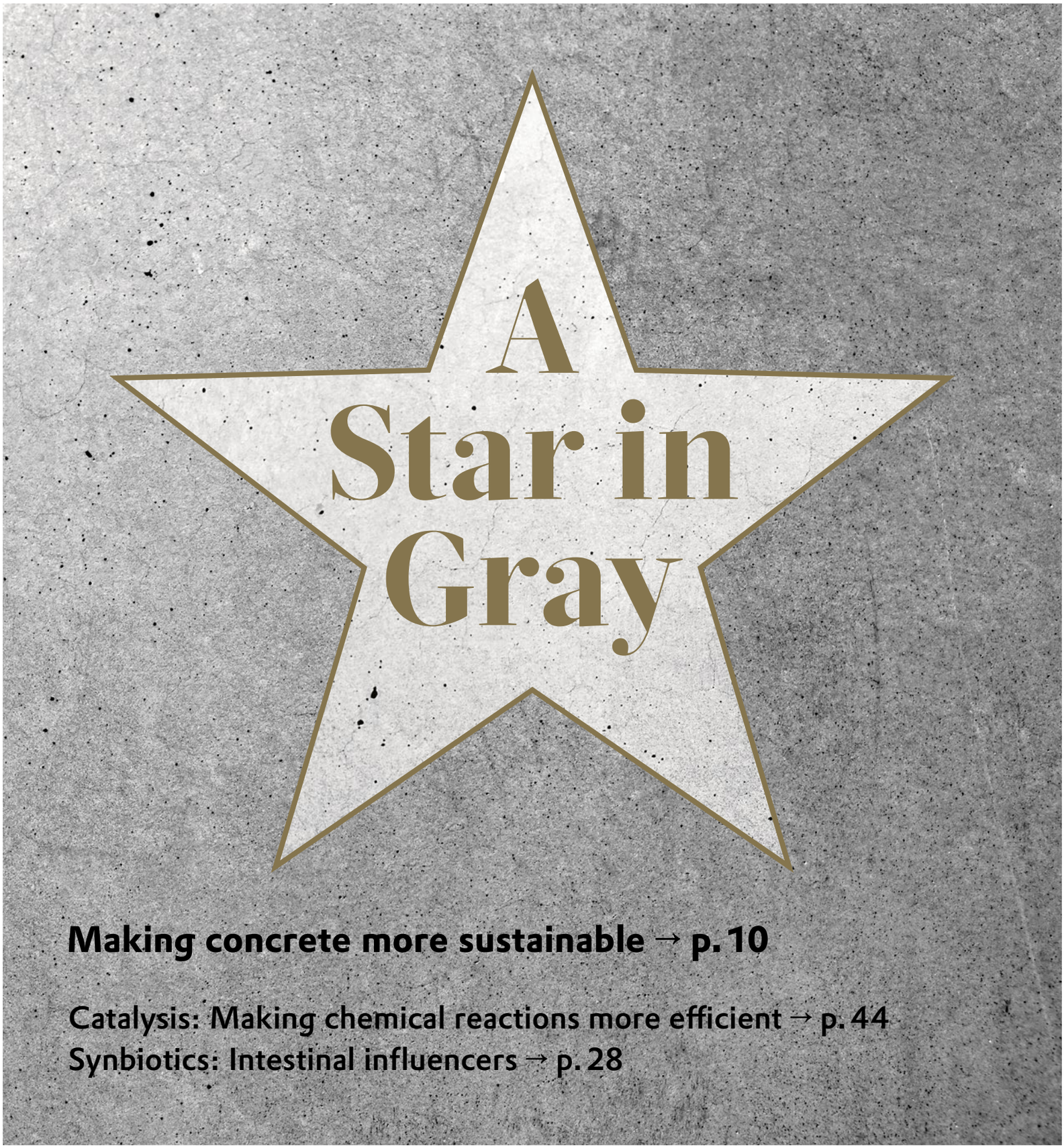
2/2021

EVONIK
Leading Beyond Chemistry

ELEMENTS

Research. Knowledge. The future.



Concrete

A durable construction material

Concrete consists of cement, water, and mineral aggregates. It differs from mortar because of its granulation: Mortar has a grain size of up to four millimeters, whereas coarser-grained material is known as concrete. As a rule, concrete is mixed at the construction site. Alternatively, it is delivered in a liquid state and hardens on site. In its hardened state, it can basically withstand high levels of stress. The water-cement ratio of a concrete mix is the measure of its compressive strength. In order to withstand higher levels of tensile force, concrete requires additional reinforcements. These are usually made of steel, but glass, carbon fiber, and textiles are also being used increasingly. Special high-performance and ultra-high performance concrete is used for structures that are especially complex or that must bear extremely heavy loads.

Concrete aggregate A mixture of sand and natural or artificial stone
Water-cement ratio (w/c ratio) The ratio of water to cement in concrete
Ultra-high performance concrete (UHPC) A high-density and high-strength type of concrete consisting of a large proportion of binders, a small amount of water, special reinforcements, and additives

DEAR READERS,

Concrete is the world's most important construction material. It has many fantastic qualities—and a really terrible carbon footprint. Concrete is responsible for eight percent of global carbon dioxide emissions. If we want to reduce this figure, we basically have two options: either replacing concrete with materials such as wood wherever possible, or making it a better and more sustainable construction material. Stephan Birk from the Technical University of Munich strongly advocates the first option in the debate that begins on page 22. The second option is represented by Evonik. Our researchers have found ways to make concrete more durable and more sustainable. The report that begins on page 10 explains exactly where they're focusing their research and what role bacteria are playing in these efforts.

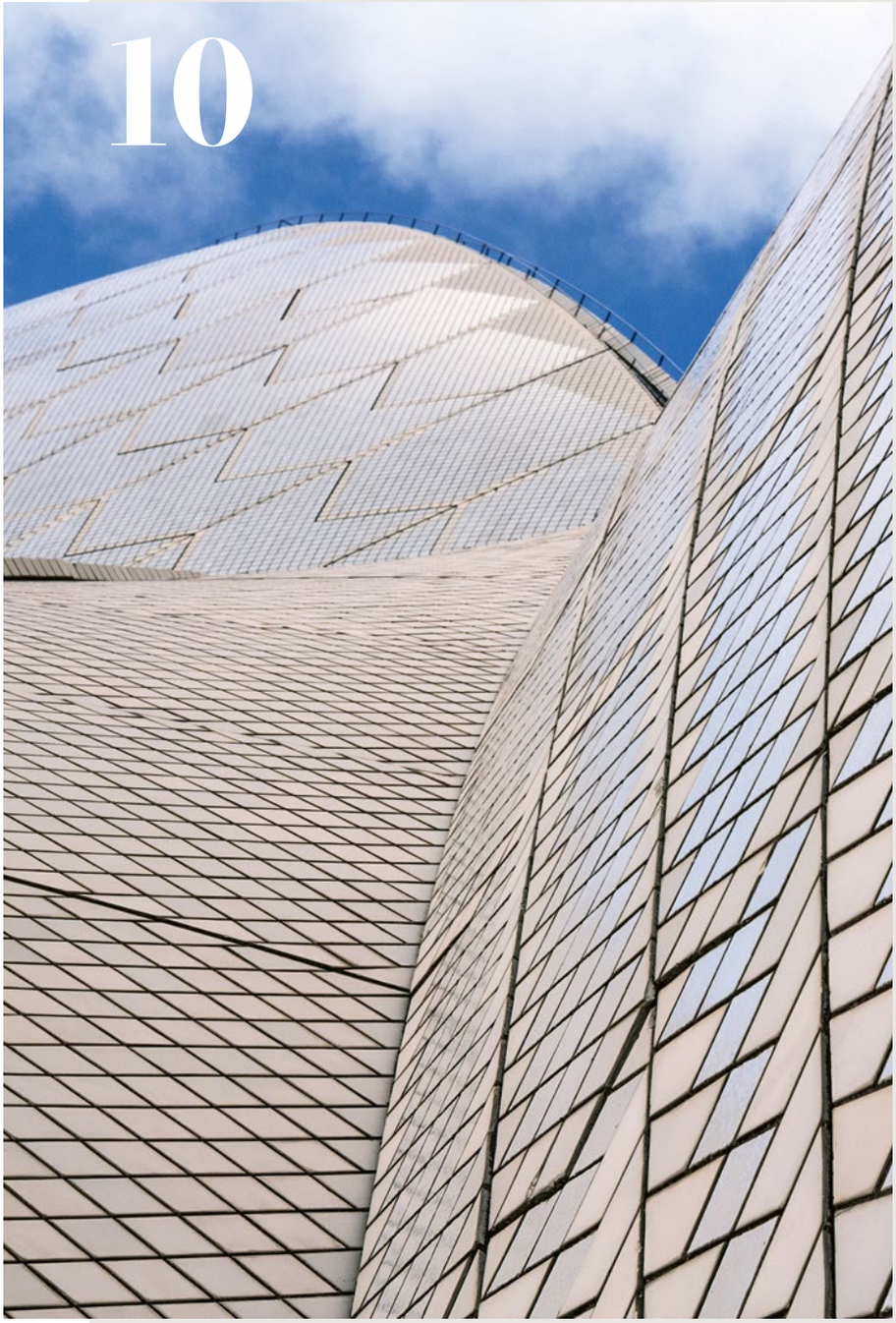
The nutritionist Heike tom Dieck also works with microorganisms. She is investigating the relationship between gut health and an overall sense of well-being. Surprisingly, 90 percent of all illnesses are linked with the tiny organisms that live in the digestive tract. Starting on page 28, we explain how scientists are making sure that synbiotics will be fighting for our gut fitness in the future.

We also take a look at the Torre del Gombito, a 13th-century tower in the historic city center of Bergamo. You can find out how it's connected with specialty chemicals in the photo gallery about the Evonik country Italy, which begins on page 36.

I wish you a thought-provoking reading experience.

Matthias Ruch
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



Spectacular buildings such as the Sydney Opera House would not be possible without concrete. The challenge is now to make this construction material more sustainable

The experts at Evonik use the model of a chicken gut to investigate the microbiome

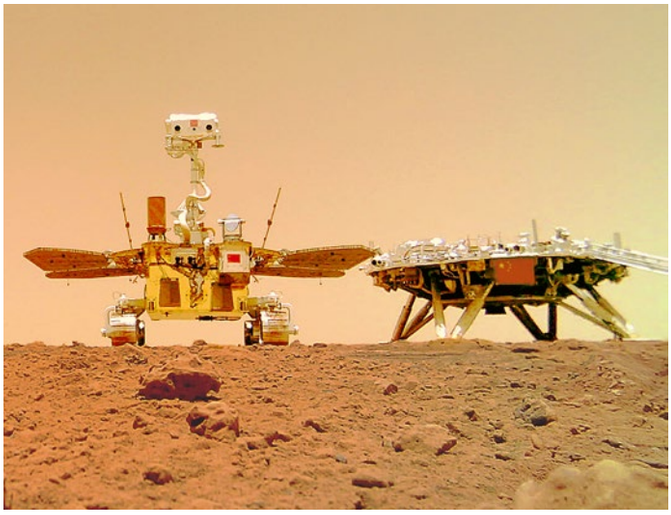
The new MACBETH reactor could make huge purification plants unnecessary

REAL OR DIGITAL?

A "digital twin" is a virtual reflection of reality. In the same way as this illustration of innumerable animated points of light and circuits creates the image of a bird's-eye view of a big city, a digital twin is not composed of anything tangible. On the contrary, it consists of data that flows into a predictive model. In this way, the US startup Element Analytics, in which Evonik has held an equity investment since last year, creates virtual copies of production facilities, including all of the machines that keep the operation running. This can provide Evonik with a digital twin of a pump, for example, that can be used to accurately forecast when the real-life pump in a particular chemical plant will fail. This enables technicians to take action early on—and in a completely analog manner.

A Galactic Lubricant

Because conventional fats and greases reach their limits in outer space, researchers have now come up with an alternative to these products

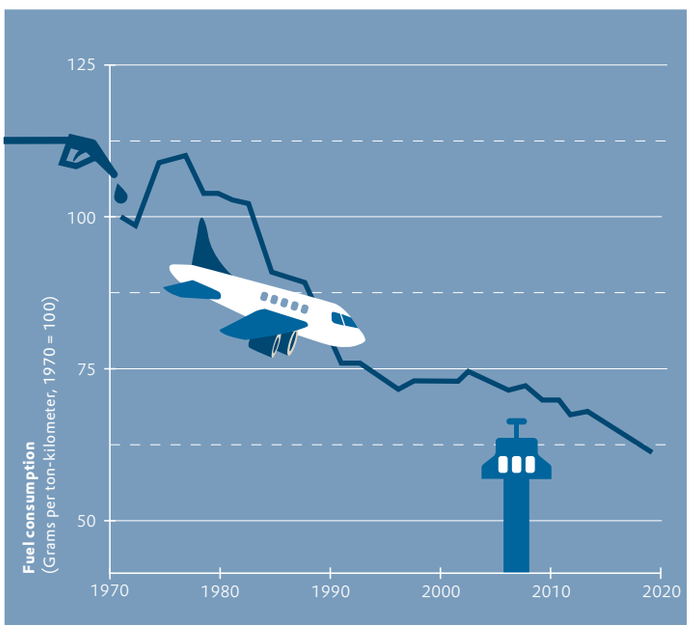


The Chinese rover Zhurong has been moving about the surface of Mars since May. Conventional lubricants would evaporate due to the planet's thin atmosphere

When people hear the word "lubricant," they generally think about oils and fats for use in automobile engines or bicycle chains. However, the movable parts of a Mars rover also have to be able to move smoothly. Conventional substances quickly reach their limits under the extreme conditions of outer space. However, this is not the case with a class of dry lubricants that a research team at the Technical University of Vienna has now investigated: MXenes. They consist of ultra-thin titanium and carbon layers that can slide against one another and thus prevent abrasion. MXenes have a special structure that makes them very heat-resistant, which is why they can be employed in the steel industry, for example, where production takes place at high temperatures. It also enables MXenes to be used in outer space, where their high performance is undiminished because they don't evaporate under vacuum conditions.

THAT'S BETTER

Economy Class



Air traffic plays a key role when it comes to climate protection. Reducing fuel consumption is an important adjustment that can be made. The good news is that the fuel consumption of new aircraft has declined by around 40 percent per ton-kilometer over the past five decades. One of the reasons for this is the fact that propulsion systems have become more efficient. Another reason is that increasing numbers of lighter but strong components are being used.

