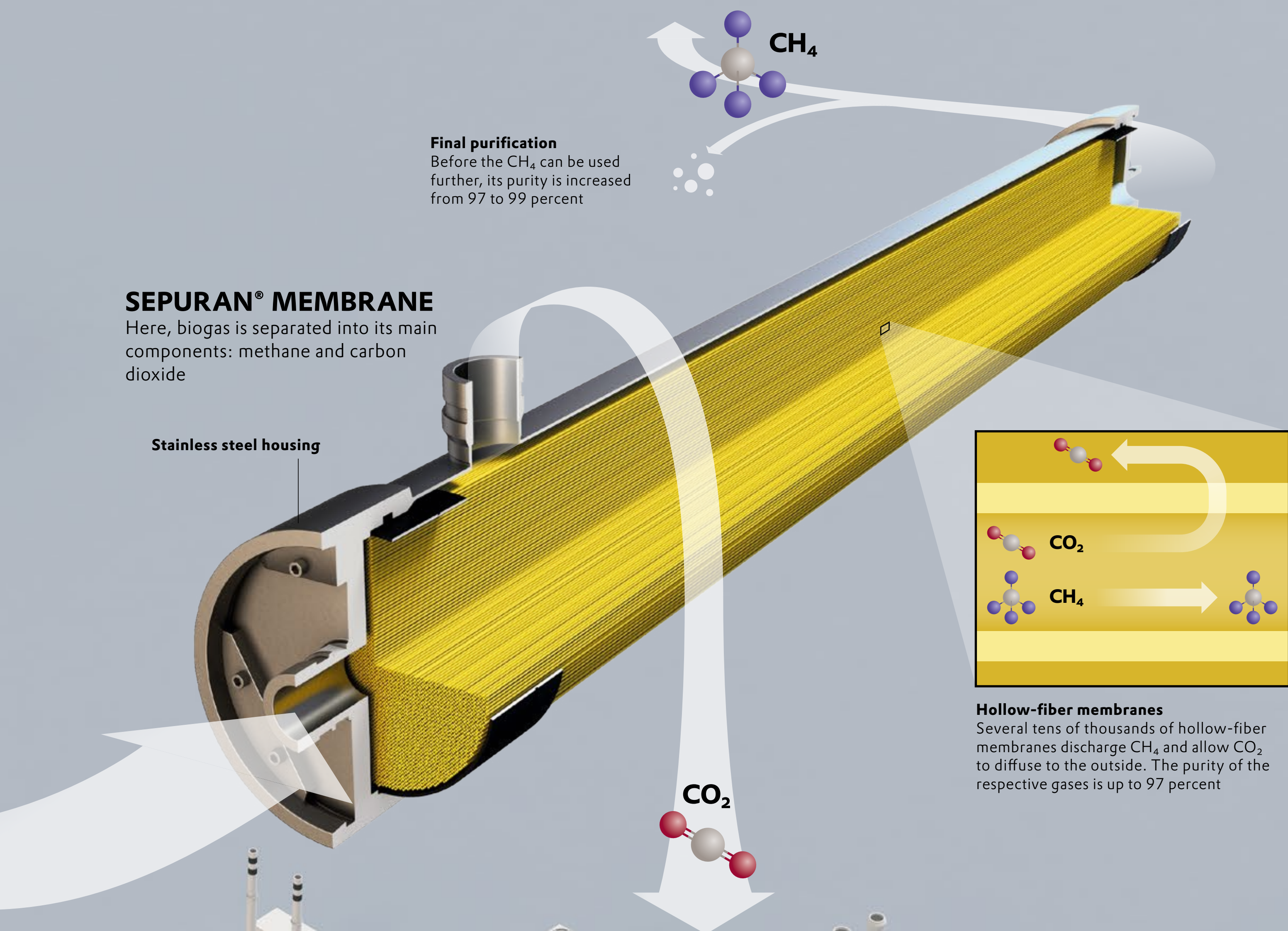


ELECTRICITY
Gas-fired power plants generate electricity and heat decentrally from methane

INDUSTRIAL PROCESSES
Methane is an important initial product for the technical syntheses of hydrogen, methanol, and ammonia

TRANSPORTATION
CH_4 is compressed into CNG or liquefied into LNG and then used as fuel for trucks and cars

ENERGY
The methane can also be fed directly into the natural gas network

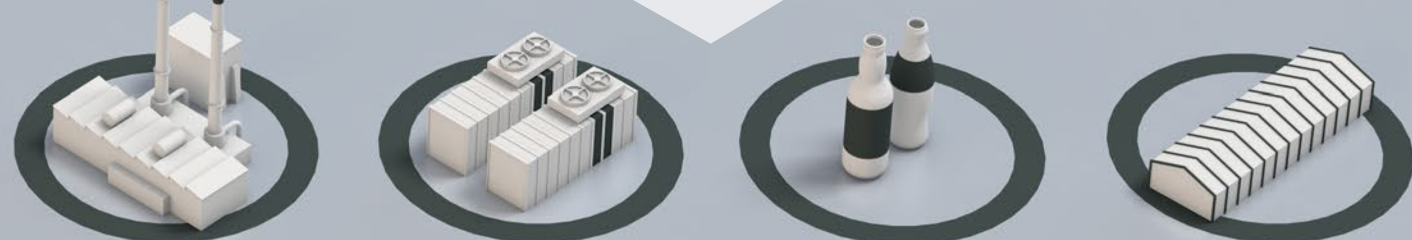


Final purification
Before the CH_4 can be used further, its purity is increased from 97 to 99 percent

SEPURAN® MEMBRANE

Here, biogas is separated into its main components: methane and carbon dioxide

Hollow-fiber membranes
Several tens of thousands of hollow-fiber membranes discharge CH_4 and allow CO_2 to diffuse to the outside. The purity of the respective gases is up to 97 percent



INDUSTRIAL PRODUCTION
In the chemical industry, CO_2 serves as a base material for various products

METHANATION
Green CH_4 can be produced by combining green hydrogen, H_2, and bio-CO_2 by means of methanation

FOOD
Beverage manufacturers use high-purity CO_2 as carbonic acid

AGRICULTURE
In greenhouses, CO_2 is used as a gaseous fertilizer

“We can make it if the conditions are right”

The European Union has set itself the goal of replacing one fifth of natural gas exports from Russia with biomethane by 2030. The head of the European Biogas Association EBA, Harmen Dekker, believes this is realistic—provided that approval procedures for new plants are accelerated and local residents benefit to a greater extent

INTERVIEW **CHRISTOPH BAUER & CHRISTIAN BAULIG**

Up to early 2022, biogas cost twice as much as natural gas and therefore was hardly competitive. Since then, the price of natural gas has increased drastically—and biogas is seen as a viable alternative. Will the Russian invasion in Ukraine ironically help biogas make a breakthrough?

HARMEN DEKKER To some extent, maybe. However, biogas or biomethane has already been gaining attention for some time. At the EBA, we have been relentlessly knocking on the doors of political decision-makers all over Europe. One year before the crisis started, there was already an increased interest in biomethane—for two reasons. One is the European Commission’s desire to fulfill its “Fit for 55” target aiming at a reduction of greenhouse gas emissions by at least 55 percent within the next seven years. But biomethane also gained more attention from companies that are committing to the Paris agreement and need to fulfill their climate goals.

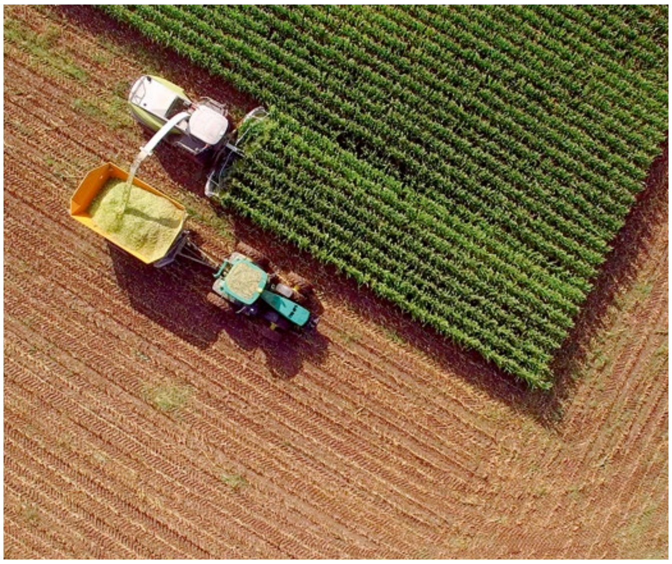
The EU Commission wants the biogas sector to cover 20 percent of current EU gas imports from Russia by 2030—that is 35 billion cubic meters. Is this a realistic goal?
Absolutely. We’ve compared all the studies of biogas within Europe over the past few years—and we’ve found a steady increase of the total sustainable potential, which will add up to 167 billion cubic meters by 2050. And we do not even take into account all the biomass or manure that is available. Looking toward 2030, there is no doubt in my mind that we can make it if the conditions are right. Just to give you an idea, for 35 billion cubic meters we need roughly 5,000 biogas plants. Germany after 2006 managed to build 6,000 plants in nine years’ time.

Which are the biggest bottlenecks?
First, permission procedures across Europe for building a biogas plant can take ages. On average, it takes up to four years, which in this time of need for energy security is not acceptable. Secondly, we need to have a market where methane can flow freely between countries. We need to make sure that the borders are being opened—in the same way as the market for electricity. Thirdly, we need more personnel dedicated to renewable energy. Besides all this, we will need to mobilize the sustainable feedstock and ensure a stable regulatory framework across Europe.

Until now the quality of biomethane has not been the same in different countries—which makes cross-border trading difficult.
Well, if we take natural gas from Norway, Russia or the Netherlands there is a difference in quality as well. With biomethane we can solve that problem easily: Biogas plants can produce different qualities. For example, membranes can take out the CO_2 to certain levels and make the biomethane extremely pure. In any case, we should improve the harmonization between different legislations in countries to make sure that we can speed up production. →

Harmen Dekker (50) is the CEO of the European Biogas Association EBA in Brussels. The EBA represents more than 200 members from Europe and other parts of the world, Evonik being one of them. The Brussels-based organization advocates for the recognition of biomethane and other renewable gases as sustainable, on demand, and flexible energy sources. Dekker has worked for almost 15 years within the sustainability sector as a manager and advisor. He joined the EBA after being involved in the biogas sector for over five years

Today, many smaller biogas plants on farms convert gas into electricity on site. Shouldn't this technology be discarded in favor of more efficient technologies for the generation of biomethane?
Electricity generation with biogas is at best 42 percent efficient when heat from the process is not utilized. Using both heat and electricity can be very reasonable, for instance when there is no gas network nearby or there is a need for a stable form of green electricity and heat in the neighborhood. However, we're seeing things change with more electricity coming from solar and wind. There is a need to stabilize the grid from a more central place. So it makes sense in some cases to produce biomethane and transform it into electricity.



Up to now, energy crops such as corn have been used for the most part to produce biogas. In the future, waste from landfills could also serve as an input

Nobody objects to renewable energy in general, but when it comes to building windmills, solar parks or biogas plants in their neighborhood people are taking to the streets. How can this problem be solved?
The European Commission is paying extra attention to this situation. Permission procedures across Europe are cumbersome and far too long. In times of energy and climate crisis we need to rethink our approach to this. In addition, our advice to all project developers and farmers is: Make sure that you involve your community! One plant can support a village of 3,000 households with biomethane at a very cheap price compared to current natural gas. So it is green, it is cheaper, and it is local. People can even bring their own organic waste if it fits the design of the plant.

And what about the smell?
At the beginning of the biogas industry, digestate was sometimes not covered, and if a biogas plant is not operated well, you can get such problems. But the industry has evolved and professionalized.

Critics of biogas use complain that in many places energy crops such as corn are used, which displace plants for food and feed. The positive climate effect is thus reduced. Isn't there some truth in that?
The issue is about how do we do our farming. We are not displacing food and feed. We do not want to do anything detrimental to either the soil or the land use such as monocropping. When you look at all the relevant studies, they do not include any additional crops that require a change in land use.

Furthermore, the biogas industry depends on manure, and thus a substantial amount of livestock farming, in order to have enough substrate for its plants. How will this work in a world with people consuming less animal products?
Eating meat or not is a decision which is outside the control of our industry. To curb emissions it makes sense to use animal manure as feedstock. At this moment less than five percent of manure is being utilized. Should there be less manure other sustainable feedstocks can be used. We will adapt if people or politics are moving away from livestock farming.

