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POWER TO CREATE

ELEMENTS

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2/2018

Polyamide 12

High-performance polymer

Polyamide 12 is a partially crystalline plastic with good dimensional and temperature stability and good damping characteristics for noise and vibrations. It has the lowest density of any polyamide and absorbs the least water. The suffix "12" refers to the molecular structure of the individual building blocks. They are composed of 12 carbon atoms and are distinguished by a particularly long alkyl chain. This fact, together with the interaction between specific parts of the molecule, make the plastic especially impact-resistant and resistant to oils, fuels, and other chemicals. Polyamide 12 is thus used in an extremely wide range of applications.

Partially crystalline: composed of regularly arranged (crystalline) and irregularly arranged (amorphous) building blocks

→ More about polyamide 12 starting on page 10

DEAR READERS,

How can genuine leather be replaced with environmentally friendly artificial leather? How can we use the components of crude oil even more comprehensively? How can we use the research findings of scientists to make new products? And how are these products changing our daily lives? Here at ELEMENTS, the connections between research, innovation, and society are the engine that drives us.

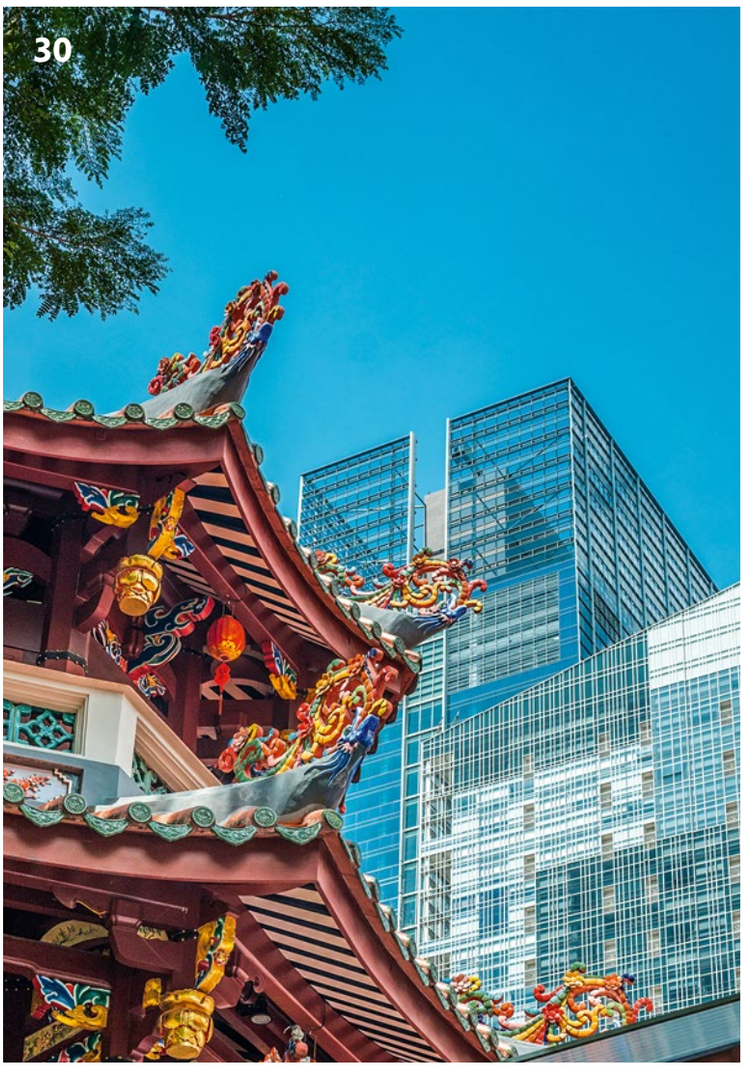
For example, the possibilities opened up by 3D printing seem practically limitless. The stuff these 3D dreams are made of is called polyamide 12, or PA 12. What can it do? Where are its limits? We are working to answer these questions, and we're starting our search in the city of Leuven in Belgium. This is where the 3D pioneers of the Materialise company do their work.

In order to meet the growing demand for PA 12, Evonik is planning to build a new facility for €400 million—not in Asia or the Americas but in North Rhine-Westphalia. Is that a sign of Germany's appeal as an industrial location? According to the renowned US economist David Audretsch, Germany is one of the best industrial locations in the world. His French colleague Sylvain Broyer begs to differ: He points out that Germany is facing tremendous demographic problems. We invited the two researchers to engage in a debate.

Outside Germany, innovations thrive most in places where creativity and capital combine and legislators create appealing framework conditions. In this context people automatically think of Tel Aviv or Silicon Valley. It's easy to overlook Singapore, which is currently doing its utmost to top the list of the world's most innovative locations. Will this ambitious city-state reach its goal? We decided to investigate this question on site.

ELEMENTS magazine is published four times a year, in German and English, in a print version and digitally on the Internet. If you would like to continue reading ELEMENTS, you can order a subscription free of charge. I wish you pleasant and instructive reading, and I look forward to receiving your suggestions and comments at: elements@evonik.com

Matthias Ruch
Editor in Chief of ELEMENTS



COVER STORY: POLYAMIDE 12

SINGAPORE

INNOVATION

ELEMENTARY

“A Piece of Clothing That’s an Extension of the Skin”

Source: The designer Behnaz Farahi (Model: Alexis Hutt)

“CARESS OF THE GAZE” is the name of this piece of clothing created by the designer Behnaz Farahi. It’s not only an eyecatcher—it also reacts to the observer’s gaze. That’s because a tiny eye-track camera inside it records the observer’s angle of vision and aligns the spiky fibers accordingly. The fibers, which were made via 3D printing, are sure to pique people’s curiosity

1

“The World’s Smallest 3D Ballpoint Pen”

Source: Lix Pen Ltd.

THE LIX PEN looks like a pencil, but it’s actually a miniature 3D printer. The plastic that is melted inside it cools off and hardens as soon as it leaves the pen. In the future, artists can use the Lix pen to “draw” three-dimensional works in space

2

3

"The Bridge Embodies the Endless Potential of 3D Printing"

Source: Tim Geurtjens, CTO of MX3D

THE PRINTING ROBOTS of the Dutch startup MX3D have successfully built the world's first bridge via 3D printing in only six months. Starting in 2019, this steel construction, which weighs 4,500 kilograms, will span a *gracht* in Amsterdam—a symbol of technical progress in one of Europe's most popular historical city centers

“A Revolution in Architecture”

Source: Massimiliano Locatelli

MASSIMILIANO LOCATELLI wants to get people excited about houses made by a 3D printer. At this year’s Design Week in Milan, the Italian architect used his time constructively. He had an assembly robot additively manufacture a complete house—thus demonstrating that the future of construction has already arrived

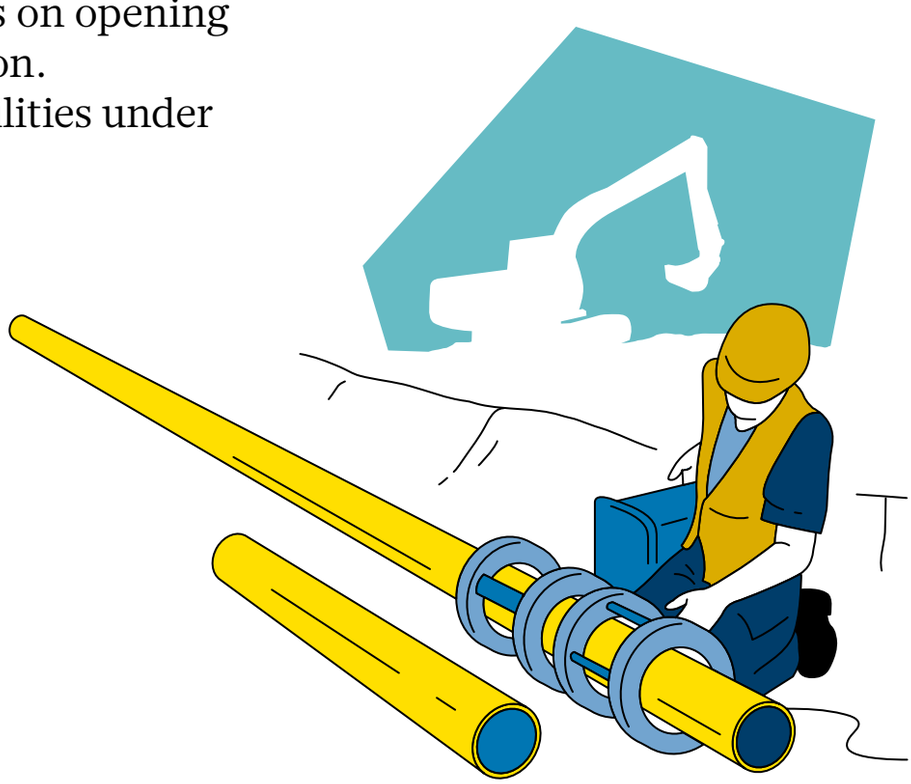
POLYAMIDE 12

The selective laser sintering printer at the Materialise company uses a laser to fuse polyamide 12 powder into solid structures

ESPECIALLY RESILIENT

From 3D printing to gas pipes and the coolant pipes for batteries in electric cars—polyamide 12 keeps on opening up new areas of application. It demonstrates its capabilities under extreme conditions

TEXT **TOM RADEMACHER**
ILLUSTRATION **MAXIMILIAN NERTINGER**



Gas pipes made from PA 12 can be fused using simple heating elements

It would be an almost normal construction site—if it wasn't for the TV crew. In the small town of Neubeckum, to the north of Germany's Ruhr region, the local gas utility company is replacing the old steel pipes of the high-pressure gas supply network. The media interest is focused on the new bright-yellow pipes that are being laid here. It's a first in Germany—the pipes are made from the high-performance polymer polyamide 12, PA12 for short. The German technical inspection association TÜV has issued an individual approval especially for this job. The pipes in the gas distribution network are about the thickness of a thigh, and they have to withstand an operating pressure of 16 bar. Expectations are high, and not just on the part of the network operator. That's because the 300-meter-long stretch of new pipe could signal the sector's farewell to steel. It would mark a decisive change, and not the first one that PA12 has triggered.

What the TV team doesn't see, but the construction crew notices immediately, is that the PA12 pipe is much easier to lay than steel pipe. The individual elements are maneuvered into the roadbed by hand. A couple of electrical heating elements are sufficient to fuse the blunt ends together. Basically, the new pipe could even be laid from a roll. Between 150 and 200 meters fit on a drum, while steel pipe segments that are transported by truck can have a maximum length of 18 meters. Laying pipe from a roll can also be carried out without a trench—

through a horizontal borehole. That saves not only welds but also a great deal of digging. PA12 pipes running for tens of kilometers have already been installed in this way in Brazil. But it's not only the laying but also the operation of the new plastic pipes that promises to be much easier. Corrosion protection is no longer necessary. And the pipe can even be temporarily squeezed closed when the network has to be extended or serviced.

The plastic has already long been used in automaking for brake and fuel lines. It's especially resistant to hydrocarbons such as gasoline, natural gas, and mineral oil. The pipes don't swell, even after thousands of hours in contact with fuel, and almost nothing is washed out of the material.

"The automakers' and their suppliers' requirements are extremely high and rising further," says Dr. Sandra Reemers. She heads Innovation Management for the High Performance Polymers unit at Evonik. "The automakers are controlling the combustion inside their engines ever more exactly. That means the injection profile is becoming increasingly complex and the injection nozzles ever finer. The smallest amount of material washed out of the polymer could block these nozzles." Specially modified PA12 solves this problem.

Hybrid and electric vehicles, in contrast, use high-performance PA12 lines for the batteries' cooling circuits. This is an area where PA12 can utilize its weight advantages in the future. Range is a decisive criterion for electric vehicles, and every gram saved counts. PA12 is lighter than steel and doesn't need threads and nuts because connectors can be closed directly in the component using compressed air.

A GROWING GLOBAL MARKET

The global market for polyamide 12 is growing constantly and strongly, most recently by five percent per year. A number of forces are driving this development. In the emerging economies, demand for cars and other high-value consumer goods has been growing for years. PA12 is in demand in sports equipment and for household appliances—the baskets in dishwashers, for example, are powder-coated with PA12. That's what enables them to withstand years of hot water, aggressive dishwasher tabs, and pans and knives thrown in carelessly.

"The automakers' requirements regarding materials for fuel lines are extremely high"

SANDRA REEMERS

But some of the growth in PA12 also comes from new markets. The powder variants are used in 3D printing. Growth in this area is in double digits. PA12 is in demand here because it is ideally suited for use in various printing processes and can produce components that are as delicate as they are durable. Evonik recognized 3D printing long before the current hype and has been patiently acquiring know-how in this area. For example, PA12 experts from Marl worked together with renowned printer manufacturers such as EOS, 3D Systems, HP, and voxeljet to develop custom powders for their print technologies.