Source: OECD

69,000

TERAWATT-HOURS

of electricity could be generated from green hydrogen each year, according to a study by the Fraunhofer IEE. This could be achieved if all of the technologically and economically suitable locations in the world were occupied by solar and wind power systems for the production of hydrogen. This would be enough to cover around 40 percent of global energy demand.

AN ELECTROLYTE...

...makes it possible to manufacture solid-state batteries that might one day last as long as energy storage devices made of lithium. That's because a team of researchers from Berlin, Munich, and Jülich has made an important discovery: If the crystals within the electrolyte are heated, they create a nanolayer on their surfaces that carries the charge from one crystal to the next. The layers can be arranged in such a way that short circuits are prevented, thus extending the battery's service life.

Charge Against Viruses

A new composite material should help to combat pathogens in drinking water

Tiny pathogens in drinking water pose big challenges for the developers of filter technologies. Measuring only 70 nanometers across, the rotavirus, for example, is one of the most common causes of gastrointestinal infections, especially in developing countries. Conventional water filters are often ineffective against such tiny viruses. However, a team from the Swiss Federal Laboratories for Materials Science and Technology (Empa) and the Swiss Federal Institute of Aquatic Science and Technology (Eawag) recently developed a filter system made of special composite materials that can bind the miniviruses. The solution's key feature is electrical charge: Whereas the materials have a positively charged surface, the virus particles mostly have a negative charge. As a result, they stick to the material, thus causing a very positive filtering effect.

PEOPLE & VISIONS

"Wood waste is a very good source of biofuels"

THE PERSON

Like many other children, Carolina Barcelos wanted to become a veterinarian when she was young. But unlike most kids, Barcelos, who is from Brazil, later became enamored of mathematics and the natural sciences in school. "These subjects attracted me because they involved the solving of very concrete problems," she says. As a young woman, Barcelos studied process engineering in Rio de Janeiro and wrote her doctoral thesis on the conversion of sweet sorghum into bioethanol. From then on, the recycling of biomass became the key topic of her research career.

THE VISION

Barcelos wants to protect both the climate and the forests by recycling wood waste. "Until 2050, there will be about 38 million tons of dry wood biomass available every year," she says. "Wood waste is a very good source for the production of sustainable fuels such as ethanol." The team headed by Barcelos has developed a very efficient process for this purpose. The raw material consists of agricultural waste and dead wood from forests. A beneficial side effect of this technique is that if much of this wood is converted into biofuel, it could also reduce the risk of forest fires.

GOOD QUESTION

"Why can bacteria consume plastic waste in the sea, Dr. Deines?"

Bacteria are extremely adaptable and populate all habitats on earth. What's special about them is that they can use different substrates as a source of carbon, and thus as food. Basically, this also means that they can consume plastic. Like human cells, bacteria benefit from the division of labor that exists in a community. We want to exploit precisely this principle in our approach to the research. Instead of looking for bacteria that are especially good performers on their own, we isolate entire communities from their environment, such as an ocean. We then cultivate these bacteria so that they can recycle plastic much more efficiently together than they could on their own. That's why this kind of biological recycling is ideal for use in environmental biotechnology.

Dr. Peter Deines, a biologist at the GEOMAR Helmholtz Centre for Ocean Research, is the main author of a study concerning the breakdown of plastics by bacteria.

Intact, thanks to bacteria: The concrete for these prisms was mixed with microbes that seal cracks

HEALING WALLS

TEXT **TOM RADEMACHER**

Concrete is the world's most important construction material. However, it does more harm to the climate than almost any other product. Researchers all over the world are working to improve this material's CO_2 balance by optimizing its composition. For example, they are using bacteria that can seal small cracks in concrete on their own and thus prolong the useful life of buildings

When the chemist Dr. Anke Reinschmidt is explaining the special power of WallCraft, she asks visitors to stand very close to the concrete block that is dangling from a rope in the remotest corner of her laboratory in Essen. Only then can they see the thin white line that runs through the block. "Here you can see the place where the test piece was broken and has now bonded together again," she explains. To demonstrate how firmly the crack has been mended, her team has suspended a pail of sand from the concrete block. The word "mended" is actually misleading. Special bacteria that had been added to the raw concrete have sealed the crack on their own through their metabolic reaction, without any human assistance.

The formulation of the additive called WallCraft comes from Evonik and is set to be launched on the market soon. "This additive combines traditional construction chemistry with cutting-edge biotechnology," says Reinschmidt, the technical director of application technology and the technical service for construction at Evonik. The bacteria in the brown powder can be easily mixed into mortar or cement. For the microbes, this environment is so alien that they remain in their spore state. Theoretically, this type of hibernation could enable them to survive forever. Only if water seeps into the concrete—for example, through a fine stress crack in a structural element—do the microbes revive and start producing calcium carbonate, or limestone, through their metabolic process. The limestone seals the crack automatically, the water source dries up, and the bacteria go back into hibernation—until the next case of water damage.

Evonik is not the only company that has set great hopes on this development. After all, enabling concrete buildings to repair themselves and thus substantially lengthen their useful life is an important step in economic and environmental terms. But the problem is much bigger than the tiny bacteria. It begins with the vast demand for fresh concrete. Both concrete and cement, which is one of its main components, are everywhere, and the global demand for them grows every year. At last count, the annual demand was more than four billion tons.

However, the negative effect of this building material on the environmental balance is increasingly ruining its image. That's why concrete needs to reinvent itself in order to join the movement toward sustainable construction. Construction chemistry is playing a huge role in this effort. The aim is not only to make this material →

The Evonik chemist Anke Reinschmidt has worked for decades to develop additives that make concrete and mortar better. She developed the latest formulation, which contains bacteria, together with biotechnologists at Evonik

WallCraft is marketed by Evonik under the name SITREN® Self-Heal.

THREE GORGES DAM CHINA

The Three Gorges Dam spans the Yangtze River in Hubei Province in China. The construction of the dam, which is 2.3 kilometers long and up to 150 meters high, between 1995 and 2006 required the processing of almost 27 million cubic meters of concrete

even stronger, which was the previous goal, but also to make it more environmentally and climate-friendly.

The biggest defect of concrete is due primarily to cement. This binder is mixed with water and aggregates such as sand or gravel to make concrete. Cement production releases huge amounts of carbon dioxide. The cement industry alone is responsible for eight percent of man-made global CO_2 emissions. The effect on the climate varies widely, depending on the type of cement production. In Germany, cement production releases 590 kilograms of CO_2 per ton of cement on average, but in other countries that figure is much higher.

In the laboratory, the researchers create stress cracks that seal themselves automatically, thanks to WallCraft

STEALING SAND FROM BEACHES

The main culprit in this situation is clinker, the main component of every type of cement. Clinker is basically heated limestone. The ground limestone is heated to 1,450°C (see the infographic on page 14). In addition to the huge amount of energy that is needed for this process, the chemical reaction that takes place during the burning generates large amounts of greenhouse gas emissions. When calcium carbonate ($CaCO_3$) is converted into calcium oxide (CaO), CO_2 remains. That's an unalterable natural law.

In order to reduce carbon dioxide emissions, some researchers are looking for ways to replace clinker with other materials such as ground slag from the blast furnaces that are used to produce pig iron, fly ash from the exhaust gas filters of coal-fired power plants, or various types of natural stone. Whereas traditional Portland cement consists of 95 percent clinker, all the types of cement used in the EU contain just under 74 percent clinker on average. The International Energy Agency (IEA) predicts that the percentage of clinker in cement will continue to decrease toward 60 percent in the years ahead. Newly developed formulations are already reducing this proportion to less than 50 percent with the help of climate-friendly substitutes.

But the world's ever-growing hunger for concrete also brings other risks besides the emission of climate-destroying gases. It also devours large quantities of resources—especially sand, water, steel, and energy.

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Concrete—a construction material that's thousands of years old

In past ages, concrete must have seemed almost magical. It's a man-made stone that starts out as a liquid but hardens into a solid that lasts forever. Human beings were already using materials similar to concrete 14,000 years ago. The Pantheon in Rome is not the oldest example, but it's one of the most impressive. The overarching dome, which is made of Roman concrete (*opus caementitium* in Latin), has a span of more than 40 meters. It still astonishes visitors today, almost 1,900 years after it was built. In the 19th century the type of concrete we know today finally began its triumphal march—in buildings, bridges, tunnels, and road surfaces. About 30 billion tons of concrete are used for construction every year, about half of it in China. Today China produces and uses more concrete in two years than the USA has produced and used in the entire 20th century (see Data Mining on page 15). Other emerging economies are catching up and boosting the global demand even more. "Concrete has been a major contributor to lifting many millions of people out of poverty," says Dr. Karen Scrivener, a materials scientist who heads the laboratory for construction materials at the Ecole Polytechnique Fédérale de Lausanne (see the debate that begins on page 22). "And we need to continue this because people need a chance to lead a dignified life."

"With long-lasting concrete we can significantly reduce emissions"

MAGNUS KLOSTER, HEAD OF THE CONSTRUCTION INDUSTRY MARKET SEGMENT AT EVONIK

Because desert sand, which has been worn smooth, is not suitable for concrete production, the illegal removal of sand from riverbeds and beaches is growing. "The quality of the sands that are used is getting worse and worse," says Reinschmidt. In order to mix high-quality concrete in spite of this problem, producers need the right additives. The recycling of concrete can also help producers use less cement and greenhouse gases. Here too, additives can help construction materials maintain their customary level of performance.

SOLUTIONS FOR A CONSERVATIVE SECTOR

"We solve problems. That's what we've always done," says Reinschmidt. She has dedicated her research career to concrete additives. This was the topic of her doctoral thesis 20 years ago. After a series of jobs in the USA and South America, she started working at the Evonik laboratory in Essen. Here Evonik is testing many different additives that improve concrete. For example, superplasticizers combined with defoamers from Evonik make it possible to use less water in the mix. That makes the concrete harder, yet capable of being pumped up to the top floor of the highest skyscraper. Shrinkage reducers minimize concrete components' tendency to deform or crack as they harden. Air-entraining agents ensure that air bubbles are distributed throughout the concrete in exactly the right sizes and amounts. "If there's too much or too little air in the concrete, or if it's unequally distributed, the structural element is damaged," says Reinschmidt. And hydrophobing agents prevent water from penetrating the hardened material. →

Roman concrete was used to construct the Pantheon in Rome, which was completed between 125 and 128 A.D. Depending on where it was used in the building, it contained basalt, crushed bricks, tuff or pumice stone as an aggregate

PANTHEON
ITALY

BAUHAUS GERMANY

The architect Walter Gropius had already experimented with concrete even before the Bauhaus building was constructed in Dessau. After it was completed in 1926, this concrete building with its glass curtain wall became an icon of the Neues Bauen movement in architecture

The construction chemists at Evonik use strictly standardized processes to test new formulations in the laboratory

Thus they help to protect buildings from the effects of the weather and make them more durable. In the future, the bacteria in WallCraft will have the same effects—but these effects will be more active and last longer.

"Especially in new construction projects, we have the opportunity to reduce emissions over the long term by using longer-lasting concrete," explains Magnus Kloster. He's the head of the market segment for the construction industry at Evonik's Interface & Performance business line. Before joining Evonik, he worked for a long time at a leading supplier for the concrete construction sector. "If highway bridges last for 60 years instead of 50, for example, that saves tremendous amounts of material and CO_2 emissions over the long term," he explains. Self-healing concrete, he adds, has what it takes to significantly reduce the amount of construction material that is used. "That's especially true for emerging and developing countries, where concrete recycling is sometimes not even economically feasible, partly because they do a lot of their construction from scratch," says Kloster.

WallCraft shows how this works. Reinschmidt and her team have tested this phenomenon countless times. Boxes full of tiny test pieces, which are known here as prisms, are stacked up in every available corner of the lab. New prisms are being produced just now, using standardized sand in standardized metal molds measuring four centimeters by four centimeters by 16 centimeters. The room temperature is a standardized 23°C, and the humidity is kept at a constant 50 percent. "In the construction sector, nothing stays unstandardized," says Reinschmidt. Reliability is all-important. The prisms are tested to find out how quickly, how strongly, and how often the material grows together again at different moisture contents, for example. "We also investigate how compatible the product is with other additives and with every kind of formulation," Reinschmidt explains. Each new material has to function reliably. The construction sector tries to avoid experimentation, because if concrete structures crumble the More on page 16 →

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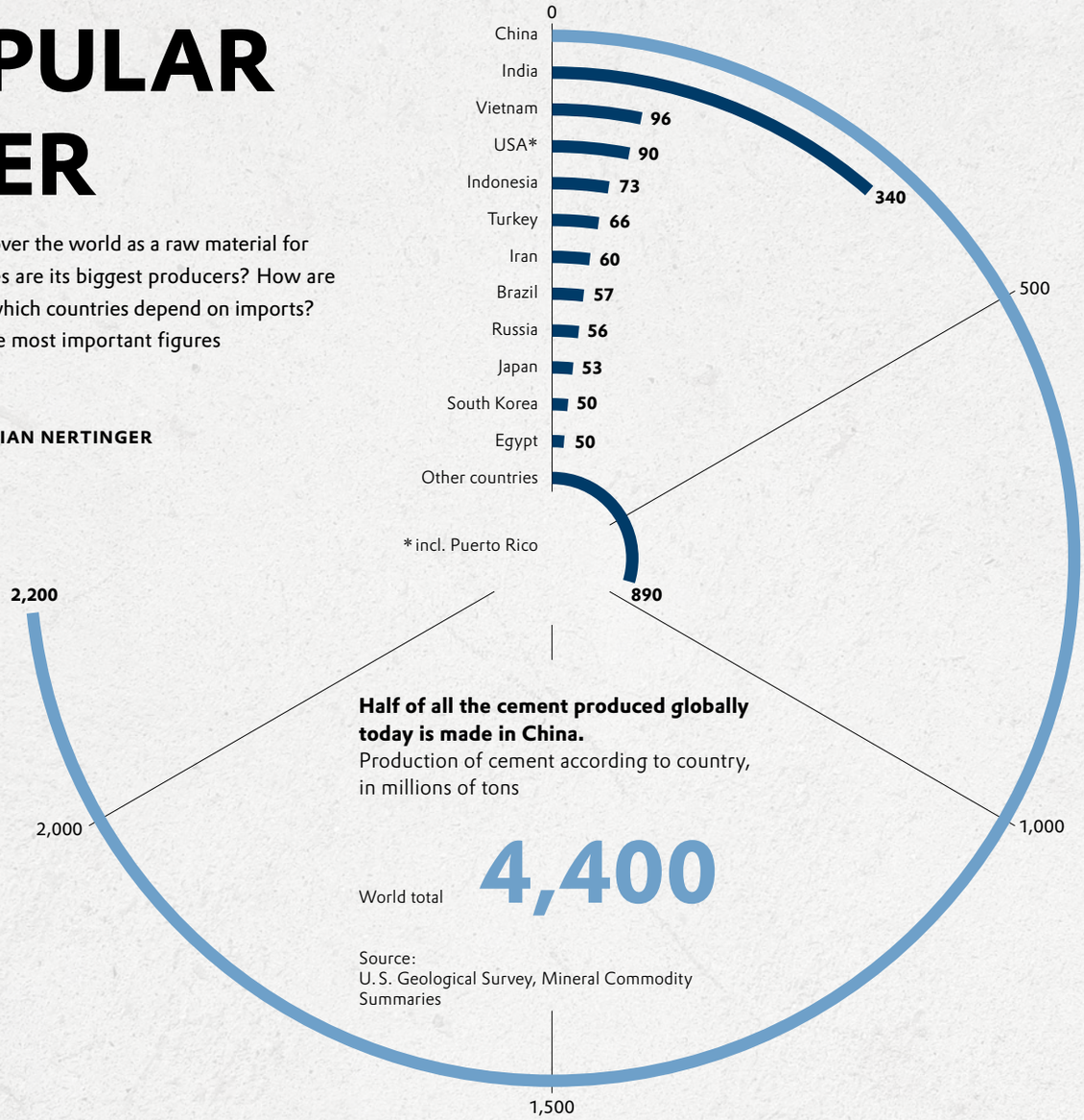
A POPULAR BINDER