Are you thinking of municipal waste or wastewater?
Indeed, those are good examples of usable feedstocks. We are advocating for all the wastewater plants of a certain size within Europe to be changed to an anaerobic system because it's cheaper than current methods and it creates energy at the same time. The same applies to the organic fraction of municipal waste as sustainable feedstock.

Will the EU taxonomy—a classification system establishing a list of environmentally sustainable economic activities—serve as a driver for this process?
Yes, the taxonomy is important, even though after including natural gas and nuclear power it has lost some of its shine. Biomethane is included as well, but what we are still missing is that pipelines are seen as a green investment when biogas plants can be connected to them.

Today Europe occupies a leading position with regard to production and use of biogas. Will other parts of the world catch up?
I foresee slow progress at first, but it will accelerate. In Asia, for example, there is huge potential for sustainable biomethane. However, in many countries fossil energy is still being supported by the government, for example through subsidy schemes. If you reshape that and introduce frameworks that foster more sustainable forms of energy, that will certainly help. In other parts of the world like America, people have already discovered what renewable natural gas can bring. In many places around the world, communities would like to have local forms of energy for energy security. Biogas fits in perfectly here because it's a stable source of energy. Unlike wind or solar, we are producing every second of the day. And because it's local, you get the circularity that we need for the future. Technology-wise Europe is in a strong position, be it the building of biogas domes or covering roofs or the technologies for purifying the gas.

In the wind and solar industry Europe saw its technological advantage dwindle quickly. Today a lot of the technologies for renewable energy come from China. Do you see the same danger for the European biogas industry?
On solar we've lost our edge a little bit, haven't we? But it also has to do with the resources you need to produce solar panels, batteries and so on. Biogas is different. We do not have to mine materials for solar panels, and we do not have to make batteries. Our resource is the feedstock that is lying around. And actually, that is our greatest strength. Of course we see technologies being developed in other countries. Perfect! Let's go for that. We need every bit of technology being developed locally to make sure that we can produce a renewable source of electricity or gas.

> **"Permission procedures across Europe are cumbersome and far too long"**
>
> HARMEN DEKKER

Biogas can also be used to extract CO_2. Combined with hydrogen, you receive methane or natural gas that can be used not only as a source of energy but also as an input for chemical processes. Does this chain of reaction play a vital role in your strategies?
Yes, I foresee a big future for this, because if you produce electricity via wind and solar you have peak supply. You can't do anything with it unless you transfer it immediately to hydrogen, which is okay. But if you have no gas pipeline connected to that, what are you going to do with it? The best way to store your peak load is as renewable natural gas, because there we have an extensive grid throughout Europe. The biogenic CO_2 coming from our biomethane production is a perfect way to ensure that we can capture the green electricity that we have in surplus at times and then transfer it and store it in our "e-methane" gas distribution system.

Do you see a risk that once the price for natural gas goes down again the boost for biogas will fade away and people will turn back to fossil fuels?
Maybe. However, the price of futures for natural gas jumps up and down. We used to have prices around 20 euros per megawatt hour. Today those prices have increased more than tenfold. If you look at 2025, futures are around 80 euros. In any case, it is expected that the price of natural gas will stay higher than we've been used to. We should use our time to develop the two most renewable gases we have: green hydrogen—and biomethane.

Delivery system meets active ingredient: Infinitec offers a broad portfolio of delivery systems technologies for optimally delivering peptides and other molecules to their target in the skin

UNDER THE SKIN

The Evonik company Infinitec develops innovative delivery systems that stabilize active ingredients in cosmetic products and transport them precisely into skin cells. These systems use “Trojan horses,” as well as exotic materials such as gold and platinum

TEXT **JOHANNES GIESLER**

The skin protects our bodies against the outside world. It is coated by an acid mantle that kills germs. Skin glands produce oils and sweat to keep dirt and pollutants out. But unwelcome intruders aren’t all that’s stopped in this way. The active ingredients contained in creams and ointments often need help to make it through the skin’s barrier as well. To resolve this problem, the cosmetics industry has borrowed special technologies from medicine. These technologies, which are known as delivery systems, can bring cosmetic products to their target.

Infinitec specializes in such delivery systems. Based in Barcelona, Spain, this biotech company combines high-performance active ingredients with innovative delivery systems. “This not only stabilizes the active ingredients in the finished goods but also precisely delivers these ingredients to their target at the cellular and even the intracellular level,” says Natascia Grimaldi, who heads Infinitec’s research and development department. She is sitting in a glass conference room with sales director Marta Gil. About a dozen computer workstations can be seen through the windows, with testing rooms behind them. Here at the Barcelona Science Park, dozens of research-based companies have their offices and laboratories—and share the expensive facilities and equipment that the Science Park has to offer.

The 60 Infinitec employees have been part of Evonik since July 2021. The acquisition of this company has provided Evonik with the largest portfolio of delivery systems in the cosmetics market. “Integrating Infinitec into Evonik allows us to globalize their business,” says Thomas Satzinger, who is responsible for the stra- →

tegic orientation of the Care Solutions business line at Evonik and drove the acquisition. The acquisition portfolio of Care Solutions already includes numerous companies specializing in active ingredients as well as functional specialty ingredients. The delivery systems from Barcelona are one component that strengthens our position as a solution provider for the cosmetic industry. These systems can be combined with plant extracts, for example, to offer our customers differentiating claims (see the interview on page 30).

LAUNCHED WITH ACTIVE INGREDIENT COMPLEXES

When Infinitec was founded in 2006, the delivery systems did not play a major role in the company's strategy, sales director Gil recounts. At that time the company's founders, Alfons Hidalgo and Josep Maria Borràs, wanted to produce active ingredients for international cosmetics companies. Since they came from a sales background, they chiefly recruited natural scientists, whose research revealed that there was still plenty of room for innovation when it came to transporting active ingredients into the skin. "In 2017 we made the decision to specialize in delivery systems," Gil says. "Today most of our technologies are patented," adds Grimaldi. In total, the company offers over 40 active ingredients and a broad portfolio of delivery system technologies.

The systems use such exotic substances as gold or platinum, algae extracts or carnauba wax, and bear equally exotic names such as Skin Shuttle, Cosmetic Drone, and Trojan®. These names are significant, say Gil and Grimaldi. They create an image in the minds of customers—mainly wholesalers and intermediaries—of how the system works. The image is that of a transport vehicle or a remote-controlled drone that delivers its cargo precisely to its destination. "We're trying to think in terms of marketing and technology together," Gil says. "This is how we're making our products better known in the industry." But this is only a first step. The second and more important step is to educate the sector. For many years, delivery systems eked out a niche existence. For a long time their primary role was seen as stabilizing—active ingredients cannot be allowed to change color or shape when they are in contact with other substances. However, delivery systems can do a lot more.

This is particularly true of Trojan® Q10, which combines a delivery system with an active ingredient. It is microscopically small, with a diameter of just 150 to 300 nanometers—one hundredth the size of a human cell. When added to a cream, Trojan® Q10 acts as a mitochon-

Startup flair: In addition to many plants, there is a large board in the Infinitec office on which employees can write inspiring words

“The active ingredients are precisely delivered to their target”

NATASCIA GRIMALDI, HEAD OF RESEARCH & DEVELOPMENT

“Today most of our technologies are patented”

MARTA GIL, SALES DIRECTOR

drial rejuvenator, reduces wrinkles, and improves the elasticity of the skin. All of this is thanks to the coenzyme Q10, which is encapsulated and delivered to the mitochondria of skin cells. “This is our most advanced product,” says Grimaldi. You won’t find anything else like it on the cosmetics market. Trojan® is a double target delivery system, which is able to first target specific cells in the skin and then their mitochondria. The capsules are made of the copolymer PLGA (poly(lactic-co-glycolic acid)), which Infinitec purchases from Evonik.

A DECORATED TROJAN HORSE

If Q10 is added at the right moment, the long-chain PLGA molecules encapsulate the active ingredient—the Trojan horse is loaded, so to speak. In the next step, the outer shell is, as Grimaldi puts it, “decorated” with two different peptides, which protrude outward like spikes. The first type of peptide is designed to dock onto membrane proteins of special skin cells called fibroblasts. There they activate a carrier that transports the Trojan® capsule into the cell interior. If Trojan® Q10 meets a mitochondrion there, the second type of surface peptide comes into play. These peptides are detected and the capsule is guided inside, where the Q10 is released (see the graphic on page 32).

“We spent four years researching the sequences for the surface peptides,” Grimaldi says. This work paid off. The highly reactive Q10 is only released within the mitochondria and is protected from reactive molecules in the organism beforehand. Infinitec has conducted a number of studies that demonstrate these results. Thanks to Trojan® Q10, mitochondria are better protected against oxidative stress—they are more active and produce more energy in the form of ATP. This enables their skin →

cells to produce more collagen, which improves the appearance of the skin. In order to make such statements, which are extremely important for marketing in the cosmetics industry, Grimaldi's team compared two identical creams: one that contains Trojan® Q10 and another that contains Q10. In the study, 18 subjects applied one cream to the left side of their face and the other to the right side twice a day for 56 days. The result: "Trojan® Q10 significantly rejuvenated and tightened the skin. And it did so with a 3,000-fold lower dose of Q10," Grimaldi explains. Because the coenzyme reaches the most effective site of action, only a very small amount is needed. "We need much less of the raw materials to achieve a level of efficacy that is similar to that of the competition," Gil says. "In many cases, our products are even better."

There is always a rocky road to such success. "Science is hard and frustrating," says Grimaldi. Nevertheless, the 13 men and women who now work at the research and development department keep on finding solutions. Grimaldi has recruited most of the team members herself. They include Camila Folle, 36. She is an experimental chemist whom we see using a pre-

In the delivery systems, active ingredients are combined with a copolymer, for example

"ENHANCING SYNERGIES THROUGHOUT OUR BUSINESS"

Evonik strategist Thomas Satzinger talks about how acquisitions underpin innovation and value creation

Mr. Satzinger, why did Evonik buy a small biotech company from Barcelona?

When we acquire companies such as Infinitec, we gain a unique opportunity to enhance our portfolio and better serve our value chains. In our life sciences division at Evonik, we have extensive expertise in delivery systems. These are used in a variety of applications such as pharmaceuticals and cosmetics. We chose Infinitec because we saw the potential to sustainably strengthen our existing business.

You emphasize sustainability. Why is that crucial?

Sustainability guides all our business decisions. The trend toward sustainability is also being driven by our customers in the cosmetics industry and consumers, who are increasingly demanding sustainable solutions. Right now, this means focusing on biodegradability, closing the carbon loop, preserving ecosystems, and reducing our use of natural resources. Infinitec's portfolio of natural-based active ingredients and several delivery systems reinforces our position as a sustainable specialties partner. In this role, we help our customers to move their operations and solutions into the safe operating space within the planetary boundaries.

What do you now plan to do with the technologies from Infinitec?

We want to enhance our entire product portfolio by leveraging competencies from Infinitec. This will help us open new markets, accelerate growth, and create value. The industry is looking for cosmetic claims that are scientifically substantiated. And the delivery systems from Infinitec can help us meet this need. We can also go further and enhance synergies within our entire Care Solutions business. For example, we can combine delivery systems from Infinitec with natural base extracts from the Swiss company Botanica, which we recently acquired. This helps us provide more unique, tailored solutions to our customers.

Thomas Satzinger is responsible for the strategic focus of Evonik's Care Solutions business line. The 53-year-old industrial engineer played a key role in driving the acquisition of the Spanish delivery system producer Infinitec in 2021.

Researching with a view: Camp Nou, the stadium of FC Barcelona (left) can be seen through the lab window. An Infinitec employee mixes ingredients for an active ingredient delivery system together (below). A chromatograph (right) can be used to precisely determine the components of a mixture

cision balance to mix a new formulation for an established product: PhytosteCol®, a delivery system based on phytosterol—the plant equivalent of animal cholesterol. Folle's goal is to substitute ingredients in order to launch PhytosteCol® on the Chinese market. To ensure that the strict access restrictions are met, the chemist is testing a certified Evonik emulsifier made of renewable raw materials: TEGO® Care PBS 6MB. This emulsifier has to demonstrate its capabilities in PhytosteCol®.