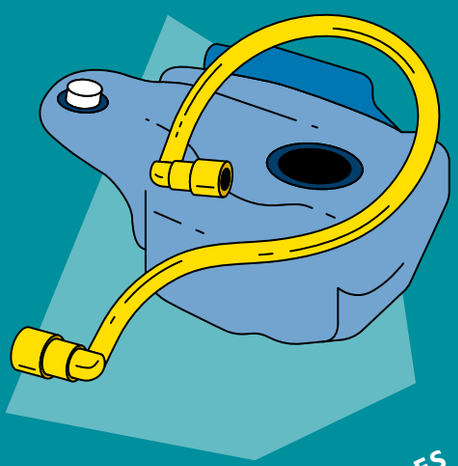
It's the material's versatility that drives the rising demand. "PA12 is outstandingly easy to modify and totally well behaved," says Reemers. "We can incorporate other monomers by polymerization and intervene directly in the molecular structure. There are very many compounds that work. That means we can control the material properties by using additives." Evonik has developed an especially large toolkit for this custom work.

BIG DATA AND ARTIFICIAL INTELLIGENCE

In order to identify further areas of application, the researchers from Evonik intend to also use the methods of big data analysis and artificial intelligence to evaluate the immense amount of data that they have collected over decades of research and development work. Evonik is already using artificial intelligence More on page 16 →

FROM GAS PIPE TO SPORTS SHOE

Thanks to its wide range of possibilities for processing, its compatibility with additives, and its susceptibility to chemical modification, PA 12 covers an extremely wide range of applications



AUTOMOBILES
e.g. fuel lines

1 HIGH-PERFORMANCE POLYMERS

This group of plastics comes into use where materials face special requirements, as they are distinguished by features such as an operating range of up to 300 degrees Celsius, for example in automaking, in space travel, and in medicine.
Price per kilogram: €10–250

2 ENGINEERING POLYMERS

If the requirements are not as high—for example, operation temperatures below 150 degrees Celsius—engineering polymers are used: for example, in machine construction, in industrial applications, and in beverage bottles (PET).
Price per kilogram: €5–12

3 STANDARD POLYMERS

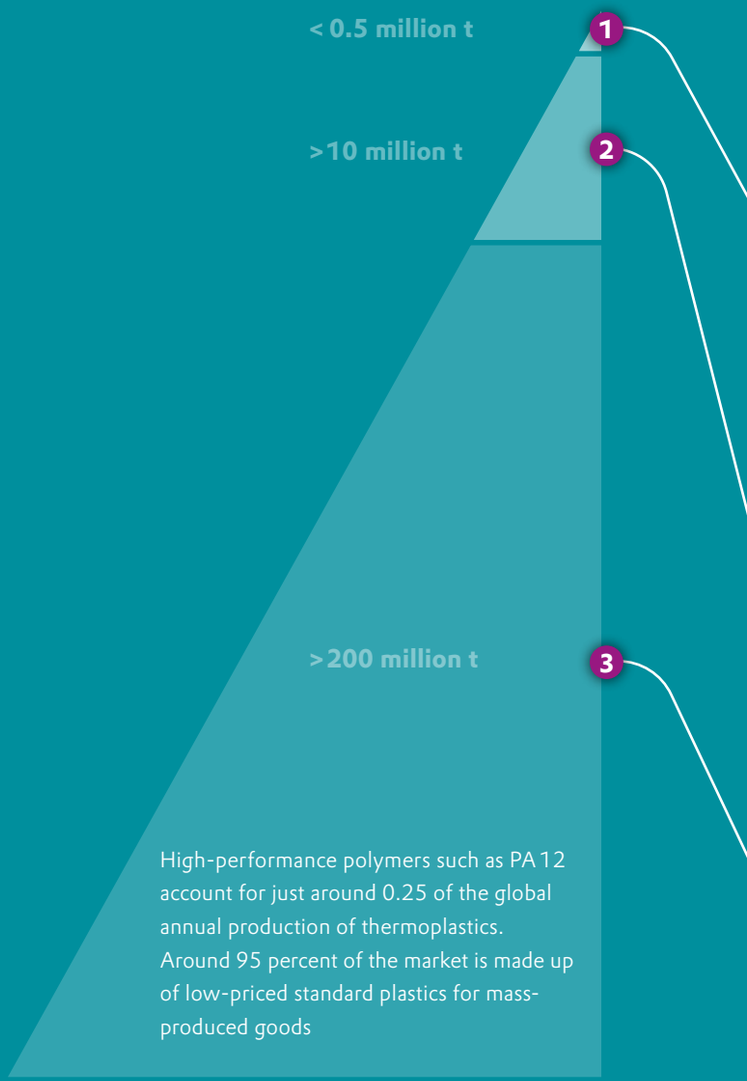
Plastics from the lower segment are used for mass applications such as plastic bags, foams, and yogurt cups. Everyday products of this type are manufactured from standard plastics.
Price per kilogram: €3–8

DIVERSITY THANKS TO A TOOLKIT

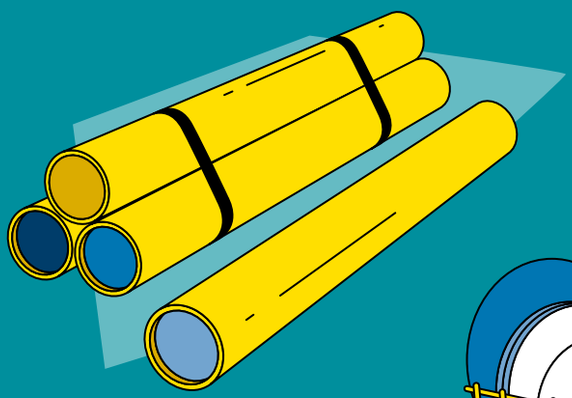
The exact characteristics of PA 12 are set to match the requirements of the respective application by means of additives or chemical modification. The chemical, electrical, and mechanical properties of the material can be adapted in this way

Additives	Effect
Nanotubes	Provide electrical conductivity
Long glass fibers	Increase stiffness
Teflon/graphite	Improve sliding capability

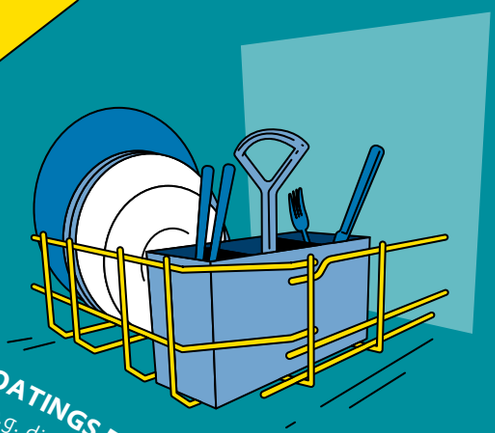
Chemical modification	
Polymers	Increase hardness
Aromatics	Increase temperature resistance and raise melting point
Short amides	Lower melting point



BREAKDOWN BY PRODUCTION VOLUMES
worldwide, in metric tons per year

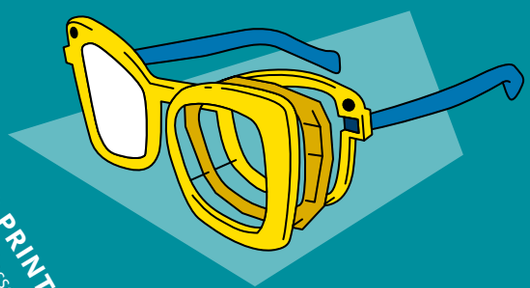


OIL / GAS INDUSTRY
e.g. gas pipes



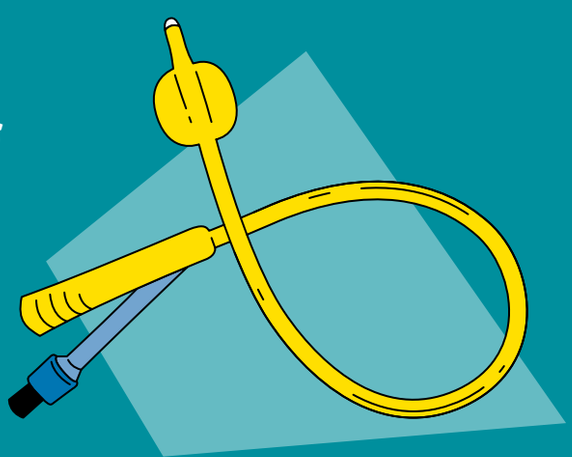
COATINGS FOR METAL
e.g. dishwasher baskets

AREAS OF APPLICATION FOR PA 12

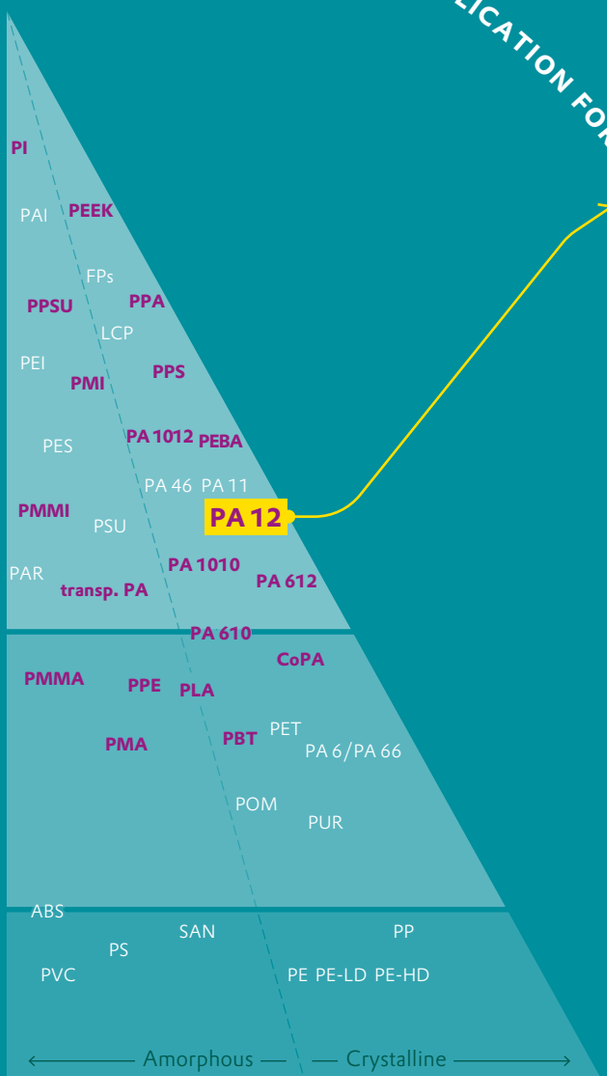


3D PRINTING
e.g. eyeglasses frames

SPORT AND LEISURE
e.g. sports shoes



MEDICINE
e.g. catheter



BREAKDOWN ACCORDING TO TECHNICAL REQUIREMENTS
(Plastics from Evonik—not from Evonik)

The experts want to use big data analyses to evaluate the data from research and development

to comb through the patent literature. Similar systems should also soon be searching through the company's own data on cause-effect relationships between molecular structure and additives, on the hunt for promising combinations. "We want to use computer support to further investigate what our developers can sometimes intuit on the basis of their decades of experience," says Reemers.

Being on the ball early and working together closely with the users are also essential ingredients in the recipe for success. "At the end of the day, we 'just' deliver the polymer, but we have to ensure that it is going to work without problems in our customers' machines," says Reemers. That's why Evonik keeps examples of all common production machines at the technical center in Marl. The Group has to be able to master processes such as coextrusion—the simultaneous extrusion of pipes made up of multiple polymer layers—at the production speeds required.

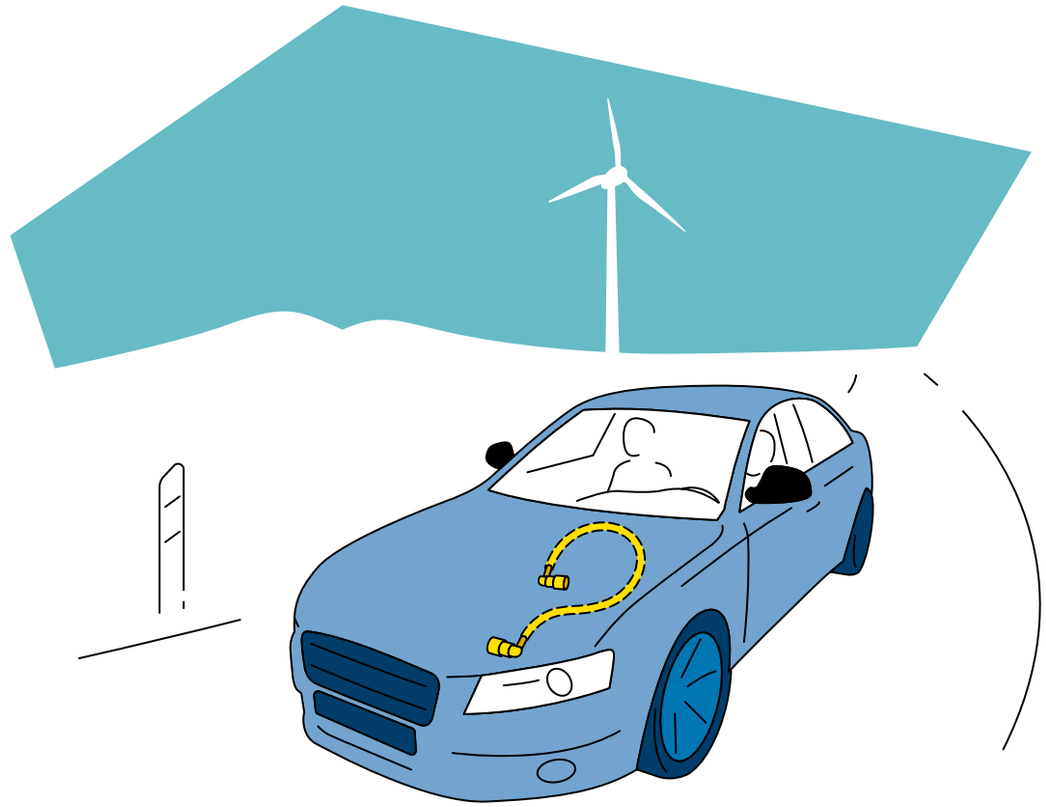
The Group is the only supplier on the market that is also completely backward-integrated, i.e. it produces all of the precursor products itself at its Marl location. "We can tune the properties of PA 12 both physically by using additives and chemically," says Reemers. "Starting from the monomer, we have various building blocks and can develop a complete molecular architecture with respect to the degree of branching, chain lengths, end groups, density, and copolymers." This is one of the main reasons why Evonik has long been able to maintain its position as the world leader in PA 12.