Cement is in demand all over the world as a raw material for concrete. Which countries are its biggest producers? How are prices developing? And which countries depend on imports? Here's an overview of the most important figures

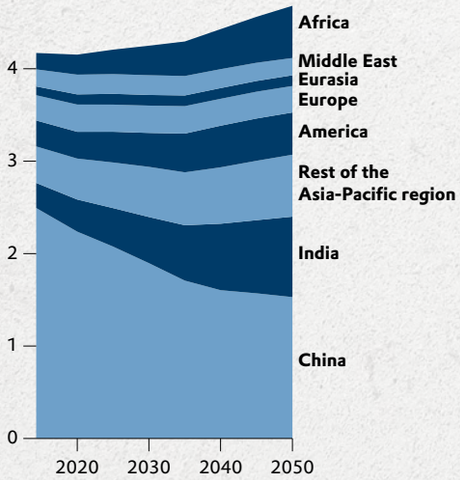
INFOGRAPHIC **MAXIMILIAN NERTINGER**



Half of all the cement produced globally today is made in China.
Production of cement according to country, in millions of tons

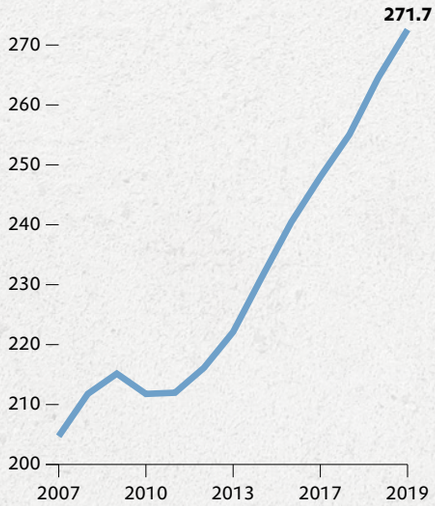
Source: U. S. Geological Survey, Mineral Commodity Summaries

However, China's lead will shrink in the years ahead
Predicted development of cement production according to regions, in billions of tons



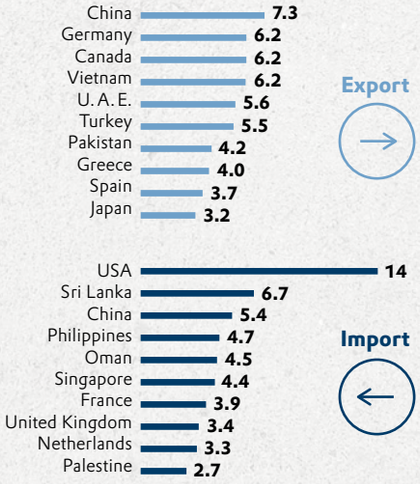
Source: International Energy Agency

Like many other construction materials, cement has recently become more expensive
Price of a ton of Portland cement in US dollars

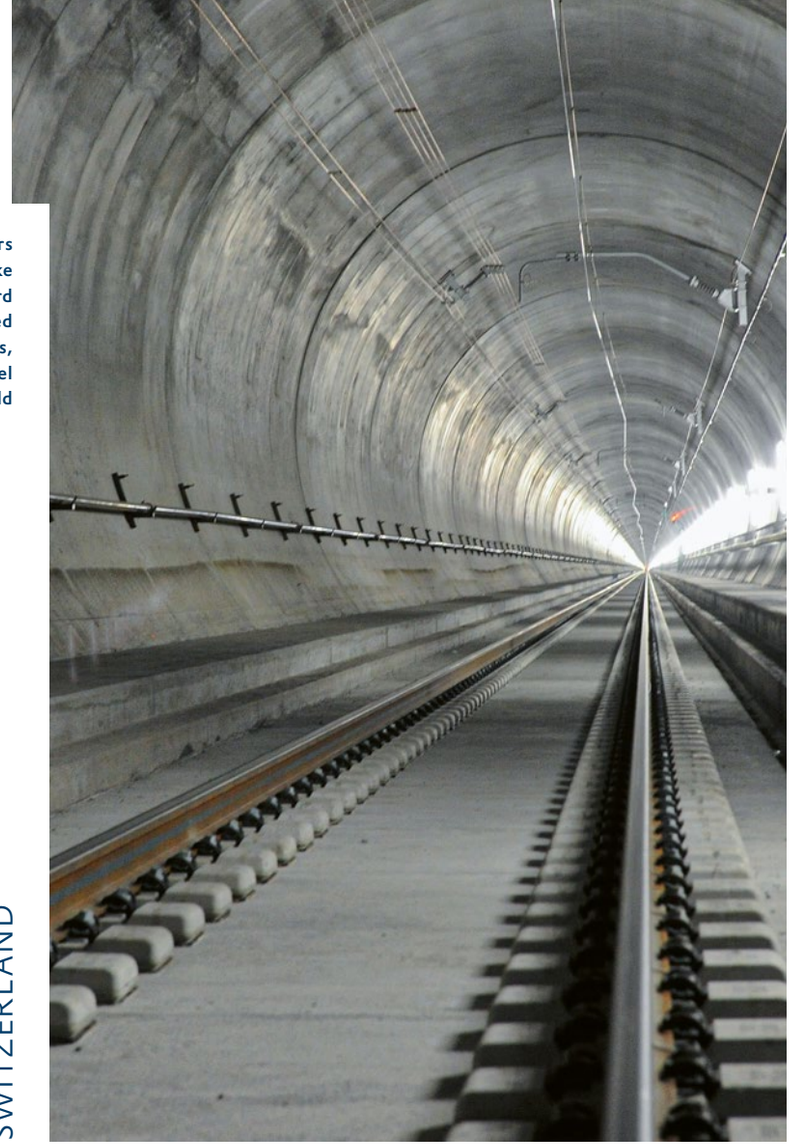


Source: Statista

Only a small percentage of production is traded across borders
The biggest cement exporters and importers in 2018, in millions of tons



Source: Indexbox



GOTTHARD BASE TUNNEL
SWITZERLAND

Four million cubic meters of concrete were used to make the boardings of the Gotthard Base Tunnel, which was opened in 2016. At 57 kilometers, it's the longest railroad tunnel in the world

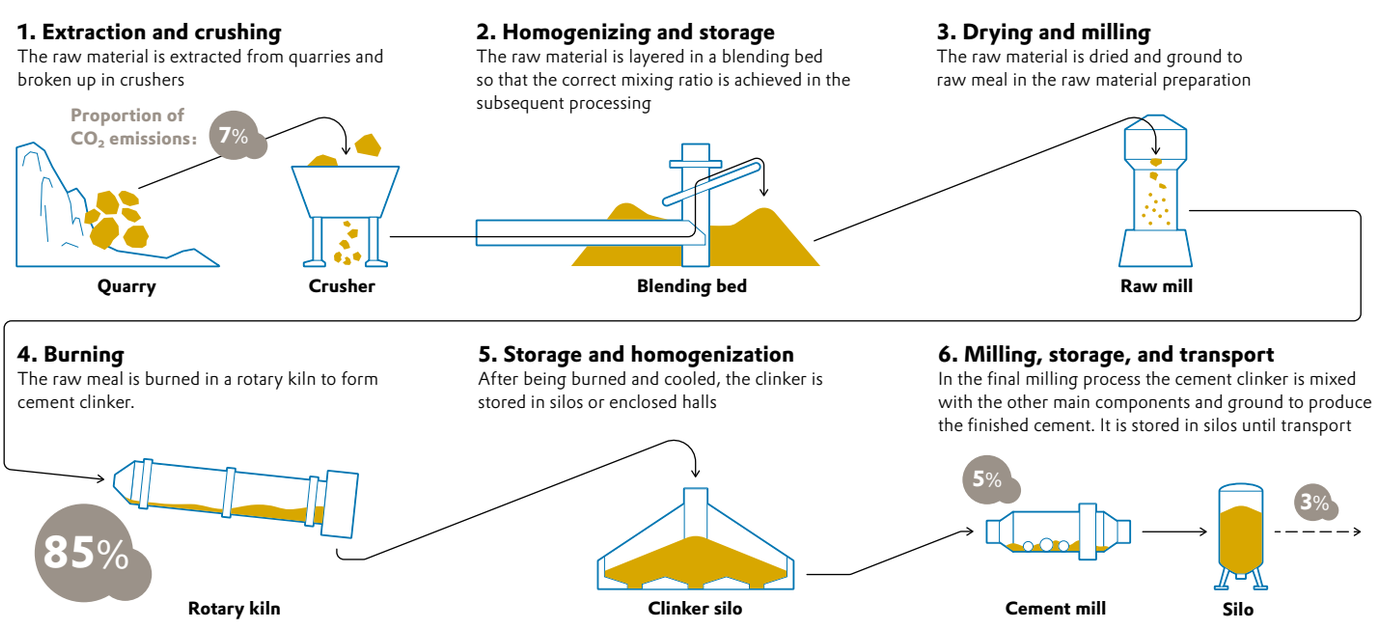
producers and processors of the concrete may be hit by claims for compensation.

More extensive and even more impressive tests are being conducted on the other side of the city. This is where Wissbau, a spinoff company of the University of Duisburg-Essen, tests construction materials in its capacity as an independent appraiser. The test lab is located in an extensively restructured 18th-century farmhouse. Last year Wissbau was commissioned by Evonik to pour a number of huge concrete troughs. Since then, the lab workers have regularly used brute force to make cracks in the troughs in a controlled way. The troughs, now damaged by fine cracks, are filled with water, which gradually seeps through the cracks. Within a month, the bacteria seal the cracks, no more water seeps out, and the outer concrete wall dries out again.

"Cracks of this kind appear in concrete again and again, either because of the hardening process or later on due to stress," Reinschmidt explains. However, she

From stone to cement

The production of the most important component of concrete releases large volumes of CO_2—especially during burning



Researchers discovered concrete-healing bacteria in Evonik's collection in Halle-Künsebeck

adds, that in itself is not really a problem. Only if water is constantly penetrating the concrete, causing the reinforcing steel to rust, or expanding during freezing weather is the structural element permanently weakened and ultimately destroyed. "A concrete that automatically seals its own cracks protects itself from serious damage," she adds.

REFILLING INSTEAD OF DEMOLITION

The concept of a self-healing concrete has been circulating in the sector for quite a while. In fact, conventional concrete also has the ability to seal small cracks on its own. However, in most cases this process takes much too long. Researchers at the Technical University of Munich have been experimenting for some time now with fine glass capillaries that are filled with liquid plastic and embedded in concrete. When the capillaries break because of movements within the concrete, the plastic runs out and glues together any cracks that have formed. Several research teams are also studying bacteria—for example, teams at Delft University of →

A protective shield for buildings

Protectosil® protects concrete and other mineral substrates from environmental impacts

The Louvre in Paris, the Sydney Opera House, and Times Square in New York—at many impressive locations, Evonik's silane-based building protection agents are helping to preserve prominent architecture. Under the brand name Protectosil®, the specialty chemicals group from Essen sells coatings and impregnation agents that protect concrete and plaster as well as natural stone such as sandstone and granite from environmental impacts and vandalism. The active ingredients here are organosilanes—compounds of hydrogen, carbon, and silicon—that the company produces at several locations around the world. Evonik operates a special competence center for silanes in Rheinfelden, close to the German-Swiss border. These multifaceted materials are used in diverse industrial sectors, ranging from semiconductor production to the manufacture of fuel-saving tires. The silanes, which protect the fabric of the building, deeply penetrate the stone. There they form a colorless and breathable impregnation layer that lets air and water vapor escape freely but prevents moisture and pollutants from entering. It also effectively protects the stone from soiling and even from attacks by graffiti sprayers. For example, Protectosil® products protect reinforced concrete from chloride-induced corrosion, a major cause of damage that requires bridges to be renovated over the years. These products can be directly used during the construction phase. A case in point is the bridge across Hangzhou Bay in eastern China—one of the longest transoceanic bridges in the world. Because silane impregnation agents can be applied subsequently without any problems, they are also frequently used for the renovation of existing structures.