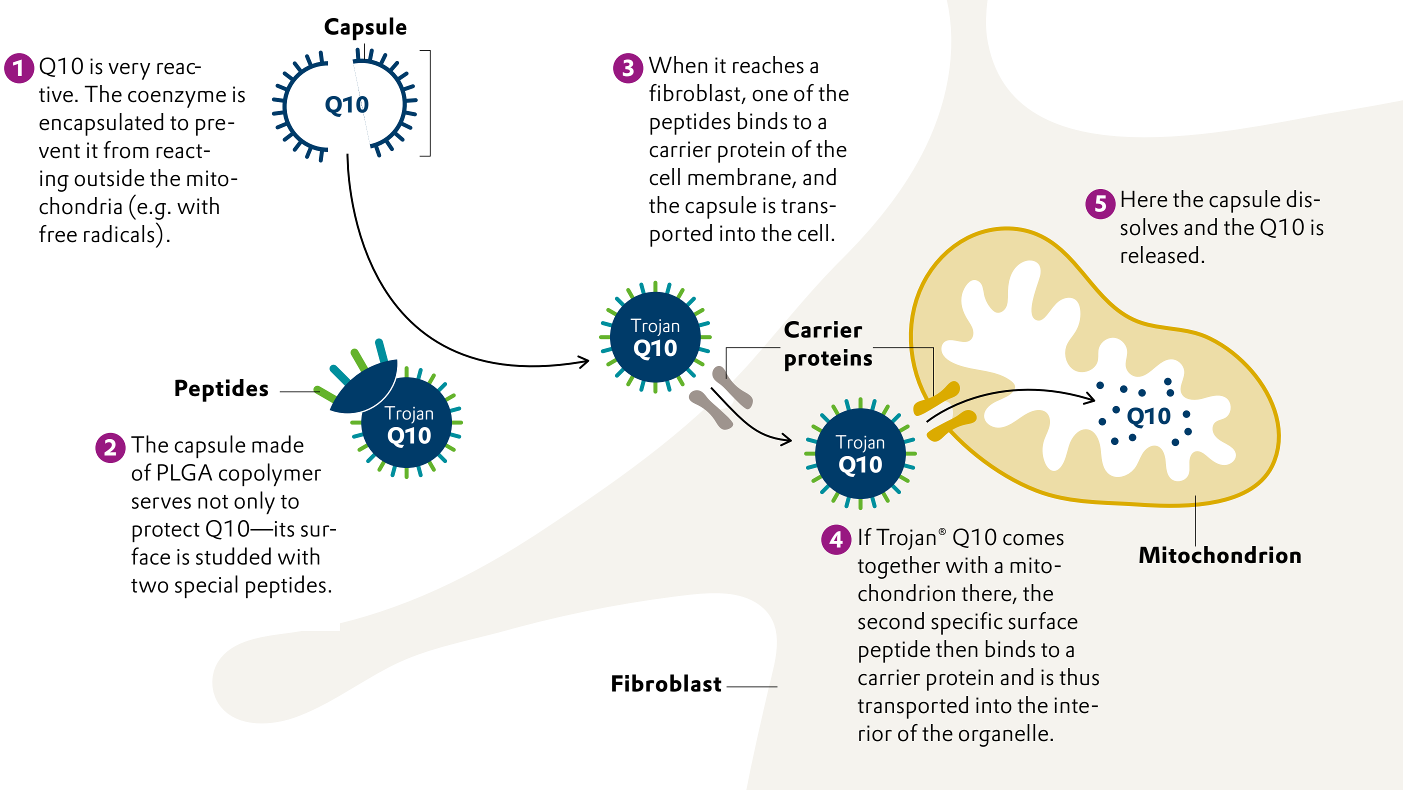
A CREAM FOR ALL CLIMATES

"I'm subjecting it to a lot of different challenges," Folle says, pointing to a shelf full of transparent jars under a lamp. Some of the jars are wrapped in aluminum foil, others are not. Here, Folle is testing to find out how the creams behave in daylight. She has placed other jars in a kind of oven at 45 degrees Celsius, while still others are exposed to 75 percent humidity. This is done to simulate the climate in different regions of the world. "The oil and water phases in the cream must not separate in any environment. And the color should hardly change," explains Folle as she holds up two jars. One is lighter, the other darker. Folle says that "the second cream should still be as light as the first, even weeks later." It will still take her some time to find the optimal formulation. Once she has done so, it will be scaled up.

The cosmetic recipes tested in the laboratory are sent to Montornès del Vallès, or more precisely to the industrial area of this small town about 30 kilometers northeast of Barcelona. Infinitec's state-of-the-art production plant is located here behind the concrete walls of a 1,000-square-meter facility, which is next to a highway. →

Into the cell

The coenzyme Q10 prevents aging in skin cells and is active in their mitochondria. It travels to its target in a transport capsule called Trojan® Q10

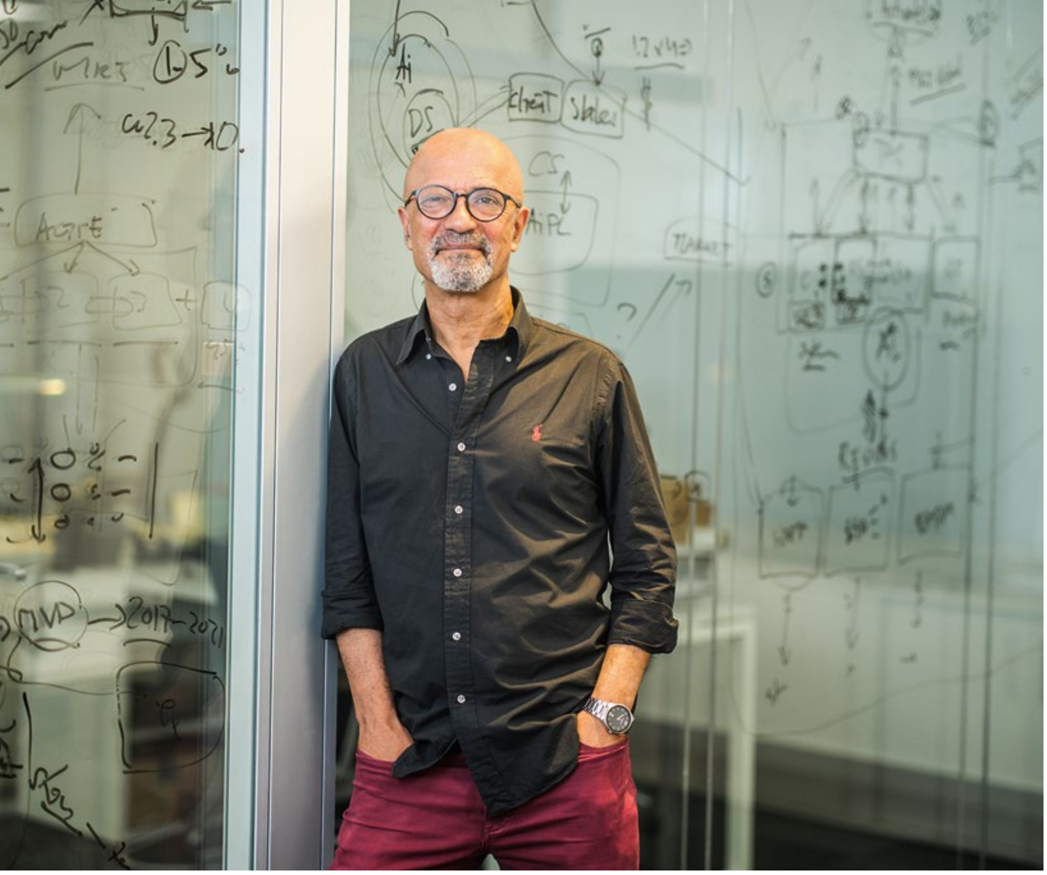


In the mixing reactor, active ingredients are mixed with the delivery system and other ingredients as well as with glycerin and water and then stirred for several hours to form a solution

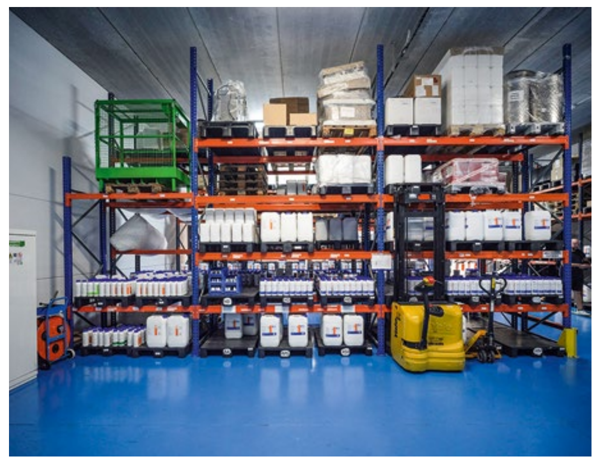
GILDED VITAMIN C

Ismael Darwish is in charge of operations, of which the production department is a part. At the heart of the facility is a 375-square-meter cleanroom. Here ventilators hum on the ceiling, replacing the air 15 times per hour and meticulously filtering it. Darwish wears a mask, a hairnet, a gown, and lab shoes. Nothing is allowed to contaminate the valuable raw materials. In his hand Darwish holds a small bowl full of orange crumbs: tetrachloroauric(III) acid trihydrate, which is also known as brown gold chloride. This exclusive substance is added to the delivery system Golden C, which serves to stabilize ascorbic acid (vitamin C). Tiny amounts are sufficient. “We have perhaps 50 grams here,” says Darwish. “That enables us to produce hundreds of kilograms of Golden C.”

Other costly ingredients Darwish works with include platinum, sapphire dust, and diamond dust, which are stored in small inconspicuous vials. But if you ask him what is the most valuable raw material, he will reply “water.” If that gets contaminated, it will endanger entire



Ismael Darwish says of himself that he works alongside his team and not from the top down (left). Infinitec products are ready to be picked up in the warehouse



"Our most valuable raw material is water"

ISMAEL DARWISH, OPERATIONS MANAGER

days of production. The water—which does not come from the tap, but is especially delivered—is therefore painstakingly purified and monitored. It is fed directly into the three large mixing reactors via a pipe system. This is where the many ingredients of the cosmetic products are stirred together, often for hours. Everything is monitored, temperature-controlled, and dosed by computers.

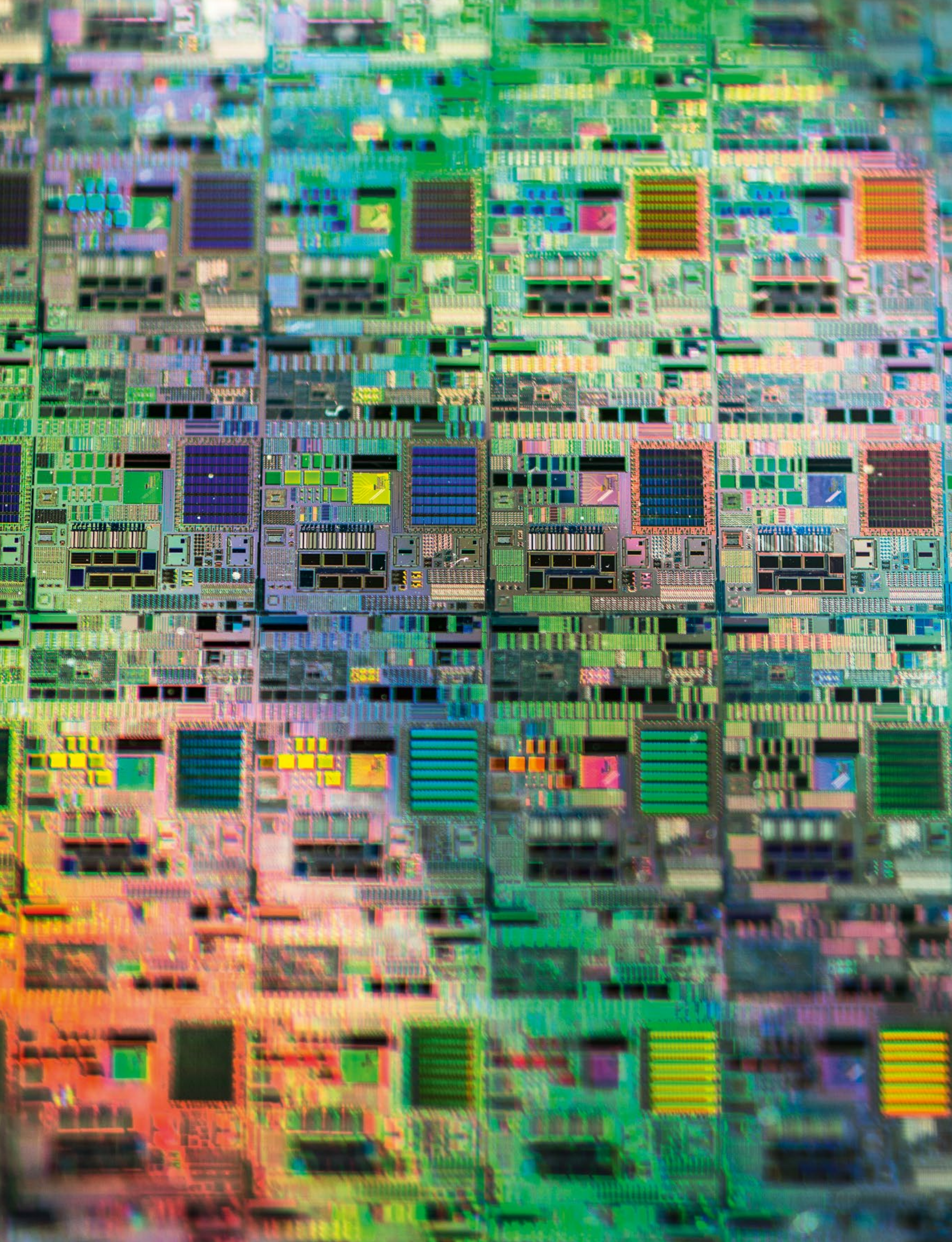
A STARTUP SPIRIT AT EVONIK

Darwish is a pharmacist. He has been working for the company for three and a half years. During this time, he says, he has accompanied Infinitec on its journey from being a small enterprise to a medium-size company that speaks the language of corporations. Each step is documented. "What isn't written down doesn't exist," he says.