Molding compounds based on PA 12 improve the damping characteristics of sports shoes

LIGHTER, FURTHER, FASTER

As Reemers explains, the Group is frequently already working in standardization groups on the establishment of new technical standards. "When we develop a better solution it eventually becomes the legal minimum requirement—often just because this better solution exists." For example, the first test rigs for determining the chemical resistance of plastic pipes were developed in Marl. Today's industrial standards are based on that work. So Evonik is in demand as a consultant not only about what's going to be possible tomorrow but also about what's going to be needed. "We talk about the trends of the coming years with shoe and sports equipment manufacturers, and about stricter future regulations with automakers," says Reemers. "If we didn't start development until the customer came to us with his problem, it would usually be too late."

The developers behind PA 12 also want to teach the material new tricks, so that it can enter new markets. "In the area of electronics, for example, plastics that work well with metals are in demand. PA 12 can do that perfectly," says Reemers. "If we were to modify the polymer



Fuel lines made from PA 12 are especially resistant to washing out

with additives so that it could stand up to the waste heat and conduct it out of the component, that would be an attractive market."

GROWING CAPACITIES

In order to be able to keep up with the increasing demand for PA 12, Evonik has substantially expanded PA-12 production in Marl. In addition, a completely new production line is to be set up at this location in 2019. The facility will go into operation in 2021 and boost the capacities by more than 50 percent in one move. The Group has budgeted around €400 million for the project—Evonik's biggest investment in Germany. Locations such as Singapore and Thailand were discussed, but the final decision went to Marl. "Nowhere else has such a good supply of all of the precursor products—and nowhere else has a better understanding of the material and the target markets," says Marcus von Twistern, who heads the project.

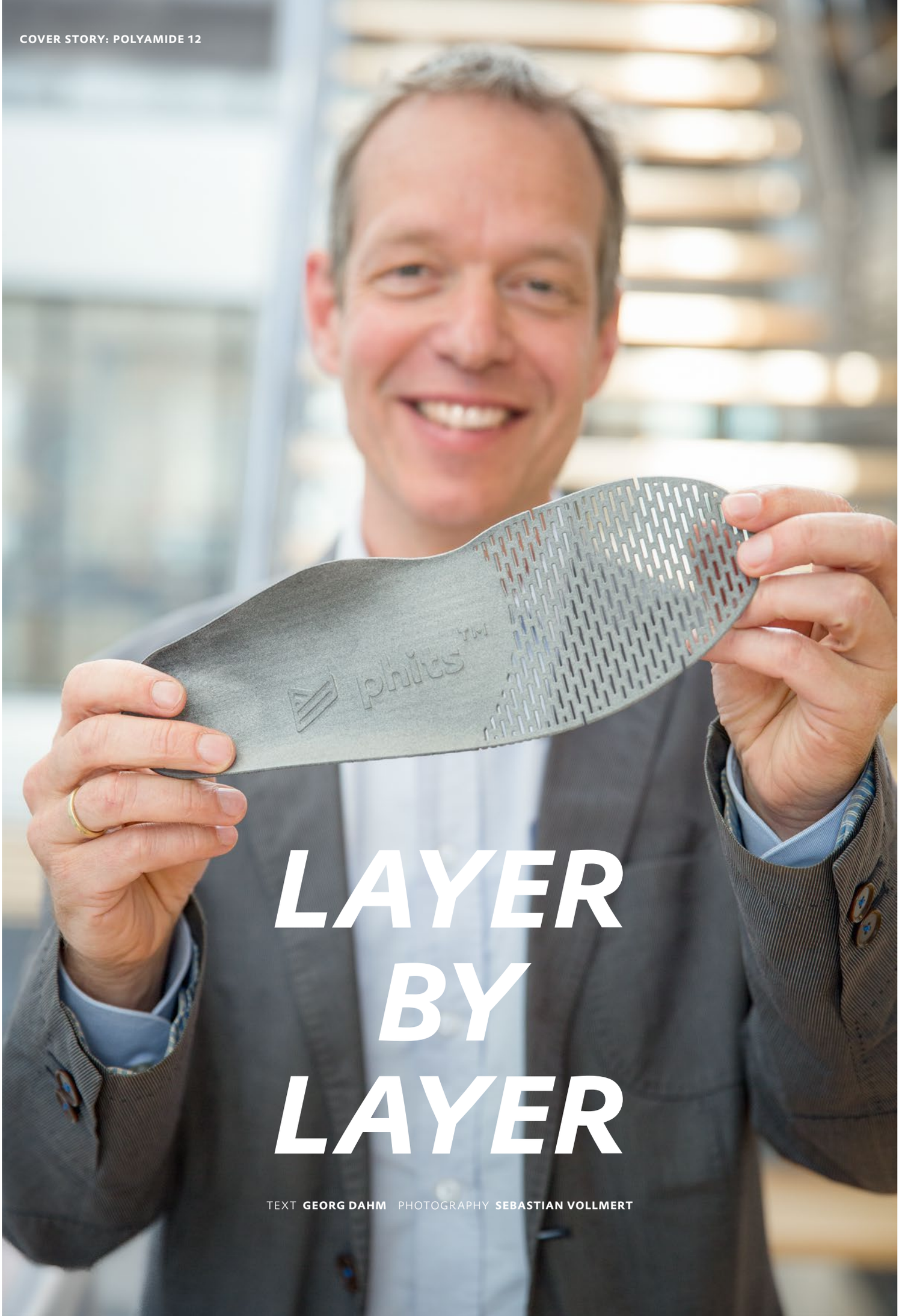
Understanding the markets also requires patience. Oil and gas extraction, automaking or power grids—the hurdles for new materials and technologies are often high. Automobile companies have optimized their production processes over 50 or even 100 years. "We talk with end customers such as VW, Opel, and Ford, but also with Petrobras and Shell about where this journey is going," says Reemers. She and her team are looking ahead to the year 2030 in order to anticipate trends and scenarios in the areas of technology and legislation. The energy sector in particular is anything but fickle. "Oil and gas applications require a 30-year service life in the hardest offshore environments," says Reemers. The steel pipes being replaced in Neubeckum had been in operation for almost 70 years. If PA 12 is going to take over from steel in the long term in this sector as well, then the bright-yellow replacements will have to last a long time. —

Glossary

Compound A plastic in which fillers and/or additives have been admixed in order to make specific changes to its properties is called a compound.

Copolymer Copolymerization enables the properties of a plastic to be influenced by uniting different plastics with different properties in one polymer.

Extrusion/coextrusion A forming process that is used for thermoplastics, among other materials. Coextrusion is a process in which multiple materials are brought together in the production process



LAYER BY LAYER

TEXT **GEORG DAHM** PHOTOGRAPHY **SEBASTIAN VOLLMERT**

The Belgian company Materialise has more experience with 3D printing than almost any other European company. It produces innovative products made of polyamide 12. A visit to the pioneers in the university city of Leuven in Belgium

If you were to put a blindfold on Bart Van der Schueren and lead him through his company's widely branching halls full of 3D printers, he would know which area he was in by the smell alone. That way he'd know which of the many printing techniques was being used there to create airplane parts, medical implants, shoe insoles, eyeglasses, lamps or prototypes—layer by layer, out of nothing.

For example, there's the slightly pungent smell of the big stereolithography printers, which look like gigantic terrariums with flickering blue lights. And there are the warm plastic fumes of the fused deposition modeling printers and the selective laser sintering printers, which are lined up in rows like incubators. Further along are the hospital-disinfectant vapors of the Multi Jet Fusion devices, which look like oversized laser printers. Every morning the technicians take the rollboxes, inside which objects have grown overnight in successive layers of powder, out of the printers.

We were unable to find out what a metal printer smells like, because in Leuven metal 3D printing is used only for the medical sector, and that area is closed to visitors. But Van der Schueren mainly wants to direct our attention to the plastics. And we do see plastic everywhere, from the exhibits in the lobby to the building's many delicate ceiling lamps, whose seemingly organic structures are based on mathematical formulas. "Many of our visitors are fascinated by the fact that we can print metals such as aluminum, titanium, and steel," says Bart Van der Schueren, the Chief Technology Officer (CTO) of the Materialise company. "But our workhorse is plastic. We produce about one million items annually, and 800,000 of them are made of PA12."

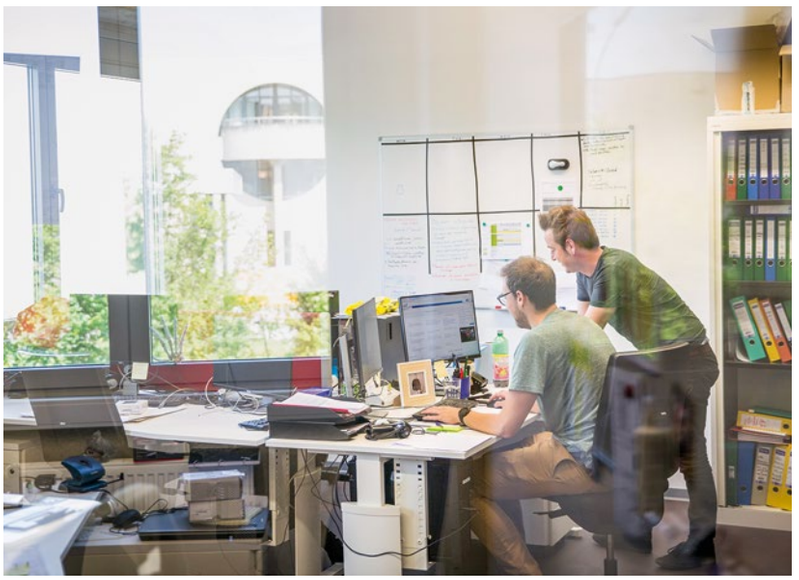
3D printing has to create added value, says Bart Van der Schueren (left photo). The selective laser sintering printers stand in long rows (bottom)

A NEW APPROACH FOR INDUSTRY

The CTO is still bemused by the fact that the company produces so many different things from polyamide 12—prototypes as well as finished products for end consumers, medicine, and automobile and airplane construction. "Actually, this material is overqualified for many applications," he says. "It's a bit too robust, too stiff, too temperature-resistant. For many applications you'd be better off using polypropylene, which is cheaper. But we've discovered time and again that PA12 is more practical to use for additive manufacturing because it can do so many things."

Many aspects of additive manufacturing—the term this expert uses instead of "3D printing"—contradict conventional experience and expectations. "Normally, a company would keep pestering its materials suppliers with all kinds of wishes for better material properties," he says. But at Materialise, almost every time the technicians calculate how much it would cost to manufacture a certain design, they find out that PA12 will produce exactly what they need—everything from lacy lampshades to metallic-looking precision parts for automobile construction, for which the PA12 powder is mixed with aluminum particles.

"In additive manufacturing, we don't alter the properties of the material," says Van der Schueren. "We give items the desired properties by creating the structure we've developed for them at the computer. For industry, this is a whole new approach." →



Many customers (of Materialise) are looking for detailed advice about 3D printing

APPLICATION: MEDICAL TECHNOLOGY

This new approach has caused a minor revolution in the field of orthopedics, for example. People who wear orthopedic insoles in their shoes know that these are expensive customized items consisting of a combination of cork and leather or various plastics, depending on the stresses they will bear. Alternatively, they are inexpensive models made from a single piece of plastic on the basis of the user's footprint.

Materialise prints orthopedic insoles made of PA12 that are based on 3D impressions of the user's gait. "We analyze the user's movements and calculate how much support he or she needs at which part of the foot," says Van der Schueren. "Our software then designs a structure that has the right properties at every point—firmer in some places, more elastic in others. Then we print it in one piece, using one single material." Does such an insole wear well? "Let me put it this way: We made a fairly big mistake with our business model. Our customers need to reorder their insoles much less often than we expected."