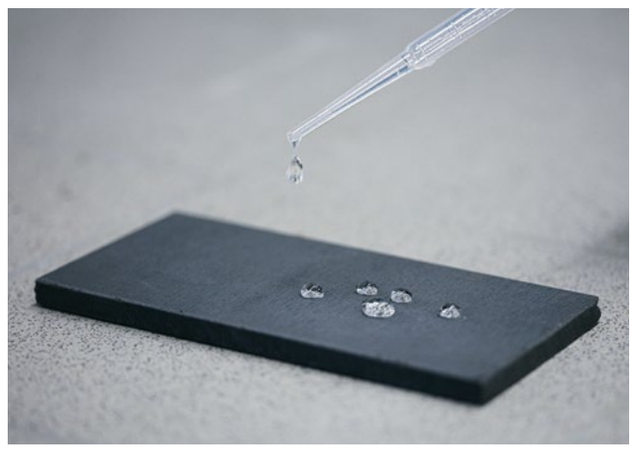
SYDNEY OPERA HOUSE AUSTRALIA

The Sydney Opera House is one of the most striking concrete buildings of the 20th century. Although this building, which was opened in 1973, has a projected lifespan of up to 300 years, the status of the construction is continuously monitored

Long-term testing shows that cracks sealed by bacteria can withstand even extreme stresses

“A concrete that automatically seals its own cracks protects itself from serious damage”

ANKE REINSCHMIDT, TECHNICAL DIRECTOR AT EVONIK’S APPLICATION TECHNOLOGY UNIT



The effects of additives such as hydrophobing agents (above) have been verified thousands of times in Essen. Test pieces are stacked high everywhere

Technology in the Netherlands and Ghent University in Belgium, which have created spinoff companies for this purpose.

At Evonik, this concept emerged during an in-house idea competition in 2016 (see the Portrait starting on page 20). The breakthrough came as a result of networking by construction chemists in Essen and biotechnologists in Halle-Künsebeck, where Evonik operates its biggest biotechnology lab. Three other labs are located in Marl, Hanau, and Shanghai. The group recently reorganized and consolidated all of its biotechnology expertise. These researchers are working on a wide spectrum of topics, ranging from fermentation processes for cosmetic raw materials to synbiotics for gut health (see also the article starting on page 28).

For WallCraft, the biotechnologists first searched their microbe library for an organism that was suitable for concrete. They found a strain they themselves had previously isolated in an environmental sample. “We were very familiar with its DNA and its characteristics,” says Lukas Falke, the head of this project in Halle-Künsebeck.

MICROBES REPLACE MANUAL WORK

The selected strain of *Bacillus subtilis* is an especially tough representative of the hay bacteria group. These bacteria exist almost everywhere, and they thrive just as well in the soil as in the human gut. However, concrete is an inhospitable environment for these microorganisms. Cement is alkaline, and as it hardens it develops temperatures over 60 °C. However, the WallCraft bacterium

WallCraft is marketed by Evonik under the name SITREN® Self-Heal.

BURJ KHALIFA
UNITED ARAB EMIRATES

The Burj Khalifa has held the record of being the world's highest building since 2007. During its construction, special pumps hauled concrete up to a height of 606 meters (a steel structure extends the total height to 828 meters)

is not too bothered by either the heat, the hostile pH value or the spiky crystals in hardened concrete.

Besides, when it comes into contact with water it quickly begins to metabolize the sources of carbon provided. Evonik equips the microbes with the provisions they need, right from the start. The precise composition of this nutrient is a well-kept secret. "In addition to the bacterial strain, for which we have registered a patent, the nutrient formulation is our most important trade secret," says Falke. The only thing he's willing to reveal is that sugar, the favorite food of many bacteria, is not part of it. Sugar would be poison for every kind of concrete, because it disrupts the hardening process.

In the small town of Gaggenau near Baden-Baden, Evonik found the first adventurous partner company that was willing to test WallCraft in practice. Here the Grötz company produces prefab garages made of concrete, which are delivered to customers by truck. Fewer cracks in the concrete are a good selling point for the company, especially because a practical test has shown that WallCraft also reduces the formation of flaws in the concrete. Such flaws occur at the surface and in the corners of the formwork as the concrete is hardening, and they subsequently have to be filled in with a trowel. Because this laborious manual work is now no longer needed, the use of WallCraft already pays off when pouring the concrete.

Plans call for this material with its microbes to be used in the future all over the world, not only in garages but also in apartment blocks, bridges, dams and beyond. That could greatly help concrete, the universal construction material, to go on having a bright future.

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

Sarah Hintermayer started to work for Evonik as a process engineer in the fall of 2016. A few weeks later, she was leading the team that would take the concept of a self-healing concrete to market maturity

THE DRIVING FORCE

A good idea is not sufficient in itself—it always needs someone who actively promotes it. Someone like Sarah Hintermayer, who resolutely drove the WallCraft project forward

TEXT **NICOLAS GARZ**

Just before Christmas in 2016, Sarah Hintermayer's career path turned in a new direction. Hintermayer, who was 28 at the time, met with her colleagues in Hanau for a brainstorming session. Their task was to develop the bioprocess technology department's submission to the Global Ideation Jam. Evonik enables the winning team of this competition to create its own business, acting like a startup.

The colleagues discussed a series of ideas. Hintermayer was one of those who presented a proposal, which was for a concrete recycling process. The feedback was positive, but the group decided to submit a different approach: concrete that heals itself with the help of bacteria (you can find more details starting on page 10). "I realized immediately that this proposal was further developed than mine," Hintermayer recalls. "So I offered to help promote it."

She quickly became more than just a helper. All the brainstormers in Hanau knew that if a good idea is to be successful, it always needs an individual who actively promotes it and gives it a voice and a face. This person must have great patience and discipline, as well as the passion that is needed to convince others—in other words, an entrepreneurial personality.

"INTRAPRENEUR" ON PROBATION

Back then, Hintermayer had been working at Evonik for only a few weeks. Before that, she had studied and received a doctorate in Munich. This job as a process engineer was her first in the private sector. But she was definitely not a shy newcomer. "Deep in my heart I'm a little go-getter," she says with a laugh. "Once I've thoroughly understood a thing, it's easy for me to explain complex issues in a way that people can understand. That's important if you want to get them excited about something."

This is one of the qualities that convinced her colleagues that she was the right person for the job of "intrapreneur"—an entrepreneur inside the company. From that point on, preparations for the Ideation Jam were in full swing. The concept had to be worked out as concretely as possible by the summer. For months, the team made meticulous preparations and sacrificed quite a few weekends to work on their project, which they had named WallCraft. All of this hard work paid off: The team convinced the jury and won the Ideation Jam 2017.

Hintermayer was now a company founder with a limited term of office: She became the only team member working full-time on the project, and her mission was to promote Wallcraft within the company for a period of 12 months. Because she bore primary responsibility for the project, each of her decisions helped to determine WallCraft's success or failure. What's more, she was doing many things for the first time. How do you prepare for making a pitch to customers? How do you put together a successful business plan? "For me, challenges like these are exciting," she says. "I learn the most after I've been tossed into cold water."

BUSINESS MEETINGS AND BACTERIAL STRAINS

Hintermayer quickly grew into her new role. She coordinated all the processes of the project and received a separate budget. "I was able to decide on every step myself for the first time," she says. "At the same time, I was constantly aware of the project's overall significance and its goal—that's a great feeling." Between business meetings and networking, she conducted experiments with concrete mixtures and bacterial strains. After less than a year, there was a breakthrough: The initial prototype was finished—a nondescript chunk of gray material that proves that concrete can heal itself.

The news quickly circulated throughout the company. As a result, Hintermayer was given the opportunity to continue working on WallCraft, this time at the Interface and Performance business line and at the Creavis innovation unit. In the months after that, she made her business idea fit for the market. Eventually the time came when she paused for a moment to think about where to go next. "The most important thing for me is to focus completely on a project and make sure I can keep learning something new in the process," she says. Because the project no longer completely fulfilled these two conditions, she passed it on to her successor.

However, she's still enthusiastic about innovations. Today she is creating a new unit at Care Solutions that helps small beauty brands to implement their ideas. In parallel, Hintermayer markets gluten-free flour in her leisure time—and continues to turn her passion for entrepreneurship into action.

At the Ideation Jam in 2018, Sarah Hintermayer reported on her experiences during her first year as an intrapreneur

WallCraft is marketed by Evonik under the name SITREN® Self-Heal.

“We need a disruptive change in the building industry within the next ten years”

STEPHAN BIRK, ARCHITECT, TU MUNICH

Stephan Birk at his architectural office in Stuttgart

From dwellings to airports, from offices to bridges—the world is building more and more every year. How can we find a way to improve people’s lives by erecting more sustainable structures? Materials scientist and concrete advocate Karen Scrivener joins architect and timber expert Stephan Birk to discuss possible paths towards climate friendly solutions.

MODERATION **TOM RADEMACHER** & **CHRISTIAN BAULIG**
PHOTOGRAPHY **ANOUSH ABRAR** & **THOMAS PIROT**

As we speak, the world of architecture is convening in Venice for the Biennale. One theme in many of this year’s exhibits and presentations is the question of how to reduce the environmental footprint of buildings. Today, construction accounts for 38 percent of man-made CO_2 emissions. Professor Scrivener, do we need to build less?

SCRIVENER I’m afraid that is a discussion people have in their comfortable little bubble here in Europe or in North America. And it’s not helpful at all. There are plenty of issues in the industrial world that we should address. For example, the living area per person, which is going up exponentially. We are selfishly devouring resources. But we can’t then just turn around and say the world needs to build less. That doesn’t account for millions and millions of people in Africa and elsewhere who don’t yet have a decent place to live. They need to build to better their lives. And they have a right to do so.

Karen Scrivener at the Ecole Polytechnique Fédérale in Lausanne

"A disruptive change may be desirable. I just think we have to be realistic"

KAREN SCRIVENER, MATERIALS SCIENTIST, EPF LAUSANNE

Should we then at least ditch concrete, which alone is responsible for eight percent of humanity's carbon footprint?

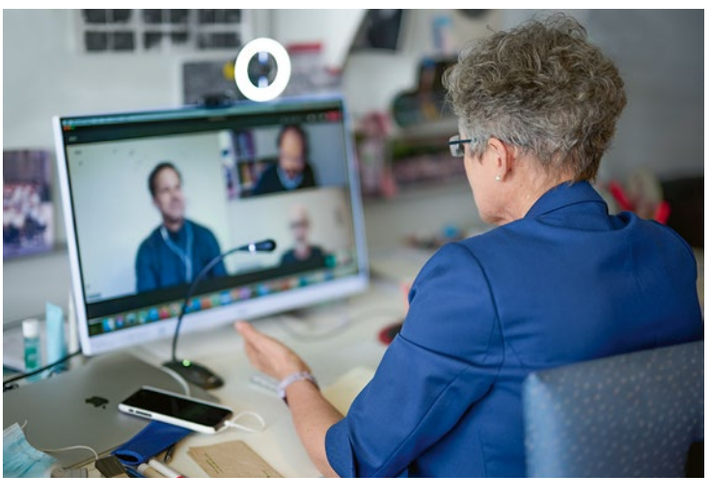
SCRIVENER No, of course not. For one thing, concrete is a low CO_2 material. The intrinsic CO_2 content per ton for concrete is ten times lower than that of steel or bricks and one hundred times lower than that of plastic. Yes, cement is carbon-intensive. But cement is just a small component in the final concrete mix. The reason it comes to these eight percent is because concrete makes up such an enormous amount of what we consume. And that's, indirectly, a result of population growth. People need housing. That is why 90 percent of concrete consumption happens outside of the rich OECD countries, in places where cities are exploding.

So are we doomed to destroy the planet with what we build, Professor Birk?

BIRK I agree with Karen that in a global context the question can't be whether we need to build less. But we do need a discussion about how we can optimize the use of resources in the world. The building sector accounts for 30 to 60 percent of energy consumption, material consumption, and greenhouse gas emissions. We have to change that drastically. And that requires a turnaround as soon as possible. That's where I have to fundamentally disagree with my colleague: We do need a disruptive change in the building industry within the next ten years because otherwise it's too late.

SCRIVENER We surely need to optimize resources and minimize CO_2. This is what I'm working on. A disruptive change may be desirable. I just think we have to be realistic. It all comes down to a matter of physics and of the resources we have available on Earth. →

Karen Scrivener, 62, is the head of the Laboratory of Construction Materials and a full Professor at the Ecole Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. She graduated from the Cambridge University in Material Sciences and earned her PhD in Materials Science from the Imperial College London, where she worked until 1995 as a post-doctoral research assistant and lecturer. From 1995 till 2001 she worked at Lafarge, the French manufacturer of cement, aggregates, and concrete. In collaboration with other universities, institutions, and companies she developed Limestone Calcined Clay Cement (LC3), a new type of low-carbon cement



98 percent of the Earth's crust is made up of just eight elements. Cement uses four of them—in a way that can't be beaten.

Why has concrete or cement become so popular?

SCRIVENER It's an incredibly useful material: You can transport cement anywhere in the world as a powder and then mix it with sand, rocks, and water to produce a block of concrete that sets and hardens. Anybody can do it. And because it's so cheap the use of cement and concrete has grown rapidly worldwide. It has been a major contributor to lifting many millions of people out of poverty. And we need to continue this because people need a chance to lead a dignified life. Otherwise, they will migrate.

Could the use of more wood instead of concrete be part of the solution?

SCRIVENER We need all the materials we have on Earth. As far as timber is concerned, it is absolutely fine if we can grow that sustainably. But the timber we're using today is mostly not sustainable. If we wanted to replace just one quarter of concrete with timber we would have to plant new forests one and a half times the size of India.

BIRK Let's grow more forests sustainably and let's increase the number of buildings made of natural materials such as timber. But after all, it is not a question of using just one or the other. It is only important to use them in the most efficient way possible. For example, we do a lot of timber construction combined

"If you want to tackle the problem of CO_2 emissions you have to address the situation of concrete" KAREN SCRIVENER

with concrete in ceilings. Just looking at Switzerland, Austria, Germany, and Scandinavia for a moment, we see that timber can be good for one third to even half of all buildings. We have to increase that share wherever we can. The more concrete we substitute for timber, the better. We also have to bring knowledge about sustainable forestry to other parts of the world in order to change the building industry there as well—at least to a certain degree.

SCRIVENER That's incredibly naive! I've worked a lot in India, where they actually set up a building institute to look for substitutes for wood because they don't have the land area. Using local wood may work in Sweden, which has a tiny population of less than ten million people but an awful lot of land area that can be forested.

BIRK Using timber is not naive. It can be a part of the solution to lower the carbon emissions of the building sector. And by the way, there is potential for sustainable forestry in other parts of the world, surely, if you look at China, Russia, Brazil, and East Africa.

SCRIVENER Then let's use all the timber we can grow sustainably. It has many virtues, no doubt. And as you said, let's stop spending time saying that we should use one or the other. We really have to look at what's the most efficient building material available. And the fact of the matter is that concrete makes up more than all of the other materials put together. If you want to tackle the problem of CO_2 emissions from construction, you need to address the situation of concrete.