In total, Darwish oversees eight units, ranging from logistics to customer service, with just 20 employees. "Everyone has to be replaceable when they're sick or on vacation, so that production doesn't stop," he says. Accordingly he has trained his team so that every member can take on someone else's main tasks.

The Spaniards' orientation toward sustainability and their entrepreneurial mindset also impressed Evonik strategist Satzinger and ultimately gave rise to the idea of acquiring Infinitec. "This mindset is an inspiration. We want all of our employees to think as entrepreneurs, make fast decisions, and take calculated risks whenever they are meaningful for the business.," he says.

Johannes Giesler works as a freelance science journalist in Leipzig. His hands have been very soft ever since he visited Infinitec in Barcelona



PURE AND PRECISE

Microchips are scarce worldwide, and manufacturers are working to create large new production facilities. Evonik is helping industry achieve its goals by supplying it with high-class silanes and hydrogen peroxide

TEXT **NORBERT KULS & TOM RADEMACHER**

Precision and purity are crucial in chip production (l.). Evonik researcher Purnima Ruberu has opened up a completely new business for the company with a silica based on the so-called Stöber process

Allentown, Pennsylvania, and Portland, Oregon, are almost 4,500 kilometers apart. At the end of September, Dr. Purnima Ruberu made the long trip from the Evonik facility in the east of the United States to the city near the Pacific coast. Her destination was the International Conference on Planarization Technology, or ICPT for short, which brings together companies and experts from all over the world. For three days, the participants focused on the microscopically precise polishing of semiconductors—a highly specialized industry that holds great significance. Evonik wants to enter this market, and Ruberu has the key.

"The ICPT is an important event for the industry—and Portland is an important place," she says. There is a bustling semiconductor industry in the "Silicon Forest" that surrounds the city. Intel alone—the world's second-largest chip producer after the Korean market leader Samsung—employs more than 20,000 people in the region. Taiwan's TSMC comes in third. The conference was held at just the right time. It offered the participants an opportunity to take stock of the situation for the first time since the forced pause caused by the pandemic, and right →

in the midst of the global chip crisis. Ruberu, who heads applications research for silanes in the semiconductor industry at Evonik, added a few more days to her stay to meet experts, visit potential customers, and tour a production facility in Portland. “Things are really kicking off,” she says.

A race is on in the chip industry. One of the main reasons for this is the continuing supply bottlenecks for microprocessors, which threatened to stall the post-pandemic economic recovery in many places last year. Lots of developments had come to a head. During the pandemic, many people digitally upgraded their home offices while streaming services and video conferencing providers expanded their server farms. Microsoft and Sony launched new game consoles at the same time and ordered large quantities of chips in advance. Moreover, the boom in cryptocurrencies consumed processor capacity. And all of this happened while virtually every supply chain worldwide was stalled by the coronavirus pandemic and geopolitical conflicts.

BILLIONS FOR MORE INDEPENDENCE

Around 80 percent of the world’s microchips are currently produced in Asia. Like Europe, the USA is desperate to reduce its dependence on foreign suppliers and wants to add more links to its domestic semiconductor supply chain. The latest boost came this year from President Joe Biden with the CHIPS and Science Act, a national investment program worth around $280 billion. The European Union also wants to promote its domestic chip industry more strongly—with the European Chips Act, which has a volume of €43 billion.

The consequences of the chip shortage can be felt far and wide because processors are now found in almost everything. Two out of three companies in Germany import digital components, according to a survey by the industry association Bitkom. If the supply falters, the effects are correspondingly drastic. This was particularly evident in the automotive industry. At Volkswagen, for example, production was halted for weeks in 2021 due to a shortage of semiconductors. However, this situation also harbors opportunities. Chipmakers and their suppliers are open to new ideas as they try to counteract this problem, create additional capacity, and broaden the supplier base. Purnima Ruberu experienced this in Portland. “Many more doors are opening for us compared to just a few years ago,” she says.

As a specialty chemicals company, Evonik supplies a whole series of solutions for microchip production. Demand for new materials is growing, partly because the chips are getting smaller and smaller. Today the company’s palette ranges from special cleaning agents and precursor products for polishing to material components for individual semiconductor layers.

That’s fine: Nanoparticles of silica float in a milky dispersion. They are perfectly suited as abrasives for microprocessors

Silanes play an especially important role. Silanes are molecules that have a silicon atom at their core. Like the legs of a spider, various other functional groups are connected to this central atom. Evonik produces silanes for a variety of applications, such as coatings, sealants, and optical fibers. In chip manufacturing, the “legs” of the silane play a secondary role; the silicon in the core is the key. For example, chlorosilanes are used to produce silicon monocrystals known as ingots that are up to 30 centimeters thick and two meters long. Cut into round ultra-fine wafers, they form the basis for every modern microprocessor.

Another product called tetraethoxysilane, TEOS for short, serves in later processing steps as a sort of silicon cab that can be used to apply ultrafine insulating layers. For this purpose, TEOS is applied to the wafer using a process called chemical vapor deposition (CVD). The attached ethyl groups are then reacted off at high temperatures, which means the “legs” are removed from the TEOS. What remains is a body of silicon dioxide. The fused quartz-like coating that is formed is just a few nanometers thick.

"Many more doors are opening for us compared to just a few years ago"

PURNIMA RUBERU, HEAD OF APPLICATIONS RESEARCH FOR SILANES IN THE SEMICONDUCTOR INDUSTRY

From lab to industry: All the samples are created in Allentown's Innovation Center. Now Purnima Ruberu is working on getting the first plant up and running for commercial production

Evonik produces TEOS in more than a dozen grades of purity. For the CVD process, however, only the highest grades are wanted. Even the smallest traces of foreign metals would cause defects in the final chip. This effect is even more pronounced in the production of five-nanometer-class chips, let alone the latest three-nanometer class. For TEOS, Evonik therefore controls the absence of metallic impurities down to the parts per trillion range. "You can think of it as trying to find a sugar cube in a reservoir," says Matthias Abele, the head of quality control at the Silanes business line. Abele supervises the company's purity standards from the Evonik site in Rheinfelden, Germany. Situated on the border with Switzerland, this location houses the reference laboratory for the company's silane division.

In the hunt for impurity atoms, Abele's team uses elemental trace analysis techniques such as inductively coupled plasma mass spectrometry (ICP-MS)—"measuring homeopathic concentrations," as Abele jokingly calls it. Evonik ensures reproducible and reliable results through interlaboratory tests, in which the same sample is also analyzed in the company's laboratories in Belgium, China, and the USA.

A STARTUP WITHIN THE COMPANY

The highest purity and uniform quality are also a concern for Purnima Ruberu, who studied chemistry at the University of Colombo in her native Sri Lanka. After graduating she came to the USA to earn her doctorate at Iowa State University, then worked in Texas as a senior researcher at two tech startups in the semiconductor and electronics industries. In 2018 Evonik recruited her for the Allentown location as an expert in the production of nanostructures for the semiconductor industry. Ruberu became the preferred candidate not only because of her professional expertise. Her experience with young and fast-moving technology companies also played an important role. "It was all about building a startup within Evonik," she says. Since then, Ruberu has set up a dedicated development laboratory for abrasive particles for semiconductor manufacturing at the Allentown location, which this year became one of Evonik's global competency centers. This lab creates new solutions for further processing steps in chip production. →

The first innovation aims to achieve absolute precision in polishing. Some modern microchips consist of more than 100 ultrafine layers. Virtually every layer is etched, patterned, and polished after application. Chemical mechanical planarization (CMP) achieves surface specifications that must be precise within one nanometer. The polishing agent consists of slurry, a milky suspension containing an abrasive and a chemically aggressive component. The material of choice is silicon dioxide, also known as silica.

Evonik is one of the world's leading producers of silica. This simple molecule, which consists of one silicon atom and two oxygen atoms, occurs in nature primarily in crystalline form as quartz. For polishing semiconductors, the industry relies on colloidal silica. This consists of extremely small, round silica particles that float as a suspension in water or another solvent.

Evonik produces colloidal silica using the Stöber process. Back in 1967, the German scientist Werner Stöber and two colleagues described in a technical journal how they had produced particularly round and uniform silica particles by means of the hydrolysis of alkyl silicates with ammonia as a catalyst and subsequent condensation. Purnima Ruberu uses this process along with Evonik's TEOS, which serves as the starting material. "The idea had already been floating around in the company for a while," she says.

With the purchase of the US company Silbond in 2014, Evonik acquired not only its TEOS business and its Allentown location but also some fundamental patents for this process. "However, it was a long road from there to a process ready for practical application," Ruberu says. The process she and her team perfected over three years of laboratory and pilot-scale work now makes it possible to produce particles as small as twelve nanometers. By comparison, human hair is about 6,000 times as thick. "But the main thing is that these peanut-shaped particles we produce are extremely uniform in size and shape," Ruberu explains.

When used as abrasives in slurry, these particles can achieve exact surface specifications. The silane-based process also has another advantage over the current standard process, in which silica is obtained by ion exchange from water glass, i.e. sodium or potassium silicate. Water glass-based colloidal silica is comparatively easy and inexpensive to produce. But even the tiniest remnants of some alkali metals pose a significant problem for microprocessor manufacturers. "We control our process diligently to minimize unwanted metal contamination," Ruberu says.

CLEANER THAN A HOSPITAL OPERATING ROOM

Evonik's first test facility for colloidal silica is in Allentown and consists of a tangle of tubes and glass reactors. The associated pilot plant already supplies enough material for customer samples, which slurry manufacturers use to test new polish formulations. Evonik is in discussions with four of the six leading companies in this sector. With input from Ruberu's technical team, the Silanes business line has now designed its first commercial plant for this product. The plan is to deliver quantities of up to several tons within next couple of years.

Silica is not the only specialty chemical with tremendous growth potential that Evonik supplies to semiconductor manufacturers. The company also ranks among the world's top suppliers of hydrogen peroxide (H_2O_2) for the electronics industry.

Hydrogen peroxide, which comes in different purity grades, is widely known as a powerful yet environmentally benign disinfectant and cleaning agent. This is because, after its powerful oxidative action, hydrogen peroxide breaks down into nothing more than oxygen and water—leaving no harmful residues in the environment. These "green" properties benefit a number of industries. Pulp and paper producers, for example, use hydrogen peroxide as a bleaching chemical and to remove printing ink in the recycling process.

Semiconductor manufacturers use hydrogen peroxide as a crucial cleaning agent in their fabrication plants—"fabs" in industry parlance. It also serves as an oxidizing agent in slurries for planarization (CMP).

Under control: The operator Anthony Castillo walking among tanks and pipes in Evonik's hydrogen peroxide facility in Bayport, south of Houston

“H_2O_2 touches every microchip on every wafer in every fab around the world”

LAURA LEDENBACH, HEAD OF THE GLOBAL INDUSTRY TEAM FOR ELECTRONICS AT THE ACTIVE OXYGENS BUSINESS LINE

Experienced and equipped: The former fab process engineer Laura Ledenbach stands in front of special storage tanks filled with high-purity hydrogen peroxide in Bayport. Chipmakers need vast amounts of this cleaning chemical.

For the electronics market, Evonik supplies the chemical in two grades: a “pre-electronic” grade goes to companies that further purify it. Evonik is, in fact, the dominant player in North America for this important market, with years of experience serving the industry from its plants in the USA and Canada. But the company also produces and directly sells high-purity grade hydrogen peroxide to semiconductor clients.