He says that many companies still need to have someone explain to them how 3D printing can contribute to value creation. "Many companies come to us saying they want to do 'something with 3D printing', but they don't know exactly what. They often have completely unrealistic expectations." The most frequent misconception is that 3D printing can replace the traditional injection molding process in mass production. The technology will someday be advanced enough to do that, but today the additive manufacturing of many series-produced items is still more expensive than many people realize.

NEW BUSINESS MODELS

Value creation by means of 3D printing is different, and that's why Materialise cooperates with each one of its customers to look for its practical applications. For instance, additive manufacturing is ideal for batch sizes that are so small that it's not worthwhile to make injection molds and other processes such as milling would not provide the desired properties.

One example of that is flying drones, in which a fiberglass support frame provides stability. Materialise prints plastic guides in which tiny channels precisely align each of the razor-thin fibers in the right order, so that they can be glued. "Considering the batch sizes in which these drones are sold, no other process would be economically feasible," says Van der Schueren.

3D printing also creates added value in segments where it enables the mass production of unique items. Examples of that include orthopedic insoles and eyeglass frames: "Here you can see the added value more clearly than in series-produced eyeglasses. We can calculate exactly where the lenses should be in front of your eyes and where the frame should sit on your nose so that the glasses will precisely match your skull. And we can produce the glasses in any design and color you want."

LIGHTWEIGHT CAR SEATS

Another example of potential value creation can be seen in the lobby: an experimental car seat for Toyota that weighs only seven kilograms—a normal seat weighs 30 kilograms—and is made entirely of PA12. Only when you look at it up close can you see that it's made in one piece but combines a variety of structures. A weblike body gives the seat rigidity, and small feathery structures on the surface provide flexibility.

The seat is only a prototype that shows how much weight could already be saved today in automobile construction. But before it can be series-produced a great deal of technology will have to be developed. At the moment, the technology for large components is still too expensive—and here the manufacturers and engineers have to do some rethinking.

"With injection molding, you simply multiply the cost of the material by the density by the quantity and you've got your costs," says Van der Schueren. In additive manufacturing, the structures are produced in a powder bath, and there are no fixed formulas for calculating how much raw material is ultimately discarded as scrap. In addition, the energy costs increase exponentially. "Normally, if you double the size you also double the costs, but in 3D printing, doubling the size means multiplying the costs by eight," he explains.

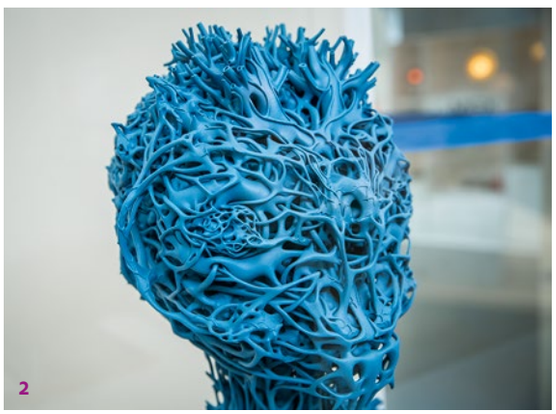
CUSTOMIZED SKI BOOTS

In additive manufacturing, products are created grid point by grid point. The raw material is heated, melted, and cooled, and then it takes shape. In processes such as selective laser sintering and Multi Jet printing, the →

COMPLEX STRUCTURES THAT WOULD OTHERWISE REQUIRE EXPENSIVE HANDCRAFTING

1

1 Materialise printed this replica of a robot for a trade fair **2** 3D printing also inspires artists: Nick Ervinck's sculpture AGRIEBORZ is based on tomographic images of blood vessels **3** Customized orthopedic insoles **4** The 3D-printed lining of ski boots precisely fits the wearer's legs **5** For the medical sector, Materialise produces implants, surgical tools, and replicas of organs that surgeons use to plan and practice operations **6** A non-proprietary prototype with a delicate structure **7** Eyeglass frames are produced to match the wearer's head measurements **8** Workpieces are made light, yet stable, through their interior structures—like those of human bones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A PRINTED CAR SEAT IS ONE FOURTH AS HEAVY AS A CONVENTIONAL ONE. AN ADVANTAGE FOR RECYCLING: NO COMPOSITE MATERIALS

raw material is a powder that is laid on layer by layer and heated at the specific points that are to remain.
By contrast, the 3D printers you can buy in an electrical supplies store work with a strand of plastic that is unrolled from a spool, heated, and laid on through a nozzle that resembles a hot glue gun. This process, which is called fused deposition modeling (FDM), is used by professionals, even though it is slower and less efficient. However, it can be used to make closed structures that are hollow inside. For example, Materialise uses FDM machines to produce the lining of ski boots on the basis of 3D scans of the wearer's feet.

Besides, more different kinds of plastic can be processed by FDM printers. That's a crucial advantage in industries where every raw material, or every production process, must be individually approved. For example, in a closed-off area FDM machines are printing components for the Airbus A350, because this process has been certified for the manufacture of airplane parts. "A couple of hundred components from Materialise are installed in every airplane," says Van der Schueren. "The batch sizes per component are so small that injection molding isn't worthwhile here, and other production processes would be too expensive."

This car seat, which is on show at Materialise headquarters, was printed in one piece from PA 12 and weighs only seven kilograms

A REPLICA OF THE ÖTZI MUMMY

Most of the 3D printers that Materialise works with at its production facilities all over the world come from manufacturers such as HP. If no printers for specific applications are currently available on the market, the company develops such devices on its own. One example of that is printers for very large components. In this area, Materialise has built printers that created a replica of the "glacier mummy" Ötzi, copies of Greek statues, and more mundane items such as complete instrument panels. "In the course of developing these printers we learned a lot about what works and what doesn't," Van der Schueren says.

Plastics such as PA12 sometimes reach their limits in the area of medicine. For example, permanent implants are still made of titanium. "PA12 is biocompatible," says Van der Schueren, "but there are still no long-term studies that prove this material can safely remain in the human body permanently." In the area of metal printing there are other disadvantages, such as the good thermal conductivity, which the engineers have to compensate for. According to Van der Schueren, "If you close up a hole in a patient's skull with a titanium plate, the patient can no longer hold his head in the sun, because the plate will get too hot. And he can't go swimming, because that would cool off his brain too much." Materialise therefore prints metal implants that have a fine mesh structure, which acts as a temperature buffer.

DRILLING AND SAWING TEMPLATES

Compared with these delicate workpieces, some of the most important medical applications of PA12 look completely unremarkable: individually produced drilling and sawing templates that are used by surgeons doing complicated bone operations. The templates help them to place their cuts and screws in such a way that the newly aligned bones grow together in exactly the way the surgeons have previously calculated at the computer. This process enables several thousand patients per month to avoid a trial and error process on the operating table.

Medical technology is one of the three specialist areas of Materialise. The two other areas are the industrial contract manufacture of prototypes and end products and the development of software for 3D printing. The latter area represents the roots of this company, which was founded in the 1990s in the university city of Leuven.

"Back then we quickly realized that 3D printing is actually quite easy in itself," says Van der Schueren. "The only problem was that we had to figure out how to prepare a design we could print in 3D." In view of today's boom

One of the company's specialist areas is the development of software for 3D printing

in virtual reality applications, it's strange to remember that back in the 1990s industry was a two-dimensional world. "There wasn't a single company in Belgium that could create a design in 3D," Van der Schueren recalls.

Materialise decided early on that it would not keep its inventions to itself. Thanks to this policy of openness, the company is now one of the market leaders. "Our software is the backbone of a large segment of industry," he adds.

Glossary

Additive manufacturing
This technical term expresses how this production process differs from processes such as injection molding: It does not involve material being poured into a mold or a workpiece being carved out of a block of material. Instead, the component is calculated on a computer and the 3D model is built up layer by layer—in a process of addition, so to speak.

Selective laser sintering
In this 3D printing process, the product is created when a plastic or metal powder is laid on in layers and melted at the key spots with a laser. The finished product finally lies in a bath of powder that has not yet been melted and is then separated from it.

Stereolithography printer
Here too, a laser creates the component. However, instead of a powder, a plastic solution is laid down and then hardened by means of UV light.

Multi Jet Fusion This is a further development of the selective laser sintering process. The difference is that the shape that is to be printed is sketched out in black paint, and then the entire powder layer is exposed to a heat source. The dark areas heat up quickly and melt.

Fused deposition modeling (FDM) This printer works in the same way a baker uses an icing bag: A strand of plastic is rolled off the spool, heated, and applied with a nozzle, layer by layer.

A GIANT PLASTIC JELLYFISH

One of the big development-related themes in the field of 3D printing is the recycling rate. 3D printing has a huge advantage when it comes to recycling finished products after they can no longer be used. PA 12 is so versatile that it can be used on its own for manufacturing even complex products. As a result, no composite materials have to be separated during recycling.

What the field of 3D printing needs today is technical innovation and, even more importantly, innovative designs. "Most designers in product development still think in terms of blocks from which they can carve out individual components and then assemble them. We are teaching them a new approach," Van der Schueren tells us. It's also possible to design components that have many more functions than conventionally produced parts. He illustrates this by picking up an object that looks like a plastic replica of a giant jellyfish. In fact, it's a folding stool consisting of many hinged components that a flick of the wrist can transform into an elegant chair. "It slides right out of the powder bath this way. All you have to do is to brush it off and fold it out."

Through its search for new employees, Materialise has also become aware of the appeal of tangible products and the fascination of 3D printing. "At our location in Bremen we initially did only software development, and it was very hard to attract new employees, even though we were located directly next to the campus. That's the kind of positioning we like to have at all of our locations." Today, Bremen is also a production location—and suddenly it has become much easier to find new programmers. "That's because now they can not only tell people that they've programmed something, but also pick something up and say, 'I've programmed something, and that's why this cool thing exists today.'"

"GERMANY IS LIVING ON ITS CAPITAL"

The US economist David Audretsch praises Germany as a highly attractive industrial location. His French colleague Sylvain Broyer begs to differ. A debate about the industrial engine of Europe

INTERVIEW **MATTHIAS RUCH AND JÖRG WAGNER**
PHOTOGRAPHY **BASTIAN WERNER**

Mr. Audretsch, Mr. Broyer, Evonik is planning to build a production plant for a high-performance plastic for about €400 million. After examining possible locations all over the world, it decided to build this complex in the German state of North Rhine-Westphalia. From your standpoint as economists and scholars who are familiar with Germany, is this a step you can understand?

SYLVAIN BROYER Evonik is following a current trend, so I'm not surprised by this decision. Among the established industrial nations of the world, the G7 countries, Germany is the only one that can successfully maintain its industrial production. The chemical sector is a good example of the fact that the trend of moving production facilities abroad has been ebbing since 2013.

DAVID AUDRETSCH Germany is a very attractive industrial location. The level of its human capital—in other words, its workforce—is very high. That also applies to the level of its infrastructure and the level of its medium-sized companies. These are the driving forces that determine the advantages of an industrial location.

BROYER Mr. Audretsch, you've brought up an important point, that of the infrastructure. I agree that the level of Germany's infrastructure is good. But how long will it continue to be good? For years now, this country has been living on its capital! Just take a look at the international rankings: Germany has slipped down in the rankings for essential categories, by comparison to all of its important competitors. In terms of the quality of its flight infrastructure, the USA now ranks higher than Germany. The Americans were much quicker than the Germans to invest in this area. In terms of railroad infrastructure, even Singapore now ranks higher than Germany. And in terms of road infrastructure, Germany has been overtaken by South Korea. Germany urgently needs massive investments.

Why have they been neglected for so long?

AUDRETSCH That has been a matter of politics. The decision-makers have postponed this matter for a while. But as a wealthy and developed country, Germany still has a very good infrastructure—especially by comparison with its neighboring countries in Europe, such as Italy and France.

BROYER Germany's economic policy has basically rested on the reform agenda of the Schröder administration since 2005. Back then, Germany regained its competitiveness. But since then, it has improved as an industrial location in only one important respect: the qualifications of its workforce and its high school graduates. Educational policy is the thing that Germany has done best in the past 15 years. In every other area, its economic policy has been characterized by stagnation.

AUDRETSCH Mr. Broyer, you've used the word "stagnation." I would prefer to talk about Germany's stability. And that's a positive concept.

Germany's stability also includes the model of consensus, in which political decision-makers, companies, and labor unions work together to find solutions. Isn't that a fairly strange concept for an American?

AUDRETSCH You've got a point there. Americans typically reject such models, which look suspicious to them. On the other hand, thinking and planning with the long term in mind is a very positive approach, especially in the current global situation. The weakness we're seeing in the USA today is of course due to very short-term thinking. This is a very narrow mindset. By contrast, if you include the perspectives of the employers, the workers, and the government, you've got large segments of the society on board. I could even compare that with what the Chinese are doing with their planned economy. They too are capable of very long-term thinking and planning, and of developing clever strategies.

BROYER Mmm. When many parties have to take responsibility for a decision, Germany's philosophy of consensus really does have advantages. When people in Germany say, "We're going to do this," the thing really does get done. However, I would criticize the comparison with China. I wouldn't say that China has a philosophy of consensus, because China is definitely not a democracy. However, China does have the possibility of enforcing the government's will through commands. That works in many centralized nations, including France. But from my viewpoint, the crucial thing is that China has a plan, a grand idea! Germany has a philosophy of consensus, but no fundamental idea about the direction in which it wants to develop. Germany is not developing a real industrial policy.