What, then, can we do to lower concrete's carbon footprint?

SCRIVENER We don't have to come up with some magical ideas. Most of the emissions from concrete come from the breakdown of limestone into calcium oxide and CO_2. Many people suggest using something else instead of limestone. But there is nothing that can replace it altogether—at least nothing that is available in the quantities we need. But we can substitute parts of the limestone with calcined clay. That's something we developed in our laboratories here in Lausanne: Our LC3 cement can reduce CO_2 emissions by 40 percent.

That's impressive, but far from climate-neutral, which is what the cement industry is aiming for by 2050.

SCRIVENER LC3 is not the end of the story. We need to look along the value chain. The share of cement in concrete can easily be lowered by at least 20 percent. Then you need to look at the concrete in the buildings, which again can easily be reduced by 20 percent and probably more. Some buildings are using two to three times as much concrete as others for the same floor area. So clearly, work needs to be done in just minimizing the amount of material used. It will take a combination of efforts to reach net zero by 2050.

BIRK That's too little too late. The cement industry is responsible for coming up with a solution more quickly. What we're seeing is simply not good enough.

SCRIVENER We surely need to go faster. That's why I'm trying to convince the industry to use our new cement, which, by the way, is even cheaper to make.

Why is that such a hard sell?

SCRIVENER Well, it takes time. There's the huge question of norms and standards put in place for buildings to ensure safety. And of course this makes it really difficult to bring these innovations to the field. All the major cement producers are convinced. But we have to realize that the top ten companies only make up about 30 percent of the world market. So we have to get out there and address the smaller manufacturers in Africa and Asia to achieve the impact we need to have. →

“Timber can be part of the solution to lower the carbon emissions of the building sector” STEPHAN BIRK

Many of those large companies have plans to capture and store CO_2 from their plants. Can this so-called CCS technology help on a larger scale?

BIRK I think we have to look at various options to fight the climate crisis. Capturing CO_2 can be part of the solution. Otherwise, it will hardly be possible to get to net zero. But CCS is still a contentious issue.

SCRIVENER Capturing CO_2 and putting it underground is far from easy. I think it has to be a last resort. With substitutions and other measures we can achieve reductions of over 70 or 80 percent overall. Technologies aren’t the problem, it’s their implementation.

We’re talking a lot about building materials. Shouldn’t we also rethink how we design and use buildings—and what happens to them afterwards?

BIRK Exactly. We need to ask how long we can keep buildings in use regardless of whether they are built from timber, concrete, clay or bricks. We as architects and engineers have to come up with better ways to design and to construct buildings in the age of the climate crisis. New digital tools are helping a lot with what we’ve talked about—optimizing the use of materials etc. In the building sector we need to follow the principals of the circular economy. Today, we’re tearing down buildings from the 1980s or 1990s because they don’t meet our standards anymore. The ceilings are too low, or the technical equipment doesn’t fit anymore. We have to think about what we do with the buildings after their first cycle of use in order to prevent them from being demolished.

Does concrete fit in with a circular economy?

SCRIVENER It’s perfectly recyclable: You can crush it up and the aggregates can then be reused in new concrete. In fact, you can even take the fine material back to a cement factory and turn it into new cement. Many countries in Europe already recycle concrete to a high extent. However, we have to be aware that in many parts of the world there’s still a lot of first-time construction going on. Furthermore, because concrete is so cheap, you end up spending more on transporting and recycling it that you would producing it afresh.

How can governments set the right incentives to improve sustainability in construction?

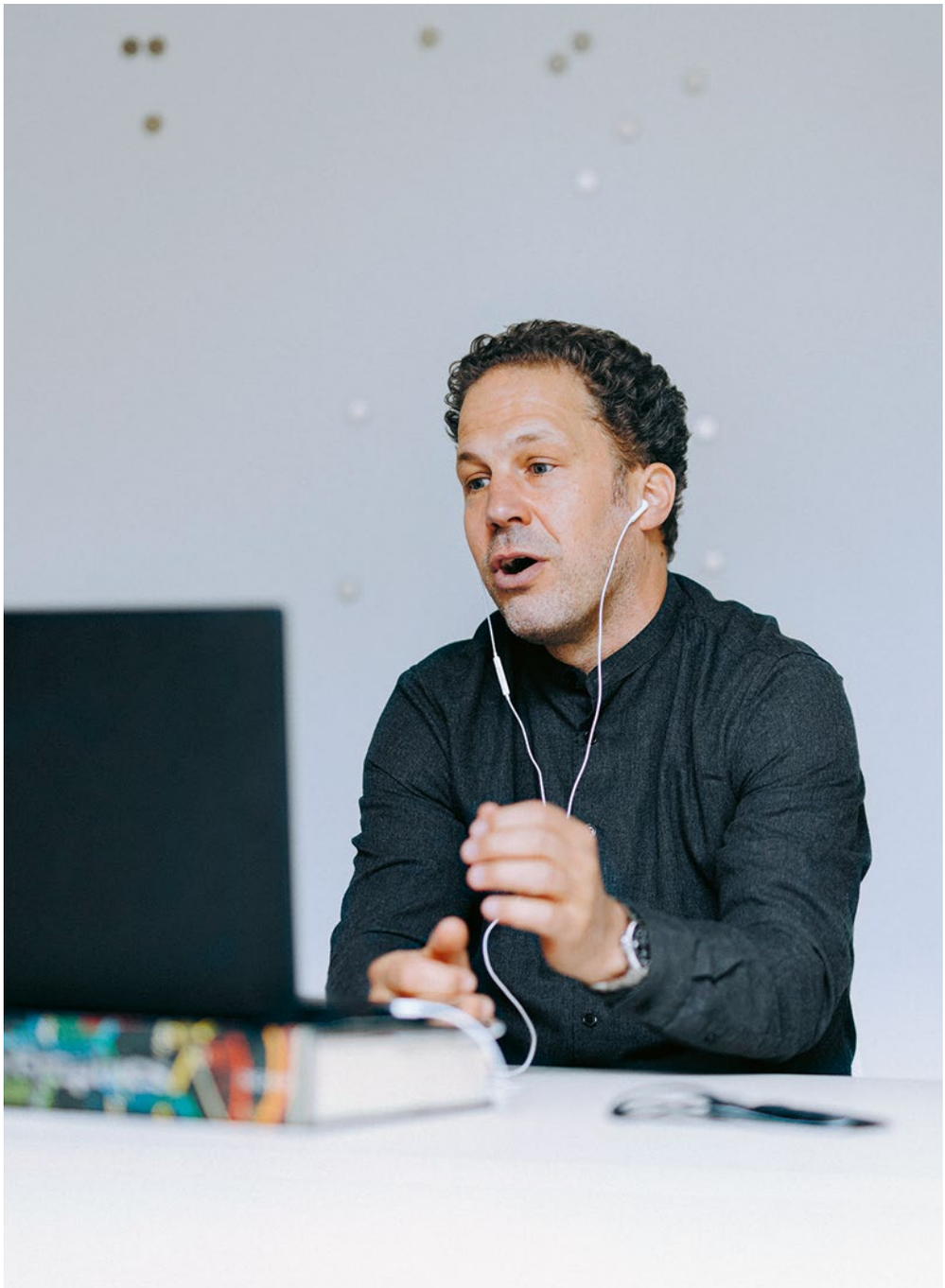
BIRK Several countries in Europe, for example, require an energy efficiency rating for most buildings. Today, these certificates mainly focus on the energy consumption during the use period. You could give any building a CO_2 budget that is good for the construction phase, including all used materials, for the time you’re using it and beyond that, when it comes to demolishing the building. The use of secondary recycled resources could be made tax-exempt. Again, at the moment that may only work in Europe and North America, but I think it’s a good start.

China currently uses more concrete than the rest of the world combined. What can we do to get the Chinese on board?

SCRIVENER My impression is that the government there is just as committed as the European Union. It’s been a long time coming, but the country is now moving ahead of pace. But China has already done most of its construction; its consumption of cement is actually going down. We have to anticipate the next China. In India, per capita consumption of cement is four or five times lower than in China. That is where we’ve got to focus. And we need to get in there before people start building on a large scale. We also have to look at Africa. But because Africa is not one but fifty-five countries it makes it even more time-consuming to engage with all of them.

How can rich countries, whose share of global construction is shrinking, still have a positive impact and be better allies of those countries?

BIRK We have to share our knowledge so others don’t make the same mistakes that we did. I see lots of buildings in parts of the world which don’t suit their environment at all. Think of glass office buildings in the middle of a desert with an extremely high energy need for air conditioning. There’s also a lot of knowledge in Europe about how to build a sustainable forest industry that can be useful elsewhere. And we have to share innovations in the area of more climate-friendly cement with these countries as well.



Stephan Birk, 46, was appointed Professor of Architecture and Timber Construction at the Technical University of Munich (TUM) in April 2021, where he is part of the research group Tum.wood. He is a founding partner of the Stuttgart-based architectural office Birk Heilmeyer und Frenzel Architekten. Birk has been engaged in teaching and research since 2007. In the last six years, he has led the Department of Building Construction and Design at the Technical University of Kaiserslautern and jointly established the research area T-Lab Timber Architecture and Wood Materials with Professor Jürgen Graf

SCRIVENER What is equally important is the use of local resources. You don't have that much limestone in Africa. Clinker often has to be imported. You also have issues with low-quality construction. We have seen some very sad cases of buildings collapsing because people are replacing cement with stuff that doesn't react at all. We need to bring in materials that can be produced locally at a reasonable price—and that are sustainable at the same time.

In Venice, the discussion about the future of architecture will continue until November. What's your vision for how we'll build and live tomorrow?

BIRK We need to be more in balance with the environment on every level, not only in the building industry. It may be a European view, but we have distanced ourselves from what's important and we have to find a more balanced approach towards consumption.

SCRIVENER It's great to have visions. But how do we realize them? We spend too much time talking in our nice offices in Europe. Instead, we need to spend more time thinking about how we can really do something in those places where cities are exploding.

BIRK That's true. But we also serve as role models. Whether that's good or bad, people still look at what we're doing in Europe. Fixing the mistakes we've made and helping others not repeat them is a good start. If we make a change, others will follow.

IN GOOD COMPANY

Microorganisms are essential for human digestion and many other bodily functions. Researchers at Evonik are investigating how probiotics influence the composition of the gut microorganisms inside human beings and animals

Evonik is developing a system solution for synbiotic products that can be ingested as capsules

TEXT **ANNETTE LOCHER**

"We need our gut, and our gut needs us." That's how Dr. Heike tom Dieck describes this vital connection, because intestinal health plays a significant role in well-being. "It's the key to our overall health—for our supply of nutrients, the immune system, our metabolic functions, and our psyche," says Dr. tom Dieck, a nutritionist who carries out research for Evonik in Hanau. Her goal is to find out the characteristics of the microorganisms that have a positive influence on the equilibrium in our intestines.

A balanced diet that is rich in fiber is known to be a precondition for this equilibrium. When fiber is broken down by bacteria inside the large intestine, one of the substances that are generated is butyrate, a short-chain fatty acid that plays a special role. tom Dieck and her team took the following insight as their starting point: "Butyrate provides most of the energy that is needed by some intestinal cells. Scientific studies have shown that this substance is essential for a healthy intestinal mucosa and an effective local immune system." If there is a lack of butyrate in the intestines, it is difficult for the intestinal mucosa to fulfill its function as a protective barrier. →

The nutritionist Heike tom Dieck is the head of research and business development for synbiotics at Evonik in Hanau

“Today scientists are discovering that about 90 percent of all illnesses have a connection with the gut microbiome”

STEFAN PELZER, THE HEAD OF MICROBIOME RESEARCH AT EVONIK’S BIOTECHNOLOGY UNIT

Using this approach, the research team found a way to increase the formation of butyrate by the intestinal bacteria by bringing together a live probiotic bacterial strain and a protein component. Tests have shown that each ingredient used by itself already boosts the formation of butyrate by the bacteria, says tom Dieck. “However, when the ingredients are used in combination they have an even bigger effect,” she says. Experts call this kind of synergetic interplay “synbiotic.”

This research-based development has now led to an innovative system solution for business customers who want to market applications for maintaining gut equilibrium. “In addition to the research, we provide all the ingredients as well as target group-specific positioning,” says tom Dieck, who is the head of research and business development for synbiotics at Evonik. “The advantage provided by our formulations is that they enable companies to make not only innovative combinations but also reliable assertions about a specific health benefit—in other words, health claims—in their communication with consumers.”

Up to

100

TRILLION

bacteria and fungi are estimated to form the human microbiome

That’s a fairly significant aspect, and the team conducts its own field trials to support it. “The regulatory environment in the area of dietary supplements is very complex,” says tom Dieck. “For example, in the EU companies are not allowed to make health-related statements about probiotic bacteria without further ado.” However, additional ingredients make it possible to explain the potential usefulness of the product more clearly.

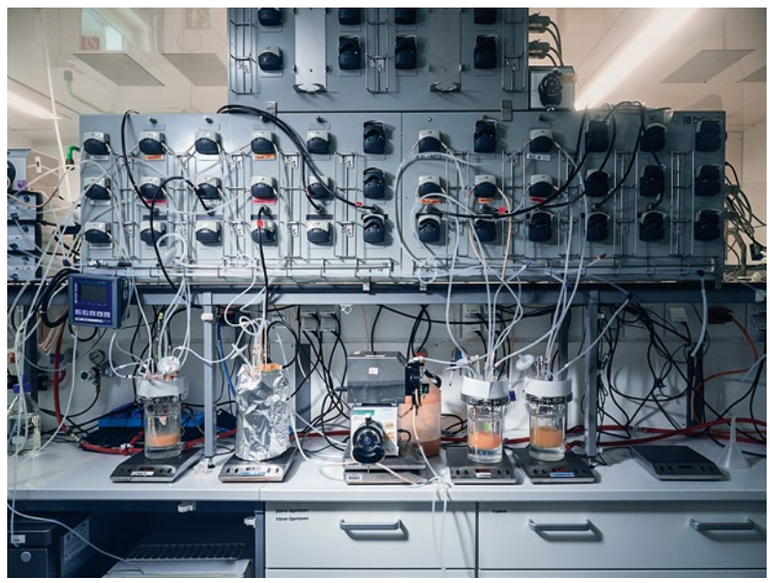
DIVERSITY PROMOTES HEALTH

The colleagues researching the microbiome and gut health in the district of Halle-Künsebeck in Westphalia are playing an important role in the development of synbiotics. The microbiologist Prof. Stefan Pelzer has been researching microorganisms in the digestive tract since 2013. His focus was initially on the question of how livestock can be kept healthy and productive without antibiotics. Today his team is also researching the human microbiome—inside the gut and on the skin.