Chipmakers need vast quantities of hydrogen peroxide. It is the second-most used chemical in semiconductor production after ultrapure water. “It touches every microchip on every wafer in every fab around the world,” says the quality manager Laura Ledenbach, head of the Global Industry Team for electronics at Evonik’s Active Oxygens business line. As chipmakers become more advanced and the chips get smaller and smaller, they increasingly need to avoid contamination. The leading, cutting-edge players in the industry can’t afford to let anything hamper their manufacturing process. “That’s why everyone is covered from head to toe, dressed in a bunny suit, and wearing hairnets and gloves,” Ledenbach says. Employees in semiconductor plants are prohibited from wearing make-up, perfume, or any jewelry or metal. “A fab is cleaner than a hospital operating room,” she explains.

Ledenbach wore those bunny suits herself when she worked in fabs as a process engineer earlier in her career. This engineering experience now helps her understand and anticipate the needs of Evonik’s semiconductor clients. “The crucial element is consistency,” she says. “Our customers want to receive the same high-quality product throughout the year—24/7.”

Evonik produces hydrogen peroxide for the electronics industry in multiple plants around the world. High-purity hydrogen peroxide is a very regional product. To avoid the risk of contamination during transportation and to ensure supply security, Evonik serves customers from plants in the respective regions. Delivery in Europe and Asia originates from Evonik sites including Zaragoza, Spain and a joint venture site in Saraburi, Thailand.

In North America, Evonik produces hydrogen peroxide at five sites. The plants in Mobile in the USA and Maitland and Gibbons in Canada supply high volumes to an eager market. Two further plants—Saratoga Springs, New York and Bayport, Texas—can satisfy the purity requirements of the most discerning semiconductor customers, up to the highest levels.

In Bayport, the purification happens on the north side of the sprawling, Texas-sized plant, where workers and engineers drive golf carts to cover long distances. To the uninitiated visitor, the purification area, with its big storage tanks, pumps, valves, and overhead pipes, looks no different from the rest of the plant. But there are subtle distinctions. The lower-grade product is shipped in railroad cars parked in the middle of the facility. The high-purity variety gets loaded into isotainers—specially built Teflon-lined tank containers pulled by a truck. Teflon creates a barrier between the product and the stainless steel in the container wall that would otherwise contaminate it. →

A hard hat with a Texas flag: Evonik employee Alex Romero collects a high-purity hydrogen peroxide sample from the storage tanks in Bayport

The details of the proprietary process for producing high-purity hydrogen peroxide are strictly confidential. But other criteria are at least equally important. “In contrast to many of our competitors, we are vertically integrated,” Ledenbach says. Evonik is involved in all stages of hydrogen peroxide production in Bayport. The company owns the railcars and trucks that deliver the finished product to customers.

A VERY HIGH-VALUE BUSINESS

Evonik’s challenge is to keep up not only with increasingly stringent customer requirements but also with an expected rise in demand. In October, the US chipmaker Micron Technology announced that it would invest $20 billion to build what it called the largest US semiconductor factory ever. In May, its competitor Texas Instruments broke ground for a new fab north of Dallas, Texas. The $30 billion investment includes plans for four additional fabs. Samsung Electronics also floated the idea of a broad expansion of its facilities in Texas. It recently filed potential plans to spend almost $200 billion on eleven plants in the state.

A year ago, Samsung announced that it had picked a location near Austin for a new $17 billion plant to make advanced chips for mobile devices, high-performance computing, and artificial intelligence. The semiconductor manufacturer GlobalFoundries recently secured the final local approvals to expand its manufacturing operations in upstate New York. In an announcement, the company had outlined plans for the construction of a new fab that would double the site’s capacity. The site is not far from Evonik’s purification plant in Saratoga Springs.

Greg Rice, Evonik’s segment manager for electronics at Active Oxygens, expects the imminent boom in US semiconductor manufacturing to drive the demand for high-purity hydrogen peroxide. “We have great opportunities to grow by capturing a fair share of the new fabs being constructed,” he says. “It is a very high-value business.”

Expanding the business line’s US operations to support the semiconductor boom will take time. This is due not only to technological hurdles, strict purity specifications, or supply reliability. A new isotainer for ultrapure hydrogen peroxide has a two-year delivery lead time. “If we don’t have enough isotainers, we will limit our growth potential,” says Ledenbach. “We have to be strategic about these investments.” Purnima Ruberu also knows how far the journey is—and how important it is to set out early. “We now have the opportunity to gain a stronger foothold in these markets and help shape the transformation of the chip industry in the years ahead,” she says.

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

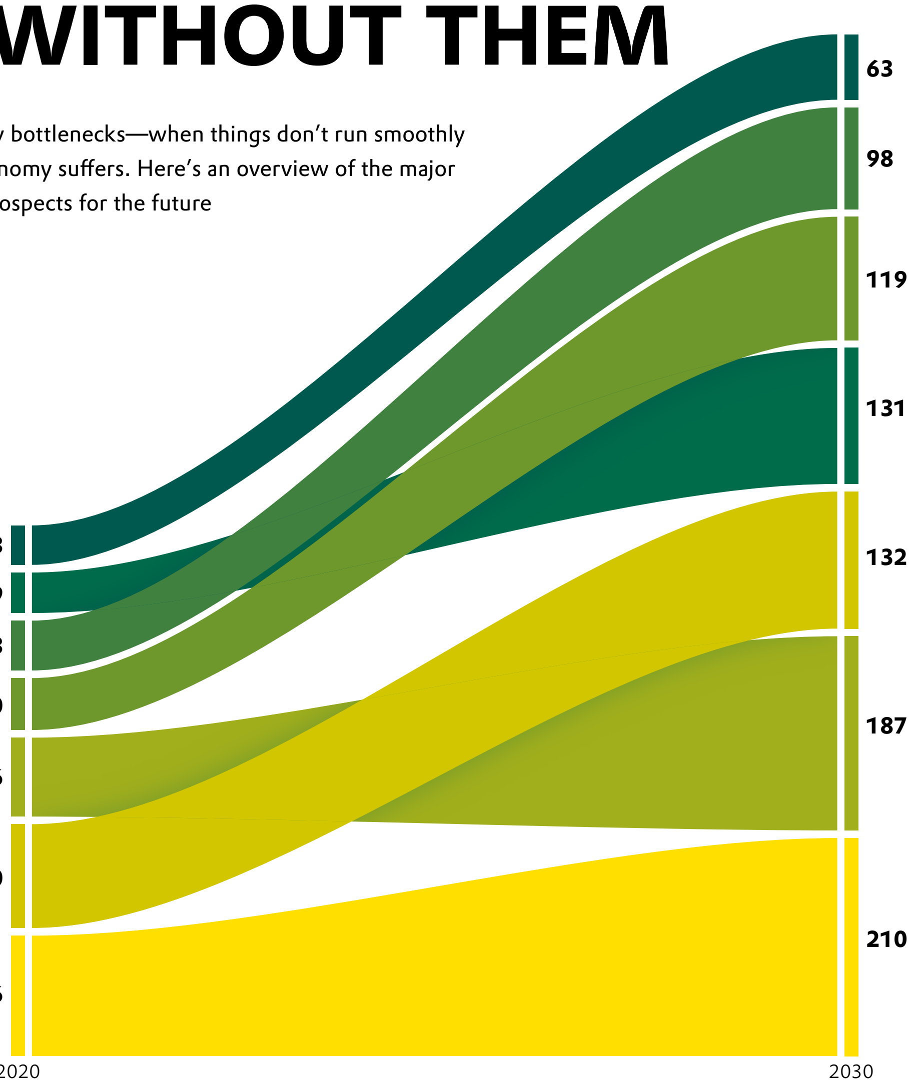
Norbert Kuls is Evonik’s Communications Manager in North America and a former US correspondent for German newspapers

CAN'T DO WITHOUT THEM

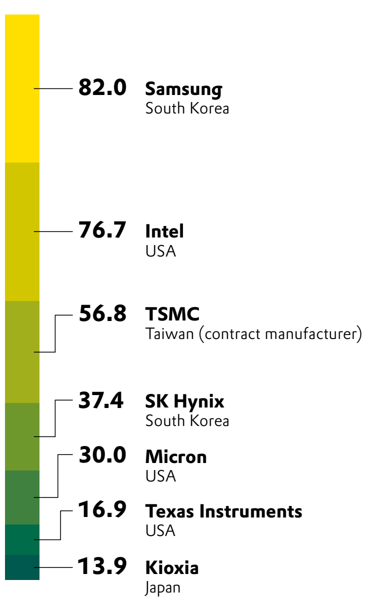
Production stoppages, cost explosions, supply bottlenecks—when things don't run smoothly in the semiconductor industry, the global economy suffers. Here's an overview of the major players in the chip world, price trends, and prospects for the future

INFOGRAPHIC **MAXIMILIAN NERTINGER**

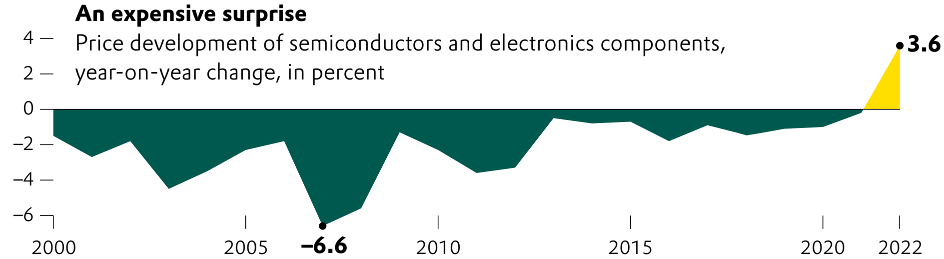
Who wants more chips?
Market forecast by area of application, in billions of US$



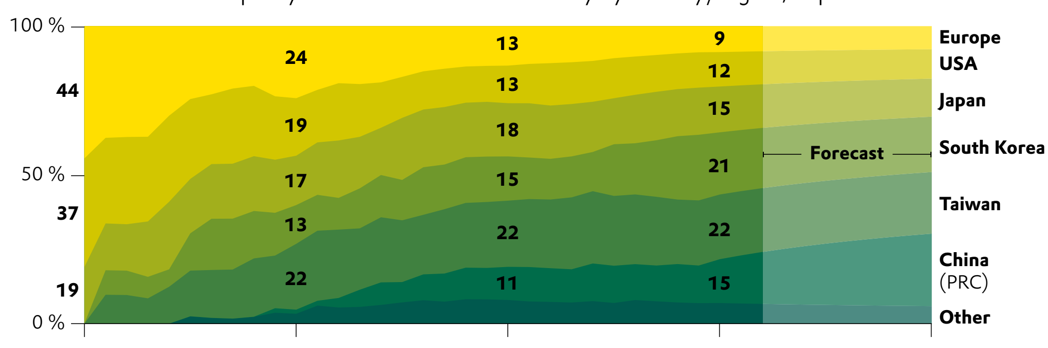
Top seven
Semiconductor producers with in-house manufacturing capacity, 2021 sales in billions of US$



An expensive surprise
Price development of semiconductors and electronics components, year-on-year change, in percent



Asia dominates
Production capacity in the semiconductor industry by country/region, in percent



Sources: ASML, IC Insights/companies/own research, IBISWorld, Semiconductor Industry Association, Boston Consulting Group

FUTURE MEETS DESERT

Gigantic sand dunes, ultramodern cities, and a long coastline are the outstanding characteristics of the United Arab Emirates. Taken together, the seven emirates are a major center of global trade and continuous progress. A photographic journey through a country that in many ways is ahead of its time

TEXT **PAULINE BRENKE**

“Connecting Minds, Creating the Future,” the motto of Expo 2020, is a good description of the aspirations of the United Arab Emirates. The global metropolis Dubai, which hosted the world fair—after it was postponed because of the pandemic—from October 2021 to March 2022, is an especially good example of the economic growth, innovation, and transformation the emirates are known for. One architectural symbol of these aspects is the “Museum of the Future” designed by the South African Shaun Killa, which resembles a sparkling eye. Adorned with Arabic calligraphy, its aim is to become a center of the latest developments in technology, business, and society, to provide space for presenting innovative projects, and to thematize future challenges that will face human beings. Attracted by a progressive mentality and a dynamic market, Evonik has also found a home in the Emirates

Welcome to the Hall of Fame for heroes of the silver screen: Warner Bros. World™ Abu Dhabi—in the capital of the UAE—is the world's biggest indoor adventure park. Under a gigantic roof that can be transformed into a blue night sky or a glowing sunset by means of a deceptively realistic lighting system, visitors can meet their favorite characters from cartoons and blockbuster films. On more than 150,000 square meters, they can enjoy numerous rides and other attractions side by side with Bugs Bunny, Superman, and other fantasy figures. In crowded indoor spaces like these, the environmentally friendly disinfectant PERACLEAN® 15 from Evonik helps to counteract the spread of germs such as the COVID-19 virus.