AUDRETSCH What do you think is missing?

BROYER For example, let's look at the process of digitalization. In Germany not enough is being invested in this area, because the responsibility for developing ideas is being left to the companies. That's a real weakness, because what's needed is public investment. At the European level as well, we need a kind of public investment, for example in the form of the Juncker plan and the European structural funds, in order to improve infrastructures all over Europe, especially in Germany.

AUDRETSCH All the same, we are observing greater dynamism, especially in the area of digital enterprises. At the end of the 1990s, many people considered Germany much too stolid, not only in its politics but also in its entrepreneurship. Back then, Joschka Fischer complained, "If Bill Gates had been a German, Microsoft →

would not exist." But since the turn of the millennium, the times have changed. Today Germany has both: economic stability as well as flexibility and dynamism among its entrepreneurs. My thesis is that Germany has successfully overcome this lack of entrepreneurial spirit—and that it has done so by decentralizing its economic policy. It has developed focal points in its various regions, possibly at the expense of a centralized industrial policy. And that kind of centralization has in fact disappeared.

BROYER Mr. Audretsch, on that point I agree with you. The only example of a grand idea in the area of industrial policy that I can think of is the energy transition. But unfortunately, it too is not proceeding according to a well-developed long-term plan. It was developed as a result of the Fukushima crisis.

As non-Germans, what do you think of the German invention of the "energy transition"?

BROYER Here I'd like to differentiate between short-term and long-term effects. In the short term, the subsidies for renewable energies are causing enormous costs for electricity customers. These costs have increased by more than 20 percent in the past five years. I also think that the indirect costs of this reform include the fact that big energy companies such as RWE can no longer pay good dividends to their shareholders. In the long run, the energy transition is opening up new markets for German companies. Germany is now the leading producer of wind and solar energy. The only thing that's now missing, in my opinion, is the medium-term perspective: How are such decisions affecting the existing business processes? I don't see any overarching concept for answering this question.

AUDRETSCH Here's an interesting thought: In general, Germany's economic policy is regarded as being very risk-averse. But the decision to launch the energy transition was a very risky one, wasn't it? Nobody was able to say where it would lead. But I see a positive short-term aspect. Through its phaseout of nuclear energy and its energy transition, Germany represents an environmentally friendly policy. Today this image is definitely a locational advantage, especially in the competition for the talents of the young generation. Young people from the so-called "creative class" want to live in healthy and environmentally friendly surroundings. For many young people, that's the top priority. As a result, talented young people—what we call "human capital"—are happy to move to Germany.

When international companies invest in the USA, one of the reasons they give is that the energy costs there are very low. That's a clear competitive disadvantage for Germany, isn't it?

AUDRETSCH Yes, it certainly is. But just take a look at Silicon Valley. I'm always very impressed by it. Silicon Valley is one of the world's most expensive locations, but that isn't scaring off the companies and people in the digital industry. It's true that there they have very high costs, but they also get a lot back! And that also applies to Germany as an industrial location. The energy costs there are very high, but in exchange German companies benefit from other advantages: the stability and, above all, the excellent workforce.

BROYER Rising prices for electricity would be a real problem for energy-intensive sectors such as the chemical industry. And as far as education is concerned, the German educational system for skilled workers is fantastic. However, Germany is only in the middle rankings of European countries when it comes to the number of

David B. Audretsch (*1954 in the USA) is a professor of economic development at Indiana University and an honorary professor of industrial economics and entrepreneurship at the WHU-Otto Beisheim School of Management in Germany, as well as a co-author of the book *The Seven Secrets of Germany.*

"Germany's economic policy is regarded as being very risk-averse"

DAVID B. AUDRETSCH

"In Germany not enough is being invested in digitalization" SYLVAIN BROYER

school and university graduates in the MINT subjects. And the competition isn't napping. Other G7 countries such as Canada and Japan are making huge efforts to incorporate younger generations into their aging societies, give them a better education, and strengthen their social bonds. Germany is certainly doing this better than other European countries. Italy has implemented a reform of its educational system, but it hasn't achieved anything. In France, President Macron has yet to initiate his reform of the school system and the trainee system.

Sylvain Broyer (*1971 in France) works in Frankfurt as the Head of Economics of Natixis, the investment bank of French savings banks and credit unions, which is one of the biggest bank groups in France. He is a member of the ECB Shadow Council of *Handelsblatt* magazine.

Germany has experienced a strong wave of immigration. What effect will this have on the country as an industrial location?

AUDRETSCH Immigration is like the World Cup in soccer…

…We want to hear more about that!

AUDRETSCH No, no, I'm not making a comment about sports. I'm referring to the international competition in this regard. The best players are in demand all over the world. And in exactly the same way, today every location, every city, and every country has to struggle to attract the best minds to work there. This is a challenge for Germany too, but it applies to every country in the world.

But many people with fewer qualifications are also coming.

AUDRETSCH That's true. But if Germany can't solve this problem, what country can? Basically, no other country in the world can match its system of education and integration.
BROYER A high level of education is a key to future success. That's especially true if an hour of work in German industry costs $25 more than an hour of work in Korea. In Korea, the workers are also highly qualified, but currently they are campaigning for the introduction of a 52-hour week instead of the 68-hour week they have now.

Will the integration of immigrants into the workforce be successful in the medium term?

BROYER From a historical standpoint, all of the major growth phases of national economies all over the world were caused by demographics and immigration. What we're seeing in Germany at the moment is the biggest wave of migration since the one caused by the war in the former Yugoslavia in 1992. At the moment, the integration of immigrants into the workforce is still too low. The likelihood that a refugee will find a job in German is 35 percent as a long-term average. Today, during this wave of immigration, it is less than 20 percent.

In spite of the immigration of young people, the average age of our population is constantly increasing. Does this development make you uneasy?

BROYER During periods when a population is aging, there are only two other opportunities besides immigration to safeguard the substance of the national economy. The first one is robotization. Germany is extremely progressive in this area, even though it isn't doing so well in terms of digitalization in general. Incidentally, there's a strong correlation between the average age of a country's workforce and the number of robots being used in industry. Three countries lead the world in terms of the robotization of industry: Japan, South Korea, and Germany. These are exactly the three industrialized countries whose population is aging the fastest. →

Audretsch and Broyer met in the Electoral Palace in Koblenz

The second opportunity to safeguard the substance of a national economy is to keep older people working longer. However, this process works only once. Where should additional growth come from if all of the "silver workers" are still occupying all the jobs? That's why educational policy and immigration policy simply belong together.

Let's talk about taxes—an important factor for industrial locations. US President Trump has created a new situation by radically reducing corporate taxes.

BROYER President Trump isn't the only one. And to a certain extent other countries will probably have to join in this taxation contest. I'm convinced that, at the latest, the next German government will put the topic of corporation taxes and municipal business taxes on its agenda.

AUDRETSCH Here too, you can justify a high level of taxes if this revenue is invested in the industrial location. Consequently, the crucial question is: Are the high tax revenues in Germany being invested in a strategically effective way? If the answer is yes, the level of taxation balances out.

BROYER Look, President Macron has already begun to reduce corporate taxes. Above all, he wants to significantly increase the tax incentives for venture capital. That too makes a lot of sense, because it counteracts the biggest problem we have at the moment: the low interest rate. This factor is often overlooked. Especially in an aging society, low interest rates mean that big companies have to significantly increase their payments into pension funds. That reduces their ability to invest, and that in turn reduces the capacity for innovation. The main reason for the tremendous growth of the current account surplus in Germany since 2007 thus really has nothing to do with the Germans' low interest in consumption. Instead, it's due to the fact that German companies have to plow back their profits into payments on their pension obligations, because of the low interest rate. Mr. Audretsch, perhaps someone ought to explain that to Mr. Trump: If we want to reduce the current account surplus in Germany, we have to raise the interest rate. That's all.

In this connection, what role is played by the preservation of the euro zone?

BROYER Germany is one of the countries that benefits most from the euro. If Germany were still using the Deutsche Mark, the exchange rate would be between 10 and 20 percent higher, and Germany's export trade would therefore be more problematic. Moreover, the euro has strongly expanded Germany's sales markets. And the euro is also important because it enables Europe to assert itself in a bipolar world that is dominated by the USA and China.

AUDRETSCH That's certainly a huge advantage! Without the euro, Germany would have to change completely. I can't even imagine the abolition of the euro.

BROYER US economists already predicted that when the euro was established.

AUDRETSCH That's right, especially the most famous ones. But I have to admit that I was also unable to imagine that the UK would ever leave the EU.

BROYER In historical terms, the euro and the EU are not the first attempts to create a unified Europe. So far, all of these attempts have failed—after the Peace of Westphalia and after the Congress of Vienna. Unfortunately, the history of the continent of Europe is a simple one: We've got a bunch of small nations that beat other nations up in order to win supremacy over the continent. Sometimes it's the British, sometimes the Germans, sometimes the French. And every time, an alliance of other nations forms in order to stop these bullies from becoming dominant. At the moment, Germany is dominating the continent within the euro zone.

Let's end this conversation by having you imagine yourselves in the role of Germany's Minister of Finance. You are now allowed to invest €10 billion to strengthen Germany as an industrial location. Where will you invest this money? In the infrastructure? Or in digitalization?

BROYER Neither one. I would invest the €10 billion in the stabilization of the euro zone. This is extremely important, and the consequences of a breakup of the euro zone would be very bad for Germany. The money should be used strategically for this purpose.

AUDRETSCH I agree. Germany has benefited tremendously from the euro zone, and it now has to deal considerately with its European partners in order to stabilize the euro. When the crisis with Greece broke out, most German politicians said, "The Greeks have to put their national budget in order." It was a great mistake to leave the Greeks to do this alone. The EU is like a marriage, in good times and bad ones. That's why Germany has to invest in Europe, in this partnership.

EVONIK NEWS

Werner Müller Bows Out

Werner Müller had been Chairman of Evonik's Supervisory Board since the end of 2012

At the annual shareholders' meeting, the Executive Board and shareholders of Evonik bade farewell to the departing Chairman of the Supervisory Board, Dr. Werner Müller (71), and paid tribute to his outstanding achievements. "You were and will always remain our founding father," the Chairman of the Executive Board, Christian Kullmann, said. CEO Kullmann also praised Müller's "strategic vision." Shareholder representatives expressly thanked Müller for his entrepreneurial acumen, his personal commitment, and his outstanding services to Evonik. Müller had announced at the beginning of the year that because of health reasons he would no longer be available for a further term of office. Müller has also resigned from his position as Chairman of the Board of Executives of the RAG-Stiftung. The RAG-Stiftung holds around 68 percent of Evonik stock. Stable in value and dividend-paying, Evonik stock forms an important part of the RAG-Stiftung's capital base. Back in March, the Supervisory Board of Evonik appointed Müller to the position of Honorary Chairman.

Bernd Tönjes Is the New Supervisory Board Chairman

Bernd Tönjes, a 62-year-old mining engineer, is the new Chairman of the Supervisory Board of Evonik. He was appointed to the Supervisory Board by a large majority at the annual shareholders' meeting. The Board subsequently appointed him to the position of Chairman. As of May, Tönjes also succeeded Dr. Werner Müller as Chairman of the Executive Board of the RAG-Stiftung, Evonik's largest shareholder. "Evonik is moving in the right direction and is successful in its business operations," Tönjes says. "As Evonik's largest shareholder, the RAG-Stiftung has a keen interest in ensuring that this situation continues." Tönjes described the planned sale of the methacrylate business as the right step. But he also expressed some clear expectations: "Evonik must grow profitably and pay reliable dividends." The dividend from Evonik is the chief source of income for the RAG-Stiftung, which holds around 68 percent of Evonik stock. The remaining 32 percent are freely traded on the stock market. Tönjes expressed deep gratitude to his predecessor as Chairman of the foundation and the Supervisory Board: "I have profound respect for Dr. Werner Müller and his outstanding life's work."

Tönjes introduced himself to the shareholders at the annual shareholders' meeting

A World Record in Weiterstadt

Evonik has commissioned the world's most advanced stretching and polishing plant for aviation materials made of PLEXIGLAS®. Located in Weiterstadt, the new facility produces stretched sheets of polymethyl methacrylate (PMMA) that are 5.4 meters long and 3.7 meters wide—the largest format available worldwide. This format will enable the aviation industry to develop entirely new aircraft designs. Before production can start, an external validation phase must first be completed. This will certify the material for use in the US and the European aerospace markets. Initial tests are already under way. The market for stretched aviation parts is showing healthy growth.