“Today scientists are discovering that about 90 percent of all illnesses have a connection with the gut microbiome,” he says. The number of bacterial cells in the human body exceeds the number of the body’s own cells by a factor of 1.3—and most of these bacterial cells are located in the large intestine. This might make some people feel uncomfortable. But according to Pelzer, it

The chicken gut model

The chicken gut model consists of up to five glass vessels connected by tubes and pipes, reagents, and measuring instruments. It has been available to Evonik researchers in Halle-Künsebeck since 2018. This unique simulation was developed as part of the GOBI (Good Bacteria and Bioactives in Industry) innovation alliance funded by the German Federal Ministry of Education and Research. Each stage of the digestive tract and its specific environment is represented by a glass vessel. Connected in a series, they simulate the processes in the entire digestive system. The bacteria encounter gastric acids, bile salts, enzymes that break down nutrients, competing microbes, and other stress factors—in a natural sequence and over a realistic period of time. The researchers can sample at every point in order to observe how the local conditions influence the probiotic bacteria and vice versa.



would be disconcerting if the opposite were the case. "The composition of the microbiota—in other words, the assemblage of microorganisms—is altered by many illnesses as well as by the aging process," he says. "Specifically, the diversity of the gut bacteria decreases." This occurs alongside a loss of the products of bacterial metabolism, such as butyrate, that are necessary for human health. "Researchers are increasingly documenting the fact that a decrease in the diversity of the microbiome has a negative effect on the body's fitness and its resistance to infection," Pelzer explains.

Consequently, those who aim to enhance high performance and resilience in human beings and animals often do so by adapting the microbiome—for example, by means of probiotic products, which contain live bacteria. These products generate multifaceted momentum, either directly by forming substances such as lactic acid or indirectly by influencing the composition of the microbiome (see the diagram on pages 36/37).

The first probiotic developed in-house by Evonik was meant for chickens. Probiotics reinforce the balanced composition and resilience of the natural microbiome, and that prevents colonization by pathogenic bacteria such as *Clostridium perfringens*. This pathogen causes immense economic damage in poultry farming all over the world. The Evonik product GutCare®, which contains a strain of *Bacillus subtilis*, is meant to reduce the use of antibiotics as preventive components of chicken feed. It has been marketed successfully in the USA, China, India, and other countries since 2017.

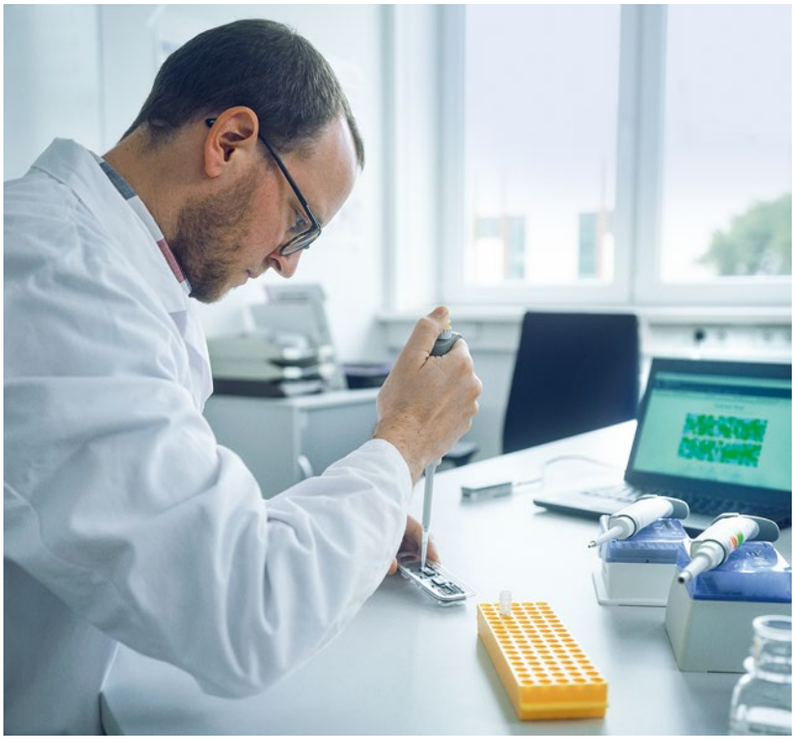
However, Pelzer was not satisfied with merely proving the effectiveness of this product in a petri dish and a feed test. He wanted to have a more precise understanding of exactly what happens in which part of a chicken's gut. To gain this information, he needed a model that simulates a chicken's gut and the physiological processes inside it (see the info box on page 33). Researchers are especially interested in finding out whether gastric acid and pancreatic juice inhibit probiotic products and how they change the composition of the gut microbiome. Do these acids increase or decrease microbiome diversity? Is there a shift in the percentages of characteristic groups of bacteria? And is there increased formation of short-chain fatty acids such as butyrate? →

At least

1,000

SPECIES

of bacteria can be found in the human digestive tract



Researchers use the "MinION," a portable DNA sequencing device, to analyze bacteria samples on site and evaluate them bioinformatically

Researchers run tests to identify and analyze the capabilities of bacteria under various conditions

Up to

2

KILOGRAMS of microbial biomass can be found in every human being

All of these questions can be answered by means of genome sequencing. In this process, all the genes in a bacterial sample taken from the gut model are analyzed. "Twenty years ago, this kind of analysis would have cost tens of thousands of US dollars and required many months of work," says Pelzer. "Today we can get this analysis done for a few hundred dollars in a few weeks. For very specific inquiries, we can even get it done on site in real time."

Computational biologists can use these data to create a rough picture of the distribution of the existing groups of bacteria and to identify possible changes. They can even use the gene sequences to find out what capabilities a microbiota has—for example, whether it is producing certain metabolites, which are the intermediate products of a biochemical metabolic pathway.

MODELS ENABLE PREDICTIONS

The expertise gained in Halle-Künsebeck can flow into the development of new probiotics for human beings and animals. "By now our models are so good that they enable us to make very reliable predictions about our products' behavior in a living organism," says Pelzer. That speeds up the development process and reduces the need for tests in live animals.

This is also true of the synbiotic product concepts that Heike tom Dieck and her team are pursuing. The initial findings came from stool samples that had been cultivated together with bacterial strains and selected substances. Next, they investigated how the microbiota composition had changed and what metabolic products were present. "Even in this simple model we already saw clear effects on some substances and some bacteria," says tom Dieck. "The composition of the microbiome changed, and we found more butyrate." For some combinations of a bacterium and a substance, the effect was even more intense.

The combination of probiotic bacterium and dipeptide that is used obviously influences the microbiome in favor of the butyrate-forming bacterial strains. "This substance is produced in different ways by the various groups of gut bacteria," tom Dieck explains. "This is where evolution probably wanted to take the safest route." The gut microbiome differs from one individual to the next, and it's also influenced by a person's lifestyle. Nonetheless, numerous further tests show that the combination of *Bacillus subtilis* and a peptide consisting of two amino acids leads to increased butyrate values. However, this result is only possible if the dipeptide and the bacterium simultaneously reach the entrance to the large intestine, where butyrate-forming bacteria are located.

"Even in this simple model we already saw clear effects on some substances and some bacteria"

HEIKE TOM DIECK, THE HEAD OF SYNBIOTICS RESEARCH

The researchers realized that it's crucial to ensure the protected transportation of these substances through the digestive tract. They found a solution for this problem in-house: the EUDRAGUARD® biotic protective coating developed by Evonik for dietary supplements. This capsule "recognizes" the transition from the small intestine to the large intestine by means of the increase in the pH value, dissolves at this precise point, and releases its contents exactly where they are needed.

INDIVIDUALIZED SOLUTIONS

The synbiotics researchers used a model similar to the chicken gut model in Halle-Künsebeck to precisely understand the behavior of the capsules containing the bacterium and the dipeptide in the human digestive tract. They showed that the bacterium and the dipeptide reach the target destination in the large intestine, and that their arrival correlates with an increase of the local butyrate-forming bacteria. This has now been confirmed by a small pilot study in human beings.

However, for the research teams at Evonik this topic is still far from being exhausted. They are continuing their work on further probiotic and synbiotic developments. The individualized nature of the gut and its equilibrium leads to many further questions. For example, are there ways to determine the current status of an individual's gut—and to make a targeted and individualized intervention with the help of microbiota? If this approach succeeds, it will open up many new opportunities for research and practical applications.

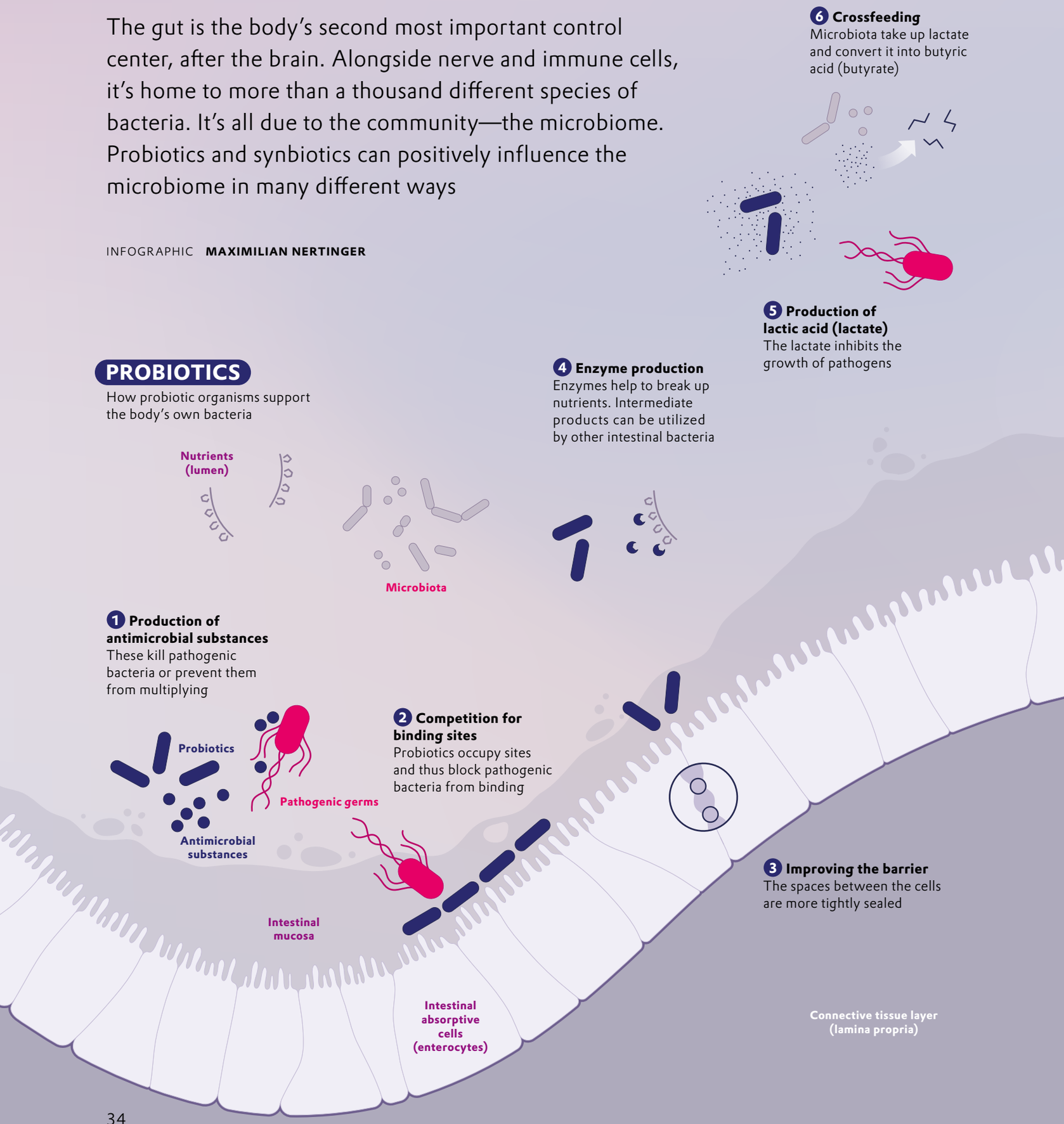
Annette Locher has a diploma in biology and has worked at Evonik since 2012. She mainly writes about healthcare, nutrition, and sustainability

The bacterial strains used for research at Evonik are kept in upright freezers at a temperature of -80°C

Intestinal Influencers

The gut is the body's second most important control center, after the brain. Alongside nerve and immune cells, it's home to more than a thousand different species of bacteria. It's all due to the community—the microbiome. Probiotics and synbiotics can positively influence the microbiome in many different ways

INFOGRAPHIC **MAXIMILIAN NERTINGER**

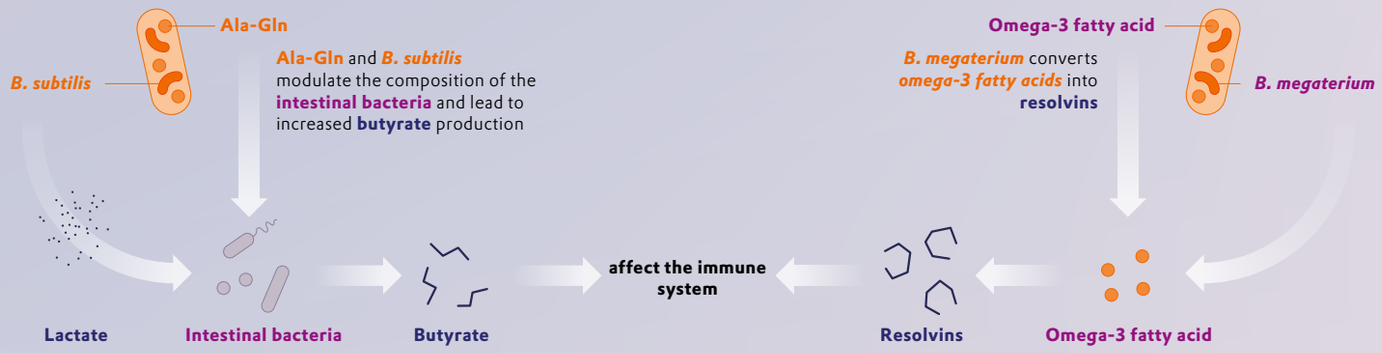


SYNBIOTICS

How combinations of probiotics with additional ingredients can boost the production of certain substances by bacteria