The flavors of this region's cuisine have been enriched over time by traders from all over the world who stopped off in the emirates in the course of their travels. Countries such as Turkey, Iran, and the lands along the Mediterranean have left traces of their cuisines here. India has also contributed an important ingredient: ghee, a kind of clarified butter that enhances the flavors of a dish especially well. One example of this effect is the traditional emirate baked lamb dish called *ouzi*, for which the marinated meat is cooked for 24 hours in a sand oven. The dish is served on rice with a spoonful of ghee. Catalysts from Evonik ensure that the fat has a longer storage life and better texture and stability.

If you loved playing in a sandbox as a child, you'll find that the United Arab Emirates are a real-life paradise. Lying directly before the gates of Abu Dhabi is the Rub al-Khali, the largest continuous sand desert in the world. It covers more than 650,000 square kilometers in all, occupying two thirds of the total area of the UAE. Dubai is surrounded by an impressive desert landscape. It offers a vast adventure playground for locals and tourists alike. One especially popular pastime is "dune bashing," in which dune buggies are driven over sand dunes at headlong speeds. The tires of these vehicles are equipped with ULTRASIL® from Evonik for a better grip, which prevents dangerous slipping and swerving on the dunes.

A petrochemical oil refinery on the coast of Dubai. Colossal plants like this one produce base chemicals derived from petroleum, which are ultimately used to make products such as plastics and cleaning agents. The United Arab Emirates are among the most petroleum-rich countries in the world. Over 85 percent of their economic revenue is based on the export of this fossil raw material. Persulfates from Evonik are powerful and especially stable oxidizing agents that are used for processing oil sands. The persulfates are also used for gel forming and breaking—processes that enhance the effectiveness of oil extraction. Looking forward, the Emirates intend to increasingly focus on renewable energy sources with their "Energy Strategy 2050." One target is to increase their share of the overall energy mix to 50 percent.

HEADQUARTERS IN THE "GOLDEN CITY"

Evonik Gulf is represented in the United Arab Emirates at a location in Dubai that serves as the company's headquarters for the Middle East and Africa. This is the central point from which Evonik manages its sales, marketing, business development, and communication in the region. Other business units that are represented include High Performance Polymers, Catalysts, and Coating Additives.

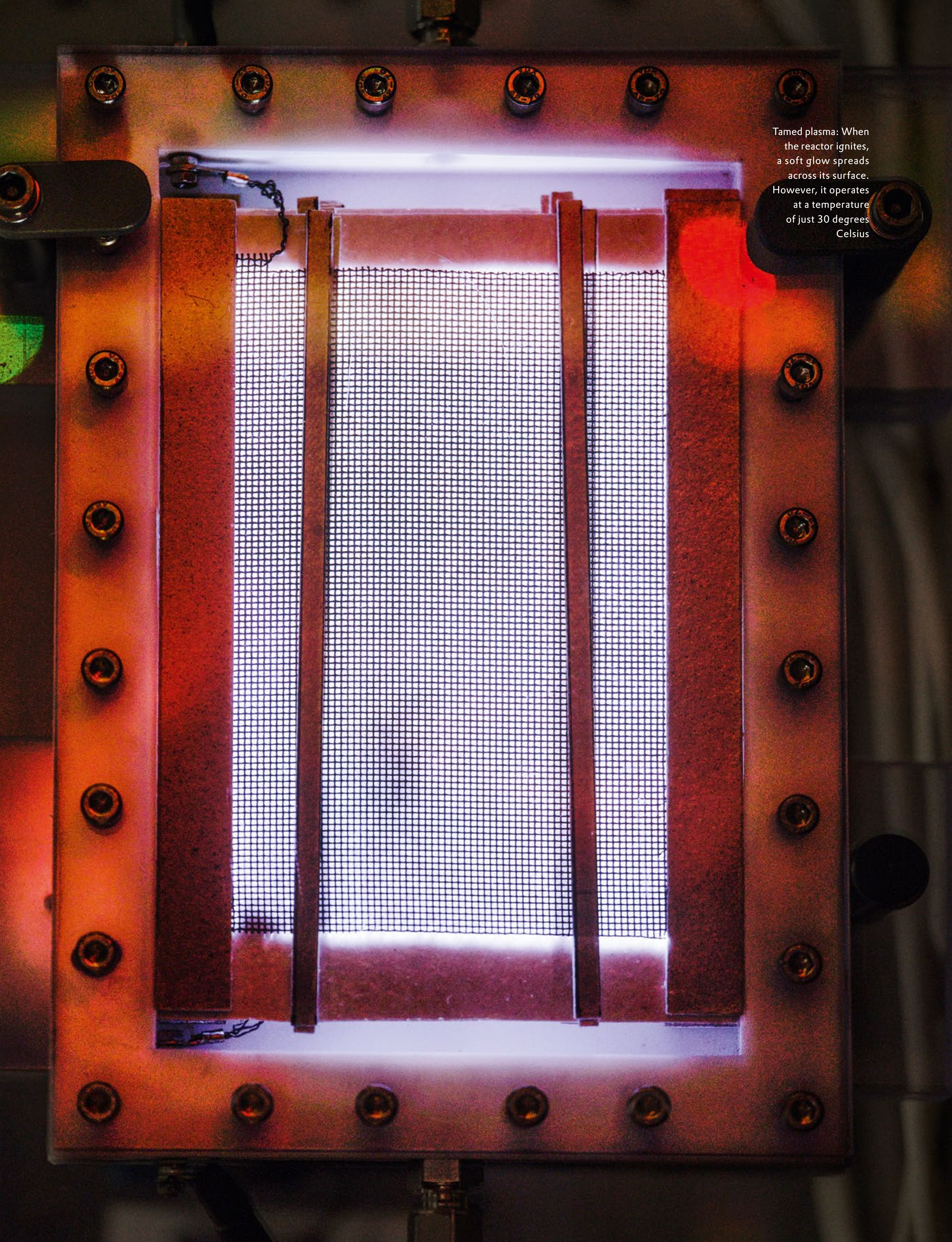
At

1

location Evonik has

26

employees.



Tamed plasma: When the reactor ignites, a soft glow spreads across its surface. However, it operates at a temperature of just 30 degrees Celsius

A SHINING EXAMPLE

Although the word "plasma" might make one think of science fiction, it may very soon be possible to produce chemicals with such electrified gases. A research group coordinated by Evonik is working on the concrete implementation of this idea

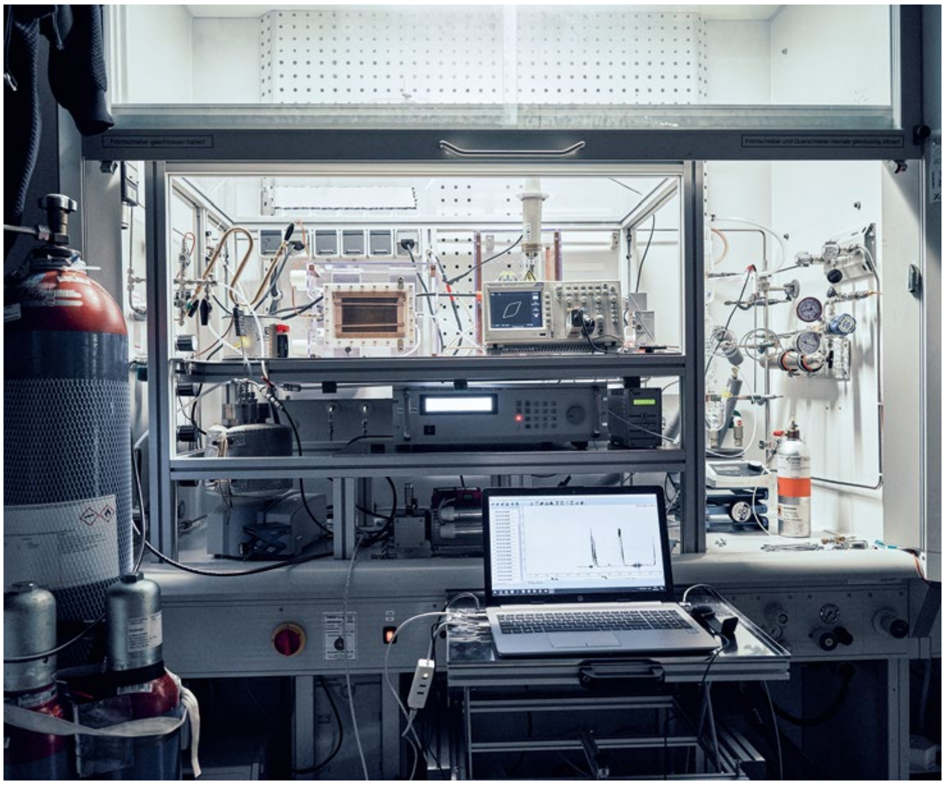
TEXT **TIM SCHRÖDER**

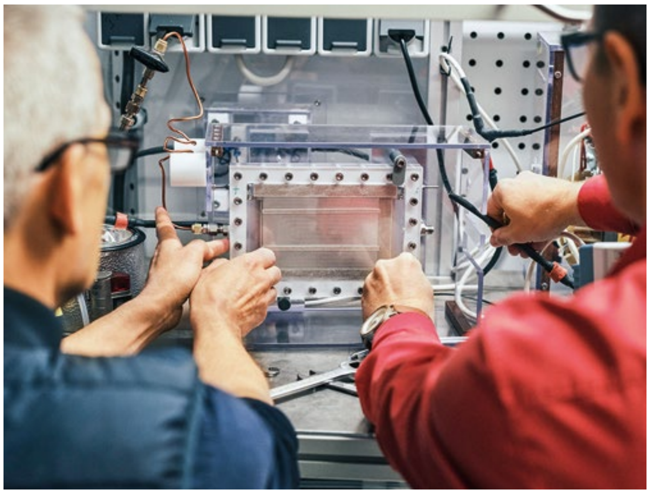
Physics professor Ronny Brandenburg from the Leibniz Institute for Plasma Science and Technology in Greifswald inspects the position of the electrodes in the lab reactor

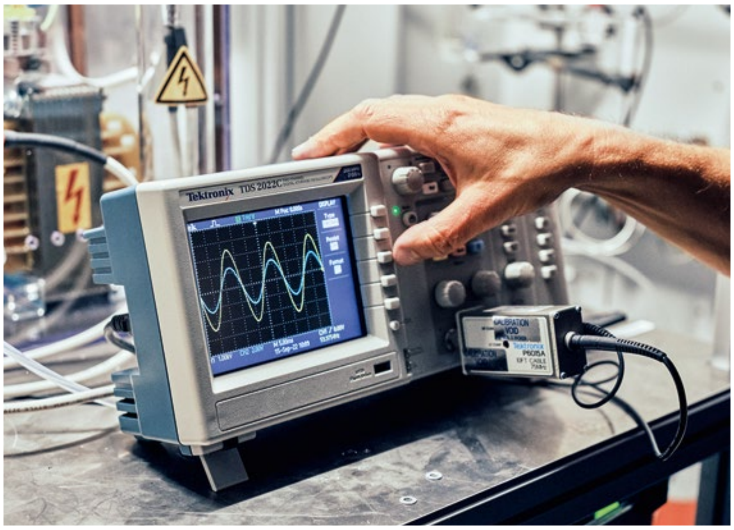
Sometimes you need a cordless screwdriver to do research," says physics professor Dr. Ronny Brandenburg as he loosens the Allen screws on a transparent plastic box lying on the workbench in front of him. A stack of metal grids can be seen inside the box. Brandenburg pulls out the last screw and lifts off the lid. "The gap at the contact is a bit too wide; maybe that's why there was a short circuit. Pass me that wrench there, please," he says to his colleague Dr. Ralf Jackstell, who is standing next to him at the workbench in the Rostock lab. Jackstell, a chemist, hands Brandenburg the wrench and replies with a smile, "Then it's one to two now: You guys wrecked two units, while we only wrecked one."

Ronny Brandenburg and Ralf Jackstell regularly tinker with equipment here in the laboratory of the Leibniz Institute for Catalysis (LIKAT)—and sometimes something breaks in the process. The small boxes are inconspicuous except for the power cable and the two connections for the gas supply, but they are surprisingly powerful. These are plasma reactors that convert the greenhouse gas carbon dioxide into valuable chemical products. Over the next three years, the experimental apparatus, which is currently the size of a box of chocolates, is to be scaled up to a large pilot plant. Evonik has been contributing its scientific know-how from the outset, but also wants to closely support the step toward large-scale implementation. That's because the research that is being conducted here on a small scale could take some of the most important reactions for the chemical industry to a whole new level.