A New Project House

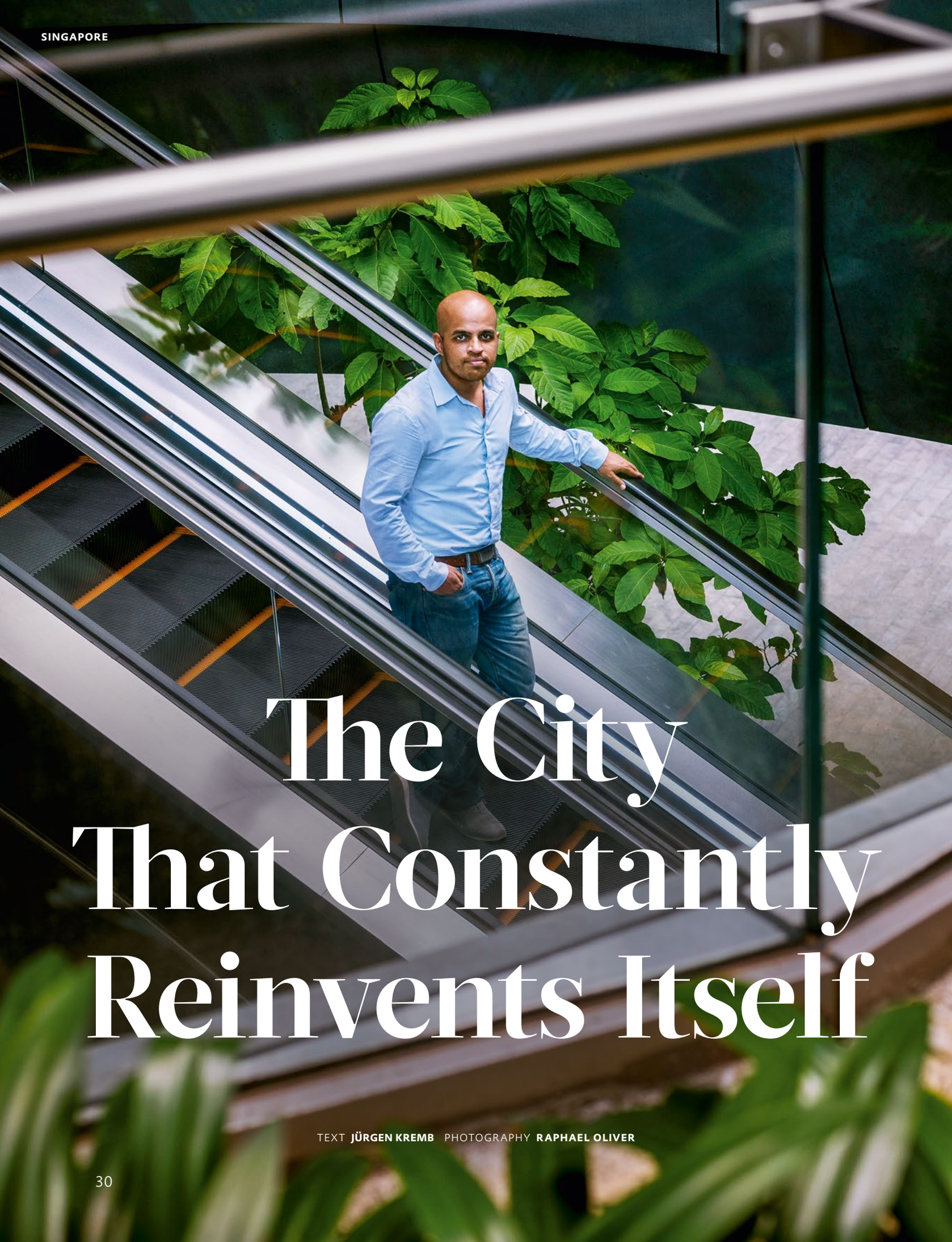
Evonik has set up a Tissue Engineering Project House in Singapore. In tissue engineering, living cells are grown on a scaffold material outside of the organism. It is a process that requires special nutrients and growth factors. This externally grown tissue can then be implanted in the organism as a way of preserving or regenerating bones or diseased tissue, for example.
Experts estimate that the market for the materials needed in the field of tissue engineering is growing by roughly 30 percent per year and will reach the US$3 billion mark by 2021. Up to 20 scientists will work at the Evonik Project House in Singapore. Their aim is to develop materials for biological implants used in medical applications.
Evonik has extensive experience with materials such as biodegradable polymers. These will now be developed further in the Project House. A key area of work will be reproduction of tissue structures using 3D-printed scaffold materials.

Evonik's Value to the German Economy

Experts have now calculated the value that Evonik adds to the German economy. According to their analysis, each euro created in the Group results in an additional €1.50 in value to society, for example in the form of investments or consumer spending by employees of Evonik or of its suppliers. There is a similar effect on public revenue and jobs: Every euro that Evonik pays in taxes and charges in Germany results in an additional €0.14 in public revenue. This is the result of tax payments by suppliers or employees, for example. Similarly, each Evonik employee secures a further 2.7 jobs outside of the company.
These calculations are based on what is known as an impact analysis.

Investments in the Future

Through its venture capital unit, Evonik has invested in two young companies that develop and utilize future-oriented technology. The technology startup mySkin, Inc. is based in Jersey City (New Jersey, USA). It has developed a breakthrough hand-held device for analyzing and improving skin properties, combined with tips for suitable skin care. Evonik is one of the world's leading suppliers of ingredients for the personal care industry.
In addition, Evonik has invested in Velox, a digital printing company based in Israel. Velox has a new technology for the cost-effective high-speed printing of photo-quality images and other decorative elements on metal, plastic, and glass packaging. The process can be used either for extremely small series or for large-scale industrial applications, both at competitive prices. In addition, Velox supplies systems for printing on cylindrical containers such as plastic tubes.



The City That Constantly Reinvents Itself

TEXT **JÜRGEN KREMB** PHOTOGRAPHY **RAPHAEL OLIVER**

Gourab Mukherjee founded an Internet startup in Singapore. It took him only one day to complete the necessary administrative formalities

Back in 1981, Singapore announced a "National Computerisation Plan." Today this island nation on the southern tip of Malaysia has 50,000 startups and is looking to become the research capital of Asia. Evonik recently opened a new research center in Singapore. What makes this city-state's culture of innovation so special? To find out, we paid a visit to this small country with great ambitions

Is this a residential high-rise with blue balcony cladding? No, it's actually a former warehouse that looks like all the other warehouses and factories that were built throughout Asia in the 1970s: plain five-story concrete boxes with massive ramps on the first floor that were used to drag machine tools and textile machines into the halls. The upper floors usually housed unattractive but functional offices that were used to arrange the shipment of rapidly produced everyday items and simple electronic devices to destinations around the world. This was also the way factories were built in Taiwan and South Korea—tiger-state architecture from the days when the Four Asian Tigers were still considered exotic members of the group of industrialized nations.

Today, Block 71 of the "Launch Pad" owned by the government of Singapore is the epicenter of the country's startup scene. The first people to move into the block, which was set to be demolished just four years ago, were a group of computer nerds who brightened up the building's facade somewhat. These days, young people wearing hoodies and colorful T-shirts occupy the halls, which have been converted into offices. The rough charm of simple factories has been replaced by an atmosphere very similar to that of the offices in Silicon Valley. No Chinese dialects are spoken here—only Mandarin and English. Block 71 is now the centerpiece of five factory halls that house more than 750 government-funded startups.

Gourab Mukherjee, 32, is the owner of one of these startups—a six-person operation for whose office space he pays around €100 per month in rent. That's amazingly cheap for a city that is notorious for its exorbitant rents. Mukherjee, who was born in Calcutta, studied computer science in Singapore. Since then he has transformed himself into an entrepreneur with the help of his "Aktivo" health app. "Data that we obtain with a normal fitness tracker can be used to generate relatively precise information about the wearer's physical condition within 24 hours, as well as a forecast of their life expectancy," Mukherjee explains. After the data is processed, users are sent nutrition, fitness, and health tips on their smartphones, as well as warnings of acute risks and suggestions for athletic activities and relaxation exercises.

Several insurance companies and major corporations have expressed interest in the app, and a study with 9,000 test subjects is scheduled to be conducted in India this summer. The money needed for this study—nearly €400,000—is being provided by government programs and an American investor. "We would never have gotten off the ground without the generous funding from the government and the outstanding infrastructure we have here," says Mukherjee. In fact, it only took Mukherjee one day to set up his company and open a corporate bank account.

Dr. Ronny Sondjaja This Indonesian chemical engineer manages Evonik's new research center in Singapore, which focuses on resource efficiency

Benefiting from innovative strength

An analysis of 10,000 startups conducted by the US organization Genome found that Singapore is number one in the world, and thus ahead of Silicon Valley, when it comes to the availability of up-and-coming professionals. The study also found that Singapore has the world's youngest entrepreneurs—their average age is 28. Innovative government policies, solid entrepreneur networks, and a business-friendly environment have all contributed to the startup boom in Singapore.

Evonik is also looking to benefit from the innovative strength of this island nation. The Group opened its first research center in Singapore in April 2018. The new facility is focusing on resource efficiency, with as many as 50 top researchers and engineers working on the development of innovative ideas and groundbreaking products in this field. The research center is managed by Ronny Sondjaja, 39, a chemical engineer from Indonesia. "We're utilizing a holistic research concept here," Sondjaja explains. "This is our first attempt to use Asia as a base for initiating innovative activities and projects."

Evonik has also launched a Tissue Engineering Project House in Singapore. Some 20 scientists at this facility are developing reliable solutions for tissue regeneration after accidents or illnesses, for example. All of these research activities are based at the Biopolis research complex, which also houses the renowned National University of Singapore. The university is partnering with Evonik on the development of techniques for regenerating bone and tissue. Biopolis is also home to the largest group of 3D printers on the planet. "Singapore offers ideal conditions for young talents in the natural sciences," says Peter Meinshausen, Regional President of Evonik Asia Pacific South.

An architectural dream come true

The five futuristic skyscrapers in Biopolis—in which new types of cancer treatments are being studied, among other things—are an architectural dream come true for Singapore's planners and politi-

The old and the new are side by side in downtown Singapore (here on Telok Ayer Street)

“We’re utilizing a holistic research concept”

RONNY SONDJAJA

cians as regards their vision for science and research in the city-state. The five ultramodern buildings were constructed between 2004 and 2014 at a brownfield site not far from the city’s trendy Holland Village neighborhood. The first tower was designed by the star architect Zaha Hadid.

Today, metal pedestrian bridges wind their way like spider legs out of this blue glass structure and into adjoining buildings, where researchers in white lab coats stroll through the corridors—and schoolchildren sometimes visit to get a glimpse of the future. Here life, work, leisure, and top-notch research have been intentionally united over an area of more than 300,000 square meters in an “air-conditioned future mall.” During lunchtime in the canteens, which were designed with Singapore’s famous and exotic hawker center cookshops in mind, the world’s leading researchers can be seen talking to curious and eager students from nearby universities. Just a subway stop away from here, the five skyscrapers of Fusio- →

An Innovation Incubator

Proximity to universities, good infrastructure, and an open-minded culture—various factors come into play when an innovation hotspot is created. The leading startup culture—in fact, the mother of all startup cultures—is still Silicon Valley, which accounted for 25 percent of all global venture capital investment in the biotech sector in 2017. However, several cities in Europe, the Middle East, and Asia are now giving Silicon Valley some competition. The innovative strength of Tel Aviv, for example, is driven by outstanding incubator programs that were established by the Israeli government in the 1990s to make the country more attractive for well-educated Russian immigrants. Israel's startup culture also benefits heavily from the country's compulsory military service, which serves as a stepping stone to Silicon Wadi. Europe's startup scene is now increasingly moving from London to Berlin, in large part due to the looming shadow of Brexit. In fact, a new digitally focused startup is founded in Berlin once every 20 hours.