1 Butyrate production
Bacillus subtilis and the dipeptide alanyl-glutamine (Ala-Gln) work together to increase the production of butyrate, which is an important source of energy for intestinal cells

2 Resolvin production
Bacillus megaterium converts high doses of omega-3 fatty acids into resolvins that can inhibit inflammation



THE IMMUNE RESPONSE OF THE INTESTINE

How the intestinal barrier recognizes dangerous intruders and renders them harmless

1 Dendritic cells and other phagocytes
ingest foreign micro-organisms and present the microorganism's antigens on their cell surfaces

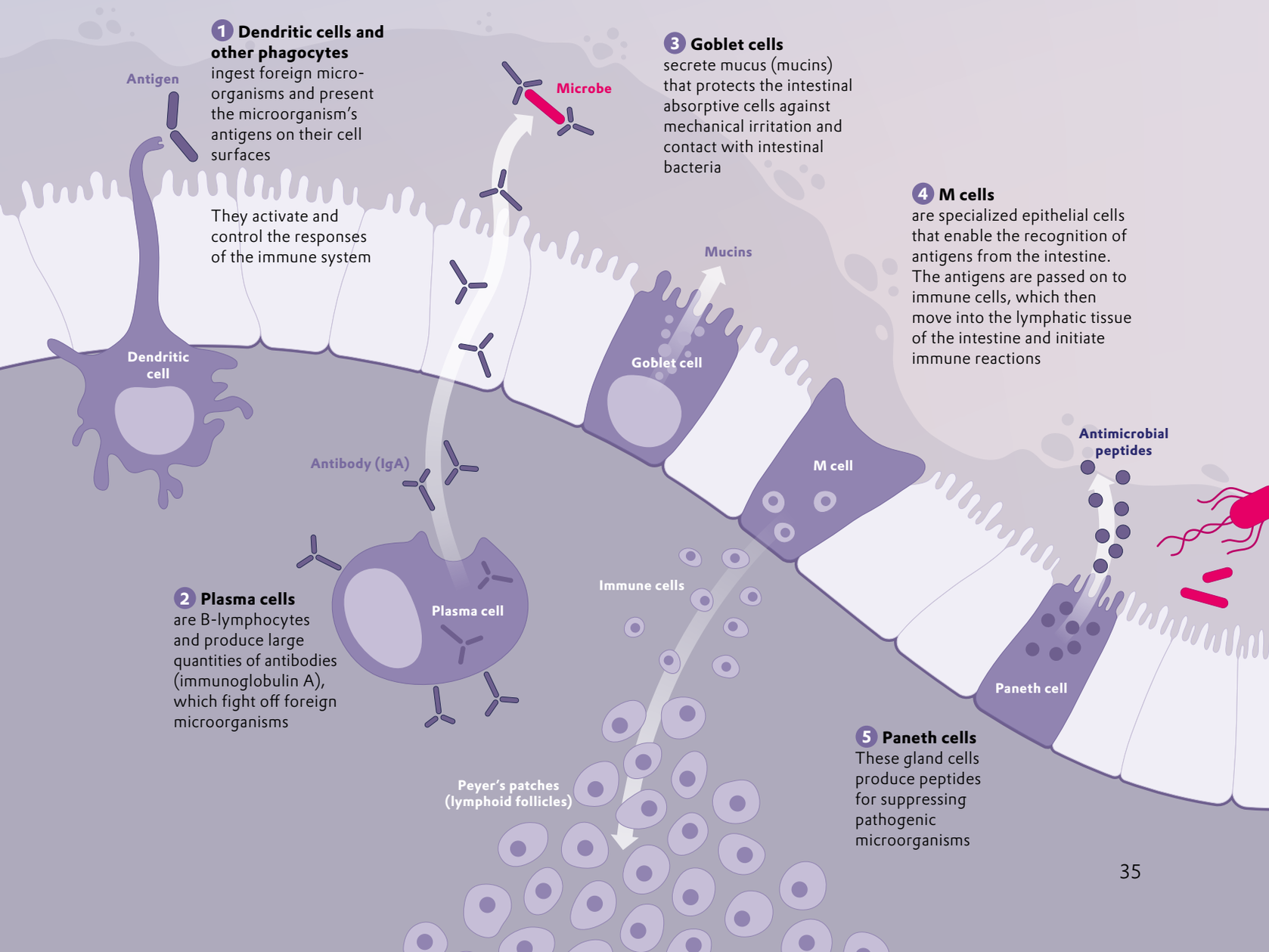
They activate and control the responses of the immune system

3 Goblet cells
secrete mucus (mucins) that protects the intestinal absorptive cells against mechanical irritation and contact with intestinal bacteria

4 M cells
are specialized epithelial cells that enable the recognition of antigens from the intestine. The antigens are passed on to immune cells, which then move into the lymphatic tissue of the intestine and initiate immune reactions

2 Plasma cells
are B-lymphocytes and produce large quantities of antibodies (immunoglobulin A), which fight off foreign microorganisms

5 Paneth cells
These gland cells produce peptides for suppressing pathogenic microorganisms



Constant Change

When people think of Italy, they usually envision romantic images: the canals of Venice, the Eternal City of Rome, the landscapes of Tuscany. But Italy is more than historical architecture and the Mediterranean lifestyle. A journey through a country that relies equally on innovations and timeless qualities during times of change

TEXT **NICOLAS GARZ**

It's no coincidence that the city center of Bergamo is called *città alta* —the upper city. Enthroned on a hill, this historical district, which is a UNESCO World Heritage Site, overlooks the lower city. From the square fortified tower called Torre del Gombito (the second tower from the right) there's a splendid view, high above the hustle and bustle in the narrow streets below. Protectosil® from Evonik protects historic buildings like this one as well as modern new buildings.

Gigantic hams dangle from the ceiling above countless varieties of salami and cheese: In this delicatessen, the Italians' love of food is clearly expressed. It's located in the heart of Bologna, the city where ragù alla Bolognese (authentically never served with spaghetti!) was born. Top-quality Parmesan is also sold here. Food labels are often printed on a carrier material that lands in the trash right after it's been removed. Silicones from Evonik make it possible to use linerless labels that require no carrier material and thus generate less waste.


AURI
AURIC
LOTTO 11/13
LOTTO : 1/15
€ 159,00 al Kg
Jamon Iberico
Cut 11 Pezzo
Nero
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Nero
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Nero

If you love to wear extravagant fashion, you'd be well advised to choose Italian brands—such as Gucci, as seen here in a new interpretation of classic loafers. The garment industry is an important economic sector in Italy. Milan in particular ranks as a center of the international fashion scene. In addition to creative design, high-performance materials also play a major role in the production of clothes in this category. For example, polyurethane foams in shoe soles provide ample support and wearing comfort. Evonik supplies additives that improve their characteristics—for a strong and confident stride, even in extravagant shoes.

Andrà tutto bene—All will be well: This sentence could be read everywhere in Italian cities in the spring of 2020—on house walls, in the streets, and on banners hanging from windows, like this one here in Rome. Italy was one of the first European countries to be struck by the coronavirus pandemic. People used the slogan "Andrà tutto bene" to encourage one another. Today people are taking heart, because more and more of them have been vaccinated against the Covid-19 virus. The vaccine from BioNTech/Pfizer has been administered most often to date. Evonik is supplying important lipids for this mRNA-based vaccine, thus making sure that all will indeed be well.

It takes the pit crew only a few seconds to change the tires of a Ferrari racing car. Every move must be exactly right so that the car can be back on the racetrack as quickly as possible, cheered on by the tifosi who make the pilgrimage to the Italian Grand Prix in Monza. This year they're hoping for a victory after a disappointing last season. More than any other racing class, Formula 1 represents precision and the highest safety standards. This is where Dynasylan® from Evonik comes into play: In the brake fluid of all Formula 1 racing cars, it ensures that even in extreme situations the drivers will have their cars under control.

OPTIMIZED AESTHETICS

In 1966 a predecessor company of Evonik opened a trade office in Milan for the first time. In 1993 a production plant in nearby Pandino was acquired. Today the plant still focuses on products that are associated in various ways with aesthetics. They range from additives for paints and lacquer coatings for products such as cars and wooden furniture all the way to active ingredients that improve the properties of cosmetics.

Evonik locations
1 Milan
2 Pandino

The

2

locations have

72

employees.

ENTER MACBETH

Until recently, catalytic membrane reactors have only been able to demonstrate their performance in laboratories, but now they are about to take the stage in a starring role

TEXT **KARL HÜBNER**

Sometimes dramatic changes start out very small. We see chemical engineer Dr. Linda Arsenjuk as she puts on blue rubber gloves at the Evonik Technology Center in Marl. She then carefully pushes a small gray ceramic tube into a metal cylinder the length of her forearm. Seven of these tubes fit into the metal frame—each of them has 30 highly symmetrically arranged holes on its front side. "No grease must get onto the highly sensitive membrane on the exterior of the reactors," says Arsenjuk. "That's why I have to do it wearing gloves."

The object that she is so carefully handling might trigger a revolution for several important reactions in the chemical industry for process technology. "The aim is to develop catalytic membrane reactors, or CMRs for short, for industrial use," says Arsenjuk. Scientists have already shown on the laboratory scale that such CMRs work in principle. The task now is to overcome the final technical obstacles on the path toward larger-scale applications and to investigate the economic efficiency of this approach in practical industrial use.

The experts have two hopes regarding this technique. Firstly, the catalyst that is needed for the reaction is incorporated into the membrane reactors in a way that makes it much more stable than conventional techniques. In addition, the integrated membrane directly separates the resulting product from the other components. Ideally, it will replace the energy-intensive separation techniques that are still commonly used. Depending on the process in question, the researchers are hoping to thus boost energy efficiency by as much as 70 percent. This would also significantly reduce greenhouse gas emissions.

In keeping with its importance, the overall project bears an impressive name: MACBETH. The acronym stands for Membranes And Catalysts Beyond Economic and Technological Hurdles. The fact that project coordinator Prof. Robert Franke is a huge fan of the English playwright William Shakespeare may have played a role in the choice of the name. Under normal circumstances, Franke travels to Shakespeare's place of birth in Stratford-upon-Avon every year in order to enjoy the local theater festivals. Now, he is using the pandemic-related cancellation of the plays to push ahead with his own MACBETH.

A PRECURSOR FOR MANY APPLICATIONS

The project encompasses four sub-projects devoted to a variety of different chemical processes (see box on page 47). One of these sub-projects is being carried out at the Marl Chemical Park. It involves an important process called hydroformylation—also known as oxo synthesis. The process is called hydroformylation by chemists when they make unsaturated hydrocarbons known as olefins react with syngas (a mixture of hydrogen and carbon monoxide) to create aldehydes. In this way, →

The chemical engineers Linda Arsenjuk (left) and Corina Nentwich from the process technology unit are working on the further development of membrane reactors

the global chemical industry produces 12 million metric tons of aldehydes every year. In Marl, Evonik generally uses aldehydes as intermediates that are on their way to becoming more advanced alcohols, organic acids or esters that are incorporated into solvents for the manufacturing of cosmetics and detergents, for example, as well as in the production of medication or as plasticizers in polymers.

Franke has been working on this approach for more than ten years. As part of the MACBETH project, the technique is now ready to demonstrate its suitability for industrial applications. That this method works in principle was already shown by the predecessor project ROMEO (see text above), which ran from 2015 to 2019. The acronym stood for Reactor Optimisation by Membrane Enhanced Operation, which naturally appealed to the Shakespeare enthusiast as well.

NO TANKS OR COLUMNS

"We now want to conduct tests in a real-life production environment so that we can find out, for example, whether the system also works with the industrial feed in our hydroformylation facility and thus with the gas mixtures that are commonly used there," says Franke. ROMEO still employed very pure input gases, although the olefins that are used at the hydroformylation facility, for example, are part of gas mixtures that come directly from the petroleum cracker, he explains. Franke also wants to know whether the process is suitable for larger production quantities and operates reliably over the long term.