The word "plasma" evokes visions of outer space, of rocket science, and of suns that are many thousands of degrees hot. But here in the lab in Rostock, you quickly realize that plasmas are very down to earth. They are formed when gases are exposed to strong electric fields. The electric voltage tears electrons from the gas →







Plasma physics under the fume hood: From the reactor to the gas analysis device, the entire system is housed within a small space (top left). Ralf Jackstell and Ronny Brandenburg like to work together on the equipment (top right). For the reactor to ignite, they have to precisely set the frequency and the voltage

molecules, which collide with other molecules. This forms a reactive mixture of free electrons, ions, and molecular fragments that come together to create new molecules. “Many people are amazed when I tell them how many everyday objects are made with plasmas,” Brandenburg says. They are found not only in plasma televisions but also in fluorescent tubes, in which they generate light. They are also used in paint shops, where components are cleaned and pretreated with plasma before the paint is applied.

Plasmas are an everyday phenomenon. The reactors Brandenburg and Jackstell are working on are correspondingly simple. “It only took us about a month to build the first lab reactor,” Brandenburg says. “The real challenge lies in controlling it to do exactly what you want it to do.”

The small reactors are at the heart of the PlasCO_2 collaborative project, which is coordinated by Evonik. Brandenburg, a physicist, is a professor and the head of research for surface plasmas at the Leibniz Institute for Plasma Science and Technology in Greifswald, Germany. Jackstell is a chemist who heads the Applied Carbonylations department at LIKAT in Rostock. Another participant is the Rafflenbeul Anlagenbau company, located near Frankfurt am Main, which manufactures plasma systems for air purification. It will build the prototype when the lab phase is finished.

30 DEGREES CELSIUS INSTEAD OF 3,000 DEGREES

One of the appealing things about the PlasCO_2 project is that it uses CO_2 as a raw material. Carbon dioxide gets a lot of bad press for its role as a greenhouse gas. For some time now, work has been under way to separate it from the exhaust gases of industrial plants, cement works, and blast furnaces in the steel industry and store it in disused natural gas fields, for example. But it can also be used in the chemical industry to make new high-quality products. The problem with carbon dioxide is that it is a very non-reactive molecule. In order for it to react with other substances, it must first be activated. For example, the thermal splitting of CO_2 requires temperatures of between 3,000 and 4,000 degrees Celsius. The energy consumption is correspondingly high. Plasma reactors would be an alternative means of making carbon dioxide reactive. All it takes to generate the plasma is electrical energy.

plasma of the sun, which has temperatures of many thousands of degrees, PlasCO_2 is a cold plasma of less than 100 degrees Celsius. The small laboratory reactors operate at 40 watts—the power of a household light bulb. The high energy of the plasma ultimately comes from knocking out the electrons, which then trigger the chemical reactions.

The PlasCO_2 team is currently testing several ways to turn carbon dioxide into valuable products. In the plasma, high-energy electrons convert carbon dioxide and hydrogen into carbon monoxide. Together with hydrogen, this forms synthesis gas, which is an important feedstock in industry for the synthesis of higher-value hydrocarbons. Carbon monoxide (CO) is used in hydroformylation, among other things. In this process, CO and hydrogen (H_2) react with larger hydrocarbon molecules, the olefins, to form aldehydes, which are needed in the chemical industry for many downstream products: for plasticizers in plastics as well as for adhesives and lubricants. Globally, hydroformylation supplies more than 10 million tons of products each year.

FAREWELL TO FOSSIL RAW MATERIALS

Until now, the carbon monoxide required for this has been obtained from natural gas. The new plasma reactor could make CO production more sustainable. It would use carbon dioxide from industrial waste gases, while the hydrogen would be produced with the help of renewably generated electricity that splits water in electrolysis plants. This would allow synthesis gas production to be decoupled from fossil raw materials.

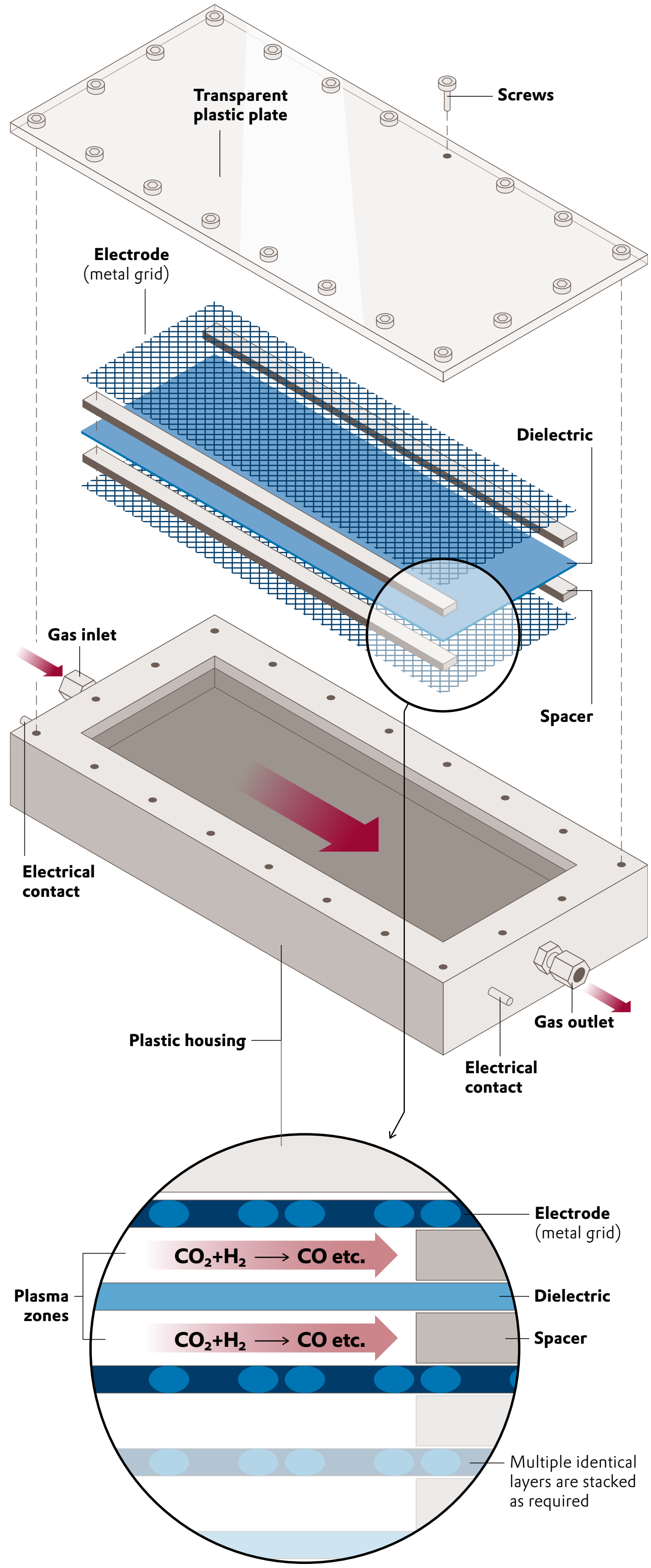
"However, the reactor can do a lot more," says Jackstell. "We can create different products depending on the molecules that we allow to flow into the reaction chamber." For example, reacting olefins with CO_2 and H_2 directly in the reactor can produce ethylene glycol and other compounds. Since the reaction of carbon dioxide and hydrogen also produces small amounts of oxygen as a byproduct, it is possible to run processes in the reactor that require oxygen—oxidative coupling, for example. "A lot of consecutive reactions start with oxygen. There are very many options," says Jackstell.

The production of synthesis gas in plasma is by no means new; it was already known back in the 1970s. However, because the production of carbon monoxide from natural gas had long been established by then, the chemical industry showed little interest in using plasma—until now. Because of the move away from fossil raw materials, the idea of producing chemicals with green electricity in a reactor is suddenly very topical.

"However, we still have to convince some of the experts of its benefits," Jackstell says. "There is a persistent belief in the community that the chemical reactions in plasma are difficult to control. But that's not quite true." Many research groups have been working →

Carbon monoxide at the push of a button

The structure of a plasma reactor that uses an electric current to produce carbon monoxide from carbon dioxide and hydrogen



with large molecules in plasma for a long time, and a lot can actually happen chemically. “It’s a molecular jungle,” says Jackstell, who points out that his group’s approach is different. “We work with very small molecules that can basically only react in one way,” he says. “This can be controlled very well.” In the coming months, the PlasCO_2 team will slowly work its way from small molecules to larger ones such as olefins.

The reactor also has the advantage that the chemical reactions can be switched on and off at the push of a button. “It lets us produce chemicals on demand, so to speak,” says Ralf Jackstell. In the future, plasma reactors would also be of interest to small and medium-size companies, which could use them to manufacture small quantities of base materials for their production operations at any time. Carbon monoxide is toxic. It is transported and stored in gas cylinders, and the people who handle it have to observe strict safety standards. In the future, the reactor could be used to produce it in small amounts in precise doses—and use it immediately.

At LIKAT, Ronny Brandenburg, Ralf Jackstell, and their colleagues have set up the entire production chain in miniature: the reactor, the gas supply, a collection vessel for the various products, and a reaction vessel in which they process the products into various chemical compounds. An FTIR infrared spectrometer, which measures which compounds come out of the reactor, is also connected to it.

The reactor itself consists of millimeter-thick grids stacked on top of one another. These grids are alternately connected to the positive and negative poles and there is always a dielectric between them. To start the reactor, an electrical voltage of about 8,000 volts is applied between the positive and negative poles. The chemical reactions take place in the wafer-thin gaps between the dielectric and the electrode grids. The trick is to match up everything perfectly: the distances between the grids, the frequency at which the alternating current oscillates, and the voltage. Any unevenness in the grids changes the spacing, the reactor performance, and the physical parameters; that’s why the stack must be arranged perfectly.

INTERDISCIPLINARY TEAMWORK

Ronny Brandenburg turns a knob in the darkened laboratory. He’s controlling the voltage. “It’s 4,000 volts, so the reactor should ignite right away,” he says. Indeed, the dark reactor surface brightens and takes on a bluish hue. There’s no flame and no flickering—just a steady glow. The reactor is up and running. “It’s at 40 watts, full power,” says Brandenburg’s research colleague Jackstell.

It doesn’t always work right away. Sometimes a capacitor causes problems, sometimes a contact. Sometimes the output suddenly drops to zero. When that happens, it means the reactor was overloaded. As ambitious researchers, Brandenburg and Jackstell accept all of this, because failures always provide insights into what can be improved. “We really like working together,” says Jackstell. “Although chemists and physicists generally speak different scientific languages, we like to jointly conduct the experiments.”

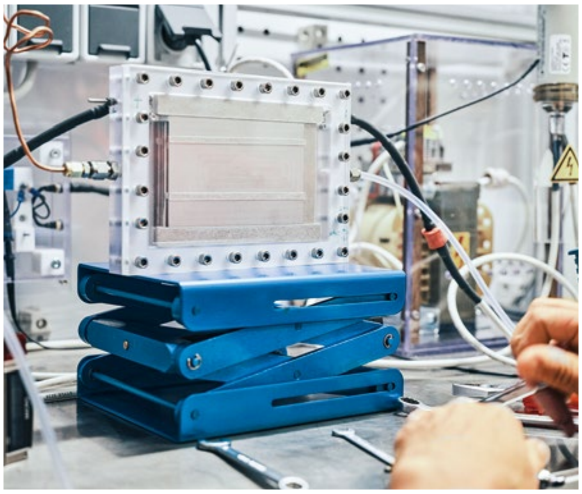
“If everything goes well, we’ll be able to do chemistry at the push of a button in three years”

ROBERT FRANKE, HEAD OF HYDROFORMYLATION RESEARCH AT EVONIK

THE PLASCO_2 PROJECT

The PlasCO_2 project is developing plasma reactors that convert carbon dioxide into carbon monoxide (CO) and hydrocarbons. When CO is combined with hydrogen, it yields synthesis gas, which is required for the production of many basic chemical substances—in particular the production of aldehydes via hydroformylation. Four partners from industry and research are working together on the project: the Leibniz Institute for Catalysis (LIKAT) in Rostock, the Leibniz Institute for Plasma Science and Technology (INP) in Greifswald, and the companies Rafflenbeul Anlagenbau and Evonik. The project is receiving €1.8 million in funding from the German Federal Ministry of Education and Research (funding code b 33RC030). Evonik is responsible for the overall coordination of PlasCO_2.