Sources: Berlin Business Location Center, Deutscher Start-up-Monitor, DIHK: Industriestandort Deutschland, *The Economist*, *Frankfurter Allgemeine Zeitung*, Global Startup Ecosystem Report 2018, *Süddeutsche Zeitung*, *Die Welt*, *Wirtschaftswoche*

SILICON VALLEY

NUMBER OF STARTUPS 16,000
ESTIMATED VALUE OF ECOSYSTEM
US$264–323 billion
EXCELS IN AI, big data, analytics, fintech, biotech
FAMOUS STARTUPS
Uber, AirBnB, Pinterest
POPULATION OF THE REGION 7.6 million
GROSS DOMESTIC PRODUCT OF THE REGION
US$619 billion

BERLIN

NUMBER OF STARTUPS 2,400
ESTIMATED VALUE OF ECOSYSTEM
US$24.7–30.2 billion
EXCELS IN Fintech, IoT, health and life sciences
FAMOUS STARTUPS Zalando, Lieferheld, Soundcloud
POPULATION OF THE REGION 6 million
GROSS DOMESTIC PRODUCT OF THE REGION
US$158 billion

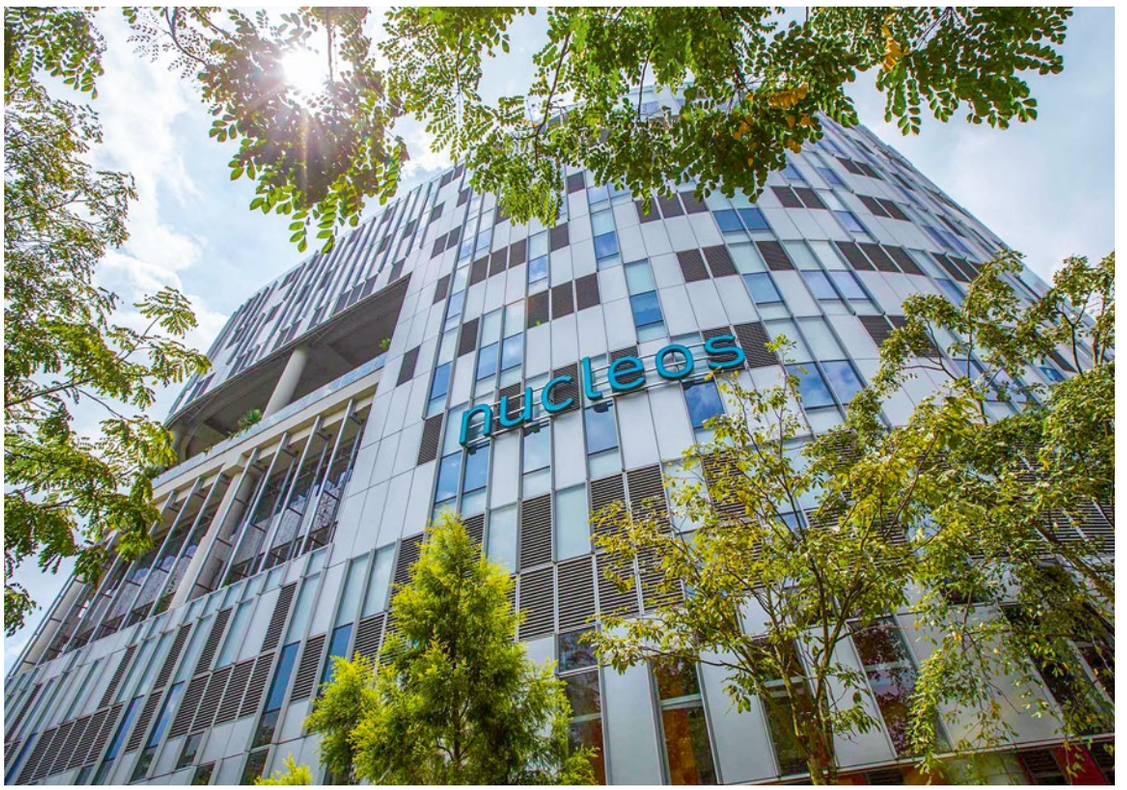
TEL AVIV

NUMBER OF STARTUPS 6,500
ESTIMATED VALUE OF ECOSYSTEM
US$23.7–28.9 billion
EXCELS IN Cybersecurity, automotive and advertisement technology
FAMOUS STARTUPS Mobileye, OurCrowd, Cyberark
POPULATION OF THE REGION 3.7 million
GROSS DOMESTIC PRODUCT OF THE REGION
US$153 billion

SINGAPORE

NUMBER OF STARTUPS 50,000
ESTIMATED VALUE OF ECOSYSTEM
US$11.8–14.4 billion
EXCELS IN Fintech, digital media, big data, analytics
FAMOUS STARTUPS Active.AI, oBike, Zuzu Hospitality Solutions
POPULATION OF THE REGION 5.5 million
GROSS DOMESTIC PRODUCT OF THE REGION
US$264 billion

> "Singapore offers ideal conditions for young talents in the natural sciences"
>
> **PETER MEINSHAUSEN**



The renowned National University of Singapore is also located in the Biopolis research complex

nopolis rise into the tropical sky. Whereas Biopolis specializes in biochemistry, the natural sciences, and medicine, the breathtakingly bold curving buildings of Fusionopolis have been designed to lure computer nerds and digital experts to Singapore. The "towers of the future" in Fusionopolis are designed to be an even more open meeting place for researchers and residents—between the future and the present—than Biopolis. It's therefore not surprising that Fusionopolis is home to music schools and ballet studios as well as world-renowned computer firms. The planners of the complex wanted to eliminate the boundaries between high tech and daily life.

On the subterranean floors of the research towers, young and old come together in huge underground food courts. A constant temperature of 21 degrees Celsius is maintained here, which makes eating, strolling, meeting, and learning a more comfortable experience here than outdoors, where the average temperatures range from 28 to 34 degrees Celsius—365 days a year.

Raw material: Knowledge

Lee Kuan Yew (1923–2015), the visionary politician who established the city-state of Singapore after it declared its independence from Great Britain, realized early on that the only raw material the island nation possessed was the diligence and thirst for knowledge of its majority Chinese population. Soon after it was founded in 1965, Singapore quickly became a banking center, and it also built the first refinery in Southeast Asia. The "National Computerisation Plan" was announced in 1981. Today this tiny island nation on the southern tip of the Malaysian Peninsula is the world's fifth-largest exporter of electronic products. Internet connections in Singapore boast speeds of up to 135 megabits per second, which is ten times faster than the common Internet speeds in Germany.

In 2014 the government of Singapore presented an ambitious plan to transform the country into the world's first "Smart Nation." Among other things, the plan calls for Singapore to become the start-up capital of Asia with the help of massive support from government agencies. "By consolidating the efforts of government agencies and providing targeted support to startups, we want to become the location of choice for young entrepreneurs in Asia," says Koh Poh Koon, Senior Minister of State at Singapore's Ministry of Trade and Industry. The government is providing nearly €20 billion in funding for various programs in order to make this happen. According to the government, Singapore is now home to more than 50,000 startups.

Such factors also figured into the decision at the end of 2017 to make Singapore the first German Accelerator location outside of the USA. The German Accelerator program, which is being supported by Germany's Ministry for Economic Affairs and Energy, has three programs running in parallel in Boston, San Francisco, and New York.

Coming soon: Flying taxis

More than 5,000 of the startups in Singapore focus on advanced technologies. Pang Kin Keong, Permanent Secretary in Singapore's Ministry of Transport, recently announced that government agencies and a Russian startup plan to start testing flying taxis in the near future. Google is now testing merchandise delivery drones on the campus of the National University of Singapore.

The government of Singapore assumes between 50 and 70 percent of the initial costs for each promising concept developed by any →

A city full of energy: View of the central business district from Chinatown

Tom Ludescher switched from the old to the new economy in Singapore

> **“No other country in the world offers so much government funding to startups”** TOM LUDESCHER

startup in the country. Although this funding is capped at around €126,000, it can be applied for three times per project. Most startups are also granted full tax-exempt status for at least five years. “Probably no other country in the world offers so much government funding to startups,” says Tom Ludescher, the 39-year-old Chairman of the Swiss Chamber of Commerce. Ludescher advises startups and also serves as an instructor for insurance topics at the University of St. Gallen’s campus in Singapore.

There are numerous exchange and cooperation programs between universities in Singapore and academic institutions all over the world. The National University of Singapore, which is an Evonik research partner, has 183 partnerships with universities in 44 countries, for example. In addition, the Campus for Research Excellence and Technological Enterprise (CREATE) in Singapore houses research centers operated by world-renowned universities such as MIT, the Swiss Federal Institute of Technology (Zurich), the Technical University of Munich, Ben-Gurion University, and the University of California, Berkeley.

“What makes this city so special,” says Ludescher, “is that it’s constantly reinventing itself.”

Thanks to its strong government policies, Singapore has become one of the world's most innovative nations. Much of this development—though not all of it—is worth imitating

by Ulrich Küsthardt

Dr. Ulrich Küsthardt
heads the Innovation unit at Evonik worldwide. Because of his work, he knows Singapore well

In the minds of many people, Singapore is still an exotic place somewhere in Southeast Asia. Even for many travelers to Asia, this city-state at the southern tip of the Malay Peninsula is just a stopover on the way to their holiday destinations. The world of industry and finance, however, has a very different view. It has selected the city as an important Asian hub—a choice reflected in the rankings of the cost of living, in which Singapore regularly appears as one of the most expensive cities in the world. A top spot, but perhaps a somewhat less attractive one.

Yet people often overlook a much more important ranking: For years now, Singapore has been one of the most competitive countries on earth. Only recently, the renowned business school IMD put Singapore in third place on its World Competitive Index—behind the USA and Hong Kong, but far ahead of Germany (15) and other major economies such as the UK (20) and France (28).

How can it be that a small island without any natural resources to speak of has become one of the most powerful economies in the world? The answer sounds simple: through long-term planning, big ideas, and rapid action. Especially in the area of innovation, Singapore is setting benchmarks that should be receiving more recognition in Germany. That's because many aspects of Singapore are exemplary.

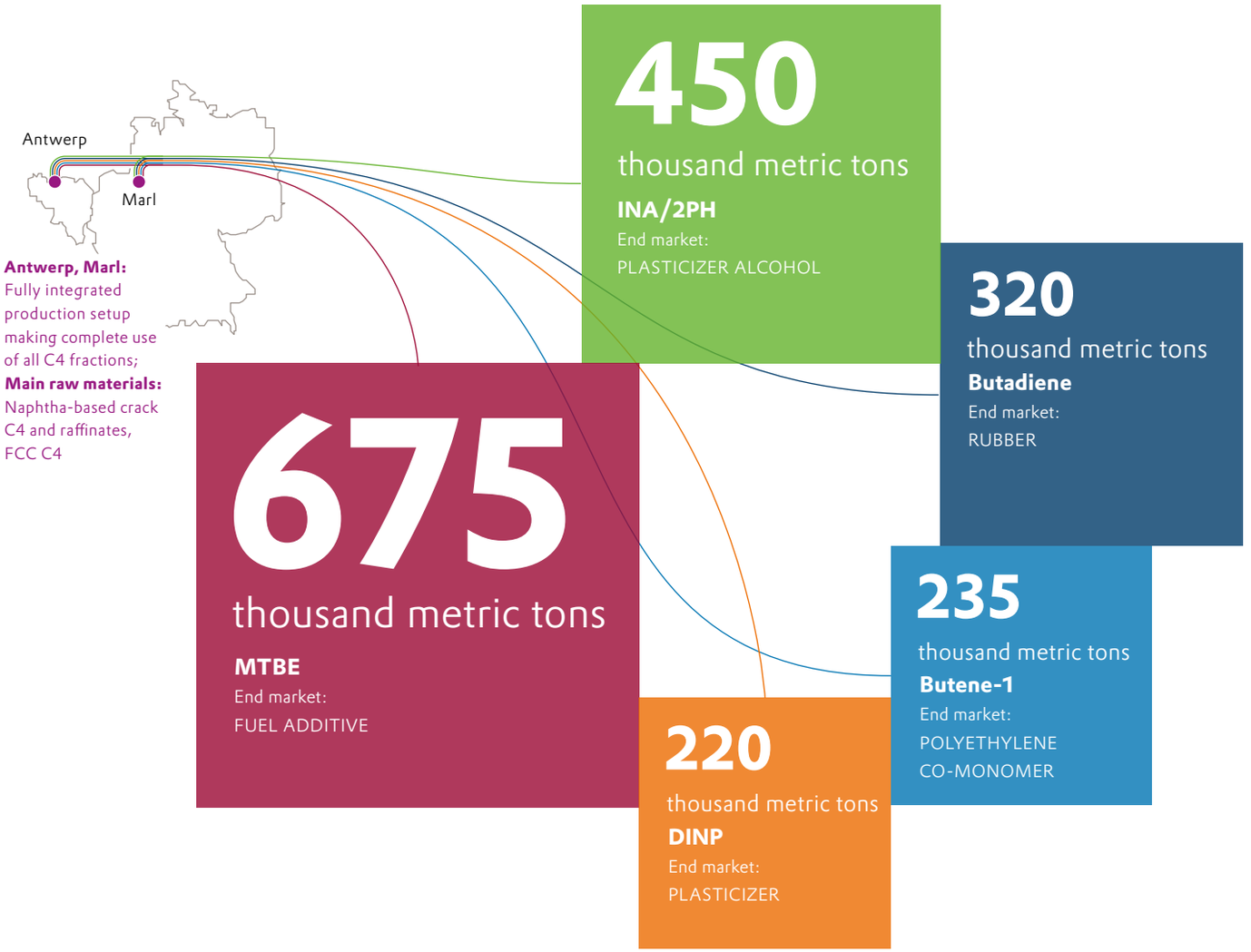
Ever since Singapore declared its independence in 1965, its government has strategically developed this country and transformed it from an emerging economy into one of the world's most modern nations. Openness to the outside world was part of the program from the very start. Major firms from all over the world were wooed with attractive business conditions. Sales offices were the first to respond, but they were followed by production facilities. Thanks to Singapore's high level of legal certainty, excellent state-financed infrastructure, and exemplary protection of intellectual property, the number of companies flocking to it increased rapidly. That also applies to Evonik. Our production plants for oil additives and amino acids will be followed this year by our research center, which will focus on future-oriented technologies such as additive manufacturing and the artificial production of human tissue cells.

This qualitative upswing was made possible primarily by Singapore's outstanding and systematic promotion of science. This tiny country, which has only six million inhabitants, can afford three national universities, as well as private colleges and various affiliates of international universities.