The researchers are currently working on the hydroformylation of the olefin 1-butene, which produces the aldehyde n-pentanal. This reaction will now be transferred to a larger-scale operation that will demonstrate its potential. In the Technology Center, Arsenjuk shows us how much progress they have already made with an experimental setup underneath a hood. It contains a stainless steel cylinder that has a thick wrapping of aluminum foil. The cylinder is strapped vertically into the setup. "It contains our tubes, into which we feed the reaction mixture of butene and syngas from above," explains Arsenjuk. Inside the tubes is the catalyst that causes the components to react. The resulting n-pentanal

The MACBETH reactor is still being optimized at the Technology Center

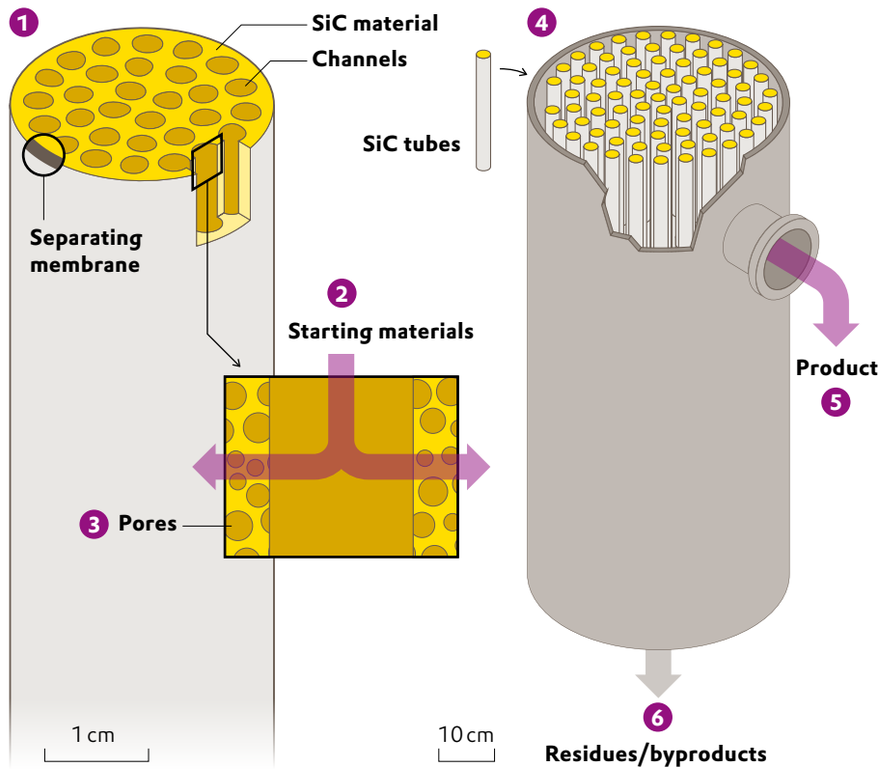
ROMEO lives—the history of solid catalyst development

In hydroformylation processes, catalysts are normally dissolved in the reactor liquid. Known as homogeneous catalysis, this process is very efficient, but also has its drawbacks. "The catalyst mixes with the product and then has to be separated with great effort," explains Robert Franke, the head of hydroformylation research at Evonik. Moreover, it breaks down over time and has to be reprocessed. Although a solid catalyst prevents such mixing, the yield is generally much lower because the reactants and the catalyst do not come into contact as closely. In the ROMEO project, researchers looked for a way out of this dilemma. Their idea was to take advantage of the fact that very porous materials have a large surface area. What would happen if the surface of the pores was coated with the catalyst, in the form of a viscous film, for example? Franke had read about researchers from Denmark and Erlangen who dissolved catalysts in ionic liquids that were used to coat the pores. Ionic liquids are salts that liquefy at temperatures of about 100 degrees Celsius. Experts in this field also took part in the ROMEO project, as did the Danish company LiqTech and its very porous ceramic tubes. In addition, the outer wall of the tubes was coated with a membrane that only lets the reaction product of the hydroformylation pass through. This is not a trivial matter. For example, the aldehyde molecules that are produced during hydroformylation are larger than the starting materials that remain in small amounts in the gas flow. During the ROMEO project, the researchers found a siloxane polymer to be the right material for the membrane. It holds back the starting materials while the aldehyde molecules dissolve in the polymer. Once they have dissolved in the membrane, the molecules travel to the outside, where they are released and can be channeled away.

A reaction in tubes

The MACBETH reactor enables catalysis and filtration in a single step.

1. The MACBETH reactor contains tubes made of silicon carbide (SiC). Each tube has 30 channels and is sheathed in a membrane.
2. The starting materials are fed into the channels and pass through the highly porous SiC material.
3. The pores are coated with a viscous liquid that contains the catalyst. As the starting materials flow through the pores, they dissolve in the coating and react there to form the product that then leaves the liquid.
4. The actual reactor contains numerous SiC tubes connected in parallel.
5. The reaction product passes through the membranes to the exterior and is then channeled away along the side.
6. Residues and byproducts are kept back and channeled downward.



can escape through the exterior wall along the side and then be extracted from the stainless steel cylinder via a connection. If it is sufficiently pure, it can be directly processed further (see the graphic above).

The actual gray reactor tubes are only two and a half centimeters in diameter and 20 centimeters long. However, this isn't a drawback as far as Franke is concerned. On the contrary, he thinks that this gives the setup its "special charm." He says, "The small dimensions allow us to use a modular design with which we can scale the process as desired. If we want to produce larger amounts we simply have to connect sufficient numbers of tubes together."

The possible dimensions can be seen at a site about 800 meters from the Technology Center. Here, in the midst of the six-square-kilometer Marl Chemical Park, is the hydroformylation facility. The hydroformylation is currently carried out in huge tanks that are several meters tall and can hold tens of thousands of liters. The distillation columns that are then needed to separate the product are even taller. However, the new generation of reactors might make these systems superfluous.

The facility will show how well the separation works and how pure the resulting aldehyde actually is. A small area is already being kept free for the planned demonstration facility. The researchers have also laid out the access points to the huge existing plant. However, some issues still need to be clarified at the Technology Center before the new reactor system can be built. "We are still working on the final design," says Arsenjuk. In this process, the researchers are also examining several innovations that weren't contained in the ROMEO reactor. One example of this is an additional membrane material that was suggested by one of the project partners, the Helmholtz-Zentrum Hereon. There is now a promising alternative to the previously used ionic liquid for the coating of the pores in the reactor. Moreover, tests are now being conducted with a longer version of the ceramic tubes from the Danish partner LiqTech.

SIMULATION OF THE MATERIAL FLOWS

The researchers also have to determine what the optimal settings are for the temperature, pressure, and flow speed of the process in practice. The aim is not only to achieve the best possible product yield, but also to prevent interfering side reactions. "One of the potential problems is always that pentanal molecules react with one another to form larger units that then condense to clog the pores like honey," explains Dr. Corina Nentwich, who is also a chemical engineer at the process technology unit. Within the MACBETH team, Nentwich is responsible for the process simulation, and that means she has to integrate the processes within the new reactor into the corresponding software as precisely as possible. Ultimately, this precise numerical description will help the researchers to theoretically simulate certain scenarios and optimally plan the reactor. →

Linda Arsenjuk and Corina Nentwich next to the distillation facility that might be replaced by the new technology

“The system lets us scale the process as desired”

ROBERT FRANKE, PROJECT COORDINATOR MACBETH

The MACBETH project

Hydroformylation is one of four areas of application for which MACBETH is researching catalytic membrane reactors. In the other project strands, further project partners are working on using the technique to produce hydrogen from biogas, to isolate pure fatty acids from vegetable oils, and to hydrogenate propane into propene. In all cases, the work involves combining suitable catalysts with membranes for separating the desired products. Although catalysts, membrane materials, and reactor conditions vary widely, all of the processes would, if successful, help to save large amounts of energy and prevent greenhouse gas emissions. From 2019 to 2024, 24 partners from ten countries are working on eight work packages in four sub-projects. The EU is funding this research with €16.6 million. Evonik is responsible for the overall coordination of MACBETH.

The project is supported by the European Union’s research and innovation program Horizon 2020 as part of the funding agreement No. 869896.

Nentwich also takes an overarching perspective and examines how the membrane reactor affects the material balances at the facility in Marl. “After all, the reaction of butene to form pentanal doesn’t occur in isolation at the chemical park,” says Nentwich. “On the contrary, the process is incorporated into an entire network of chemical reaction paths and material flows that influence one another.” For example, if the new reactor turned a certain amount of butene into more or less pentanal than the conventional process, this would have consequences for other synthesis lines because they might then have more butene available than before. Nentwich is currently working on ways to depict such interrelationships as well.

Despite the difficult conditions posed by the coronavirus pandemic, the tests at the demonstration facility are scheduled to begin in 2022, if possible. If the innovative membrane reactor shows its worth in practice, it will be a real highlight for Arsenjuk and Nentwich, who are still at the beginning of their careers. “It isn’t every day that you develop a completely new type of reactor. It’s fantastic to be part of such a project,” says Arsenjuk enthusiastically.

TWO THIRDS LESS GREENHOUSE GASES

Another achievement is the calculated effect on the sustainability performance. “To determine this effect, we conducted a life cycle assessment that compared the new method with an extensively studied conventional process,” says Nentwich. This comparison included the further processing of pentanal into 2-propylheptanol (2-PH). “The analysis showed that the new reactor can reduce the total greenhouse emissions of 2-PH pro-

duction by almost 70 percent," says Nentwich,adding that this calculation doesn't even include the effect of the membrane. The impact will thus be even bigger if MACBETH demonstrates that the membrane purifies aldehydes so well that the energy-intensive distillation steps are no longer needed.

No matter whether it concerns the membrane or the catalytic coating, the respective project partners contribute important expertise for many of the details. "We wouldn't be able to do it on our own," says Franke, adding that this also applies to the financial aspect. The EU is supporting MACBETH with €16.6 million. Franke says that this assistance is substantial, especially in view of the fact that it involves a certain amount of risk. "That's because we don't precisely know whether everything will eventually work as well in practice as we think it will and if a new process can actually be derived from it," says Franke.

In Shakespeare's drama MACBETH, three witches predict the eponymous character's future. Although Robert Franke can't rely on such arcane arts, he and his team will know by October 2024 whether catalytic membrane reactors are suitable for commercial hydroformylation. That's how long the MACBETH project will run. In order to make the best possible use of the remaining time, Franke is calling on everyone to heed a command from MACBETH's opponent Macduff in the fourth act of the Shakespeare play: "Cut short all intermission."

Karl Hübner has a doctorate in chemistry and is a journalist. He also works part-time as a freelance author and often writes about research-related topics

At the hydroformylation facility in Marl, Evonik turns olefins and syngas into aldehydes

Eating beef without having to kill the cow—thanks to technologies such as tissue engineering, that may be possible in the future

HOW WILL THE FUTURE TASTE?

TEXT **BJÖRN THEIS**

Steaks produced in a bioreactor? Anti-aging agents for dessert? Bacteria that cure cancer? The future of nutrition offers a wide range of opportunities to enhance health and well-being that are worth exploring

Sir Winston Churchill was not only one of the most significant statesmen of the twentieth century but also a serious futurologist. "Fifty Years Hence" is the title of an article the future British Prime Minister wrote for the magazine *Popular Mechanics* in 1932. In his article Churchill already envisioned a hydrogen economy, smartphones—and a time when "[we] shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium."

MARVELS OF THE MICROBIOME

Today this vision is starting to become reality. Last December Singapore became the first country in the world to approve "Chicken Bites" from the US company Eat Just—pieces of meat grown from chicken cells in a bioreactor.

Today meat substitutes made from plant proteins are available in almost every supermarket. According to a study conducted by Boston Consulting, "peak meat"—the point at which consumption of animal proteins starts to decrease—could be reached in Europe and North America between 2025 and 2035. Experts at the consulting firm Kearney estimate that 60 percent of today's meat products could be replaced with plant-based or artificially generated alternatives by 2040—with positive effects on land use and climate protection.

Meanwhile, there is increasing scientific evidence that illnesses such as diabetes and intestinal cancer can be avoided and even combated by means of targeted nutrition. The human microbiome is turning out to be the "missing link" that is helping us understand more clearly the interactions between food and our bodies. Scientists suspect that the causes of many diseases can be found in the complex interplay between nutrients, microorganisms, and metabolic products. The research community is convinced that proper nutrition plays a key role in preventive medicine.

DIETS THAT MAKE YOU YOUNGER AND HEALTHIER

Researchers also hope that findings from the field of epigenetics—the science of gene regulation—will have positive effects on human health. Isabelle Mansuy, Deputy Head of the Institute for Neuroscience at ETH Zürich, assumes that the expression of particular genes is controlled by an individual's diet, and that this makes it possible to switch genetic predispositions, such as a tendency toward metabolic diseases or overweight, on and off.

For example, scientists suspect that the consumption of olive oil significantly reduces an individual's risk of arteriosclerosis. According to Mansuy, it's even possible to influence the aging process through diet. Epigenetic studies have demonstrated that some people's bodies are younger or older than their date of birth might suggest.

The field of nutrition still offers ample room for innovations in many areas, including epigenetically effective combinations of nutrients, microbiome tuning, and plant-based or artificially cultivated meat. That's a good reason for the Foresight team at Creavis to make the future of nutrition its next focus topic. Under the heading "Sustainable Food Futures 2040" it plans to identify new innovation opportunities along the changing food value chain so that Evonik can play a role in ensuring a sustainable future for nutrition.

Such a future would certainly be to Churchill's taste as well.

Björn Theis heads the Foresight department at Evonik's innovation unit Creavis. His ELEMENTS column appears regularly at elements.evonik.com

13 26.982
Al
Aluminum

"And the aluminum suddenly broke"

LOG **FELIX ABRAHAMS**
PHOTOGRAPHY **ALEXANDRE SIMOES**

Wolfgang "Teddy" de Beer is a native of the Ruhr region. He took part in 216 official matches for Borussia Dortmund and won many titles as a soccer player and goalkeeper's coach. Almost nobody knows aluminum soccer goals as well as he does, even though he is a trained joiner

At the beginning of my career, we still played with goal posts made of wood. They were square, and it hurt a lot if you collided with them. We were very happy later on, when we got goals made of aluminum, although we had to get used to them because the goal posts were suddenly round and the balls bounced off completely differently. At least collisions with the goalposts no longer hurt as much. Moreover, the new goals were more durable because they couldn't rot like wood.

My mother loves to relate how I as a four-year-old was watching UEFA Euro on TV in 1968 and told her that she would see me playing there one day. At the age of eight, I then took part in a match as a left-back. Our goalkeeper was unable to take part in the following match, so I took over his position between the goal posts. That was a good thing too, because I couldn't have made much money as an outfield player.

I joined Borussia Dortmund in 1987. My first match against FC Bayern was more or less the game of my life. It was followed by our win of the German championship in 1989 and the most successful time in the history of the Dortmund-based soccer club. The German Cup was the most important title for me personally, because I was playing on the field. I was the main goalkeeper until 1993, after which I was the backup goalie for several years. I was still able to help the team in that position, because I could put pressure on the main goalkeeper. The trainer knew that I was there for him whenever he needed me.

I also witnessed the legendary goal incident of Madrid in 1998. It was really weird. We were preparing ourselves for the Champions League semifinals against Real when the goal suddenly fell over shortly before the match was about to begin. It occurred because some of the Spanish fans had climbed on top of the safety fence to which the goal was attached. It caused the fence to buckle and drag the goal down with it. The aluminum broke right before this important match, of all things. We had to wait for more than an hour until a replacement goal finally arrived from Real Madrid's training field and was set up. In the end, we lost 0-2.

After spending 14 years as an active player, I became part of Borussia's coaching staff in 2002. I was a goalkeeper's coach for a total of 17 years. I now work in the fan department and talk with BVB fans from all over the world.

Masthead

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elements.evonik.com

“Architecture ought to be…

…a mirror of life and of its time,” according to the world-famous architect Walter Gropius. In other words, the way we build is always an expression of the ideas and needs of a certain epoch—and thus of the people who live and work in these buildings.

With his Bauhaus school, Gropius was a pioneer in terms of aesthetics, which he believed should always follow functionality. He also focused intensely on construction materials. He paid particular attention to concrete, which along with glass and steel is the most important element of Bauhaus architecture. Today concrete still plays a central role at construction sites all over the world. ELEMENTS shows how this material is being further developed so that it can go on meeting the requirements of a changing world—in line with Gropius’ idea, so to speak.