Brandenburg and Jackstell meet regularly in the laboratory of LIKAT in Rostock to test the reactors and conduct chemical experiments. The devices are transparent so that the researchers can check whether the plasma is igniting properly



Professor Robert Franke, who heads PlasCO_2 at Evonik, is also enthusiastic about the results of the interdisciplinary collaboration. “The team in Greifswald and Rostock has developed incredible momentum,” he says. PlasCO_2 emerged rather accidentally from a predecessor project. At that time, Ralf Jackstell’s research group at LIKAT was investigating whether cold plasma could be used to modify and optimize catalysts. Carbon dioxide and hydrogen were used in these experiments. “At some point, we noticed quite incidentally that the yield of synthesis gas was considerable,” says Robert Franke. That’s how the idea for the new project PlasCO_2 was born. “I’m fascinated by the idea of using a relatively simple technical setup to manufacture complex chemical products,” says Franke. “It’s a really fascinating future-oriented technology.”

CLOSING A CIRCLE

Franke has long pursued the idea of doing chemistry in cold plasma. In the early 2000s he started a project at Creavis, Evonik’s strategic innovation unit, in which an important step was the production of ozone. The ozone was used to produce dicarboxylic acids via a process known as ozonolysis—for example, suberic acid, which is required for the production of polyamides and polyesters. The ozone can be obtained from oxygen by various means, including a corona discharge or in a cold plasma.

“The plasma reactor had comparable yields and was absolutely technically feasible, though not economically competitive at the time,” says Franke. As a reminder of the project, Franke still has a glass jar of suberic acid powder on his office shelf. The circle is now closing, thanks to the PlasCO_2 project.

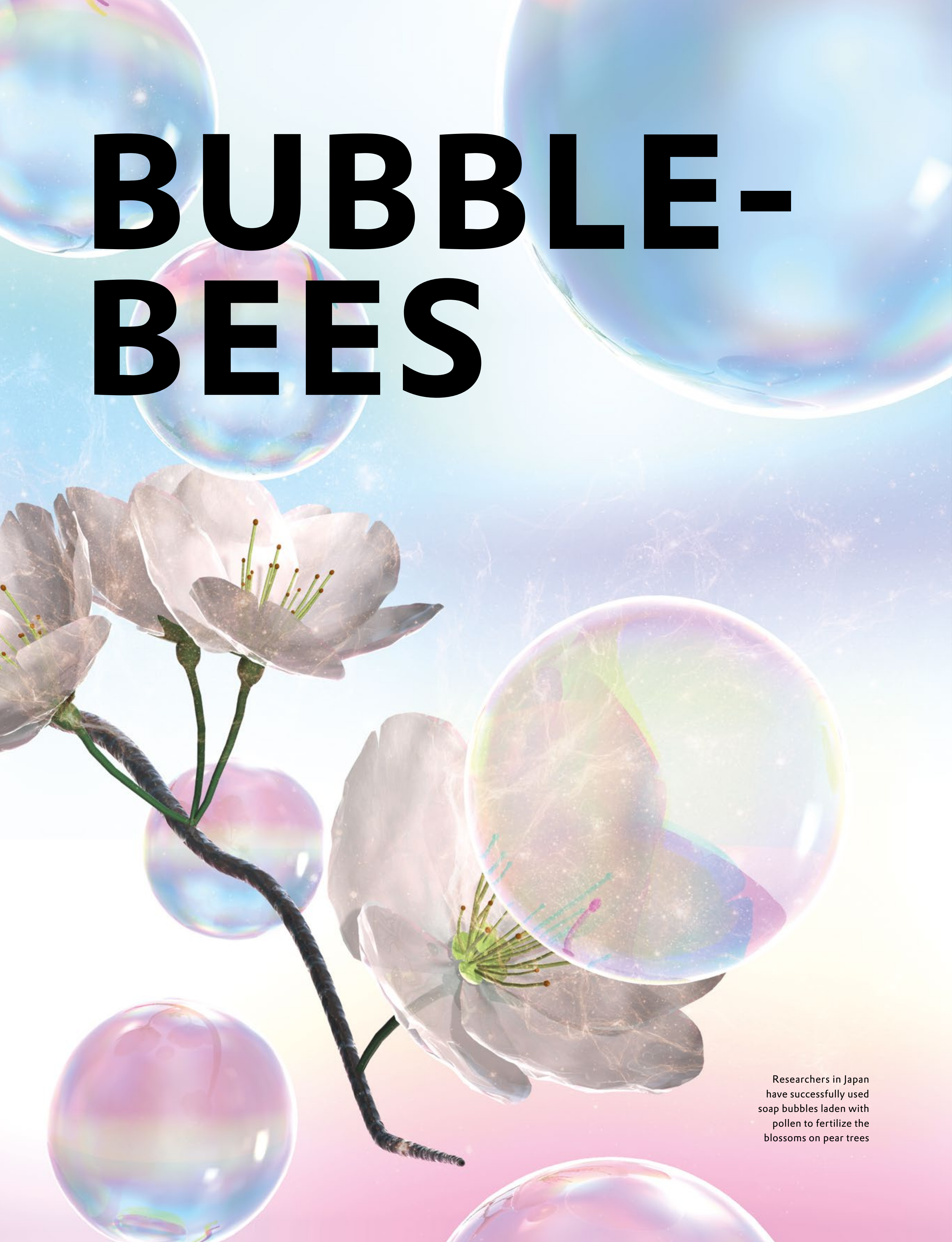
The team plans to go a step further in the months ahead. “We want to find out whether we can have other reactions take place in the reactor when the dielectric and the electrode grids also act as a catalyst,” says Jackstell. “For example, we can use catalytic metals, such as cobalt.”

This opens up many additional opportunities, according to Franke. “For example, the process could be used to produce carboxylic acids directly in the reactor from ethylene,” he says. The metal palladium, with which the group at LIKAT is very familiar, could be used as a catalyst. “If everything goes well, we’ll be able to do chemistry at the push of a button in three years,” Franke says. In order to produce larger amounts, the throughput could be increased by running multiple reactors in parallel. “It would be a truly sustainable solution if it was powered by green electricity and green hydrogen,” says Franke.

But until that time comes, the researchers will still need to pick up their cordless screwdrivers quite often to get defective reactors ready for the next test.

Tim Schröder is a science journalist who lives in Oldenburg. Although he had heard of plasmas in fluorescent tubes, he was amazed to see how easy it was to create a plasma

BUBBLE-BEES



Researchers in Japan have successfully used soap bubbles laden with pollen to fertilize the blossoms on pear trees

Without bees and other insects that pollinate blossoms, agriculture would be in deep trouble. Because insect populations are steadily decreasing, scientists are actively searching for technical alternatives that can support plant pollination

TEXT **BJÖRN THEIS**

Mama, Papa—where do babies come from? Parents caught off guard by this question like to tell their children the standard story about the birds and the bees. The popularity of this instructive metaphor is due to the German botanist Christian Konrad Sprengel. In 1793 he described the role played by insects in the propagation of plants for the first time in his book *The Secret of Nature in the Form and Fertilisation of Flowers Discovered.* Because of his research, Sprengel is regarded as not only the founder of flower ecology but also a source of ideas for Charles Darwin's theory of evolution.

Pollination is defined as the process by which pollen is transported from the male parts of a plant, or anthers, to the female parts, or stigmas, which are located at the top of a flower's pistil. Plants are pollinated not only by bees but also by many other insects, such as bumblebees and butterflies. Bats, birds, and rodents also transport pollen. And last but not least, wind and rain also play a part in the fertilization process. However, bees play the most important role. Thanks to their unpaid pollination services, they contribute approximately €200 billion annually to the global creation of added value.

However, in recent years people have observed a significant decrease in the numbers of pollinating insects. Intensive monoculture farming, the intensified use of insecticides, pollution by harmful chemicals, the increasing overdevelopment and sealing of land, light pollution, and the effects of climate change have had a severe impact on insect populations.

In Germany alone, about half of the 560 species of wild bees are at risk of extinction. Today, in some regions there are already not enough natural pollinators to ensure that the planned volumes of crops can be harvested. More and more farmers need to give nature a helping hand. One popular method is to bring in additional beehives. However, the imported bees may have negative effects on the local ecosystems. In some agricultural regions of China, fruit trees are already being pollinated by hand. It's a cost-intensive method that doesn't really solve the problem. That's why researchers all over the world are working to develop cost-effective pollination techniques in order to safeguard humankind's future food supply.

BUBBLE MEETS BLOSSOM

For example, scientists in Japan are conducting experiments that use soap bubbles for pollination. A team at the Japan Advanced Institute of Science and Technology in Nomi has successfully pollinated fruit trees with the help of soap bubbles. They used a kind of cannon mounted on a drone to shoot soap bubbles consisting of a 0.4% solution of lauramidopropyl betaine at pear trees. These bubbles are environmentally friendly, robust, and sticky enough to get up to 2,000 grains of pollen to adhere to them. If a blossom is hit by between two and ten bubbles, it is very likely to be fertilized.

The Israeli tech company Edete aims to fertilize plants with the help of electrostatic fields, and the Polybee startup in Singapore is testing microdrones that imitate the "buzz pollination" that is done by several types of bees. In this process, the pollen is shaken loose through vibrations in the air caused by the wingbeats of insects flying past.

THE FUTURE OF NUTRITION

If we want to feed the world in the future, we need to compensate for the loss of natural pollinators. That's a good reason for the Foresight team at Creavis to investigate this area as part of its Sustainable Food Futures 2040 program. Among other things, Evonik has wide-ranging skills in the area of interface chemistry—skills that can help to develop the pollination methods of the future. In addition, the Agricultural Solutions unit at Creavis is working to develop solutions for a more sustainable agriculture that can help to make bees and blossoms feel so comfortable once again that they no longer need human beings to do their pollination work for them.

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

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Oxygen

“When you’re free-diving, your strength comes from serenity”

LOG **KAROLINA FÖST**
PHOTOGRAPHY **NAZIM AHMED**

Herbert Nitsch is one of the most successful freedivers. He has set 32 world records in all eight international apnea disciplines and has dived deeper without a compressed-air cylinder than any other human being. In 2012 he dived to a depth of 253 meters but incurred decompression sickness

Oxygen is a vital requirement for human life. We take in this element as part of the air we breathe. But we breathe more than we actually need to. It’s similar to driving to the gas pump even though the tank is not yet empty. The more we breathe, the more oxygen we need, because breathing requires energy. In freediving, it’s crucial to consume as little oxygen as possible. The precondition for that is to be relaxed, so that you can dive to great depths without requiring additional air from a compressed-air cylinder. That’s why I put my body into an energy-conserving mode and my mind into a dozy state. First, I dive down and come up again several times. That way I activate the diving reflex, which slows down my heartbeat, among other things. I don’t have any thoughts, and I block out everything around me. During competitions, that means the cameras, umpires, and audience. Adrenaline also increases oxygen consumption. And the resolution “Now I’m going to make an especially deep dive” increases it even more. When you’re freediving, your strength comes from serenity. I try to go down to the depths with as few movements as possible. Movement costs you oxygen. It’s like climbing a flight of stairs: If you start off too fast, you’ll be out of breath after just one flight. Most people assume that the air they breathe is oxygen. However, only 21 percent of the air we breathe is oxygen. The biggest component of it is nitrogen. When you’re in the depths, it has a narcotic effect. You feel as though you’ve drunk one beer too many. This feeling of drunkenness, plus my relaxed state, became almost fatal for me when I was attempting to set a record in 2012. While I was resurfacing from a depth of 253 meters, I briefly fell asleep. When I had reached a depth of 26 meters, my sled, which had taken me to the depths and pulled me up again, made a planned stop. The rescue divers brought me to the surface without making a decompression stop. They thought I had fainted. Without this stop, the nitrogen that has dissolved in your blood is released as tiny gas bubbles that block your blood vessels. Your brain stops receiving oxygen. I suffered multiple strokes and lay in a coma. The doctors’ forecasts were pessimistic, but I fought my way back to life, and back to water. Two years after this accident I started to dive again—just for fun and, as always, without a compressed-air cylinder.”

Masthead

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“Every great and deep difficulty…”

… bears in itself its own solution. It forces us to change our thinking in order to find it,” according to Niels Bohr, the notable Danish Nobel Prize laureate who made a major contribution to nuclear physics. He regarded every problem as primarily an opportunity to develop an innovative approach to a solution.

The production of ultrapure methane and carbon dioxide from biogas is an outstanding example of this principle. Thanks to advanced technology, the problematic substance that is generated in gigantic amounts in agriculture, sewage treatment plants, and landfills can be used to mitigate the energy and climate crisis.