All of these institutions are part of a state planning system that sets itself clear goals based on science. A state-financed think tank called the Center for Strategic Futures sends its strategies and recommendations for action directly to the Prime Minister. Once a key sector has been defined, the state acts—and how! For example, the city-state has invested €5 billion to create the research and development center Biopolis in order to climb into the top ranks in the field of biomedicine. Singapore's Economic Development Board offers quick and attractive solutions for investors and companies. And an open innovation ecosystem authorizes and promotes a wide variety of cooperative projects in order to promote innovations.

Another example is Singapore's decision to become a stronghold for startups. A fund of €20 billion has been earmarked to finance the plan. The financial risks of founding a new company will be largely borne by the state. By comparison, the German government invested approximately €17 billion in research and development in 2017—although the German economy is more than 11 times as large as that of Singapore.

Of course one shouldn't ignore the downside of this rapid development. Behind all the strong guidance by the state stands a strong will to maintain control. Singapore's media are still subject to strict censorship, and its notorious criminal code is based on a desire for absolute discipline. It's also possible to activate waves of innovation like Singapore's in a more liberal social system. But in order to make that possible, we need to conduct some uncomfortable debates to their logical conclusions and then to implement the corresponding policies.



THE NEW C4 FORMULA

Evonik's Performance Intermediates Business Line produces thousands of metric tons of in-demand industrial chemicals every day. Thanks to a special purification process, the Group is the only company worldwide that can use a very special material—FCC-C4—from refineries as feedstock for this production. The researchers who developed the process have now been awarded the Evonik Innovation Prize for their work

The new FCC-C4 purification plant in the Marl Chemical Park

TEXT **FRANK FRICK**

A substantial part of production in Marl, Evonik's largest location, is based on the formula C4. It stands for liquid gases, the molecules of which contain four carbon atoms. These liquid gases are refined more and more, via a series of steps, at the C4 facilities in Marl and similarly at the Antwerp location. The products of these processes include MTBE (methyl tert-butyl ether), which is used as an antiknock additive to increase the octane value of gasoline and thus improve combustion, DINP (diisononyl phthalate), a plasticizer that turns brittle PVC into a flexible material, and butadiene, which is processed into synthetic rubber for car tires. All of the C4 facilities are connected closely together by material and energy flows. Even the byproducts of a process can be used as raw materials in other facilities, and the waste heat from one process step can supply the energy needed for another.

For decades, the production network in Marl has been using crude C4—an unprocessed stream of C4 from petrochemical plants that thermally decompose ("crack") crude oil fractions in steam or naphta crackers. The petrochemical industry uses these methods to obtain chemicals such as ethylene and propylene, as well as the crude C4 stream.

VALUED RAW MATERIAL

But the supply of crude C4 is not infinite. Thanks to the growth of the market for the secondary products, more and more competitors are taking an interest in this raw material flow. At the same time, the number of steam crackers in Europe has stagnated—as has the supply of crude C4.

Oil and gas extraction from non-conventional sources by means of fracking processes is booming in the USA, but the material extracted has a different composition from that of traditional crude oil. As a result, if the fracking material is then processed in crackers, the result is smaller quantities of lower-quality crude C4.

Increasing demand for C4-based industrial chemicals but stagnating availability of the raw material stream—Performance Intermediates recognized this dilemma ten years ago and started watching out for alternative C4 raw materials. During this time, the Business Line came across fluid catalytic cracking (FCC), a process used by refineries to catalytically crack high-boiling petroleum crude fractions into fuel components. As in a steam cracker, the resulting material stream is mainly made up of compounds containing four carbon atoms.

But there is one substantial difference in the composition: Crude C4 contains a maximum of five percent n-butane and isobutane, while FCC-C4 contains more than 25 percent of these compounds. Because these two alkanes contain exclusively single bonds, they are relatively unreactive and are difficult to process into valuable chemicals. "That would be a clear disadvantage of FCC-C4 compared to the established crude C4 as a feedstock for the Marl production network," explains Dr. Markus Winterberg, who was the project leader at Process Development and later took on responsibility for its implementation.

POISON FOR THE CATALYSTS

A further negative aspect of the FCC-C4 stream quickly became apparent in the laboratory. It poisons the catalysts used in the plants of the Marl network. That means the catalysts, which are essential for the highly efficient and economic functioning of the production processes, would become less effective within a matter of hours.

The analytical experts from Evonik had tested new detectors and developed appropriate methods of gas chromatography that use →

Talented Crude

Petroleum is more than just an energy carrier—it's also a raw material. It serves as a fuel and lubricant for cars, trucks, and aircraft, as a fuel for generating heat and power, and as a raw material for the chemical industry, which turns it into plastics, medicines, fertilizers, construction materials, detergents, cleaning agents, paints, and coatings.

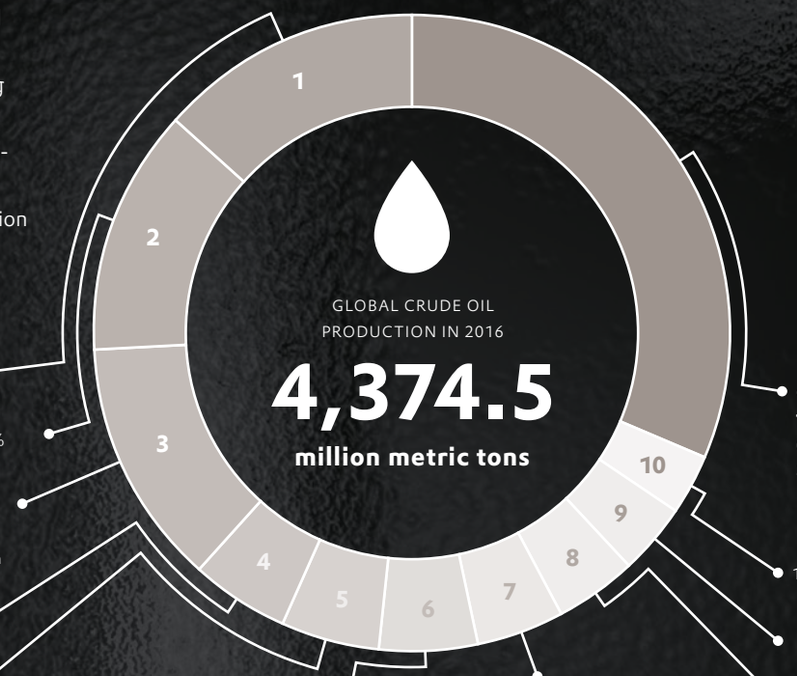
ELEMENTAL COMPOSITION OF CRUDE OIL

6 C CARBON	1 H HYDROGEN	7 N NITROGEN	16 S SULFUR	8 O OXYGEN
83–87 %	10–14 %	0.1–2 %	0.5–6 %	0.1–1.5 %

METALS: < 0.1 %

Source: G. James Speight: The Chemistry and Technology of Petroleum

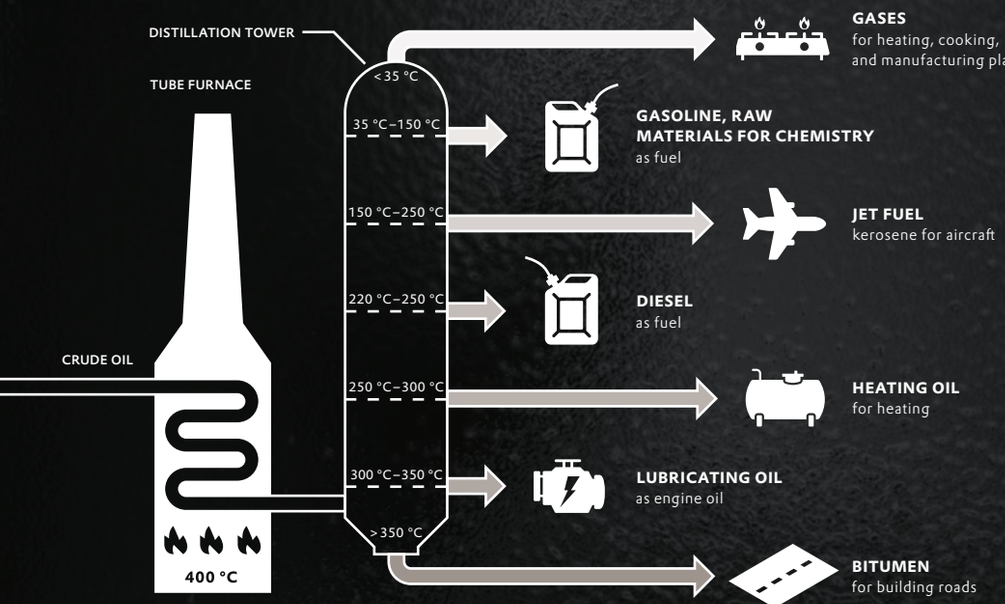
THE WORLD'S TEN LARGEST CRUDE OIL PRODUCERS IN 2016



1. SAUDI ARABIA 13.5%
589.1 million metric tons
2. RUSSIAN FEDERATION 12.5%
547.5 million metric tons
3. USA 12.4%
543 million metric tons
+ 3.6% growth due to production from unconventional sources (e. g. fracking) since 2009
4. IRAQ 5%
218.9 million metric tons
5. CANADA 5%
218.2 million metric tons
6. IRAN 4.9%
216.4 million metric tons
7. CHINA 4.6%
199.7 million metric tons
8. UNITED ARAB EMIRATES 4.2%
182.4 million metric tons
9. KUWAIT 3.5%
152.7 million metric tons
10. VENEZUELA 3.1%
134.2 million metric tons
OTHER COUNTRIES 31.3%
1,372.2 million metric tons (of which Germany 2.4 million metric tons)

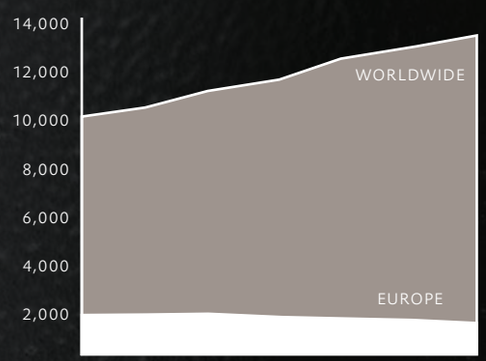
Source: BGR – Energiestudie 2017

PROCESSING OF CRUDE OIL IN REFINERIES



Source: Mineralölwirtschaftsverband e.V.

REFINERY CAPACITIES
(IN THOUSANDS OF METRIC TONS/DAY)



In Europe, the refinery capacities—i. e. the quantities of crude oil in thousands of metric tons that refineries can process in one day—have remained constant, or even fallen, since 1990. During this period they increased worldwide.

Source: BP Statistical Review of World Energy 2017

a different operating principle than the standard methods. After that approach was used, the reason for poor catalyst performance became clear. The FCC-C4 mixture contained more than 50 unwanted nitrogen and sulfur components. The new detector for nitrogen compounds is so sensitive that it can measure concentrations as low as 50 ppb (parts per billion)—that corresponds to 50 grams of nitrogen compounds in 1,000 metric tons of FCC-C4 mixture.

That laid the foundation for developing a concept to separate these components. Firstly, the boiling points and other thermodynamic properties of all of the components were determined. The data obtained about the material properties was fed into computer simulations. That made it possible to investigate which unwanted components could be relatively easily separated from the FCC-C4 flow by means of distillation.

SIMULATING PRODUCTION PROCESSES

"In the next step, we concentrated on the remaining components, which we couldn't remove by means of distillation," explains Dr. Stephan Peitz, who was responsible for carrying out the laboratory experiments as part of the process development. This step took place in experimental reactors with a maximum length of three meters and a maximum diameter of three centimeters.

The researchers fed synthetic streams of C4 into these experimental reactors—synthetic because they had added varying amounts of the impurities that they had previously discovered in the FCC-C4. "These contaminated streams of C4 enabled us to simulate and test important processes from the production network to determine how the impurities affect the catalysts and processes," says Peitz. In this way, the researchers collected information about whether and in what amounts undesired components are tolerated by the production network.

IN-HOUSE DEVELOPMENT INSTEAD OF SOLUTIONS OFF THE PEG

Sample analyses, computer simulations, and investigations of the catalytic processes were carried out in parallel and iteratively, rather than in series. Otherwise the development of an effective and economic purification process for the FCC-C4 stream within a few years would not have been possible. The original idea, to buy in an industrial-scale purification process, soon had to be given up. The purification processes available on the market either failed to adequately separate the catalyst poisons, or they were uneconomical because they used too much energy or produced too much waste.

And that's why the researchers from Performance Intermediates worked together with colleagues from Process Technology, Engineering, and Production to develop an in-house process. Its most obvious feature—and now its trademark—is the 90-meter-high distillation column in the Marl Chemical Park. The column separates isobutane and other volatile components from the FCC-C4 stream. Another process part removes sulfur-bearing impurities by chemically transforming them into higher-boiling components that can then also be removed by distillation. Additional purification stages are based on adsorption beds—large-area layers of materials that bind the catalyst poisons.

The complete purification plant went into operation in 2015 and since then has been processing several hundred metric tons of FCC-C4 per day. "Evonik is thus the only chemical company capable of utilizing this C4 stream as a feedstock for the production of specialty chemicals," says Winterberg. For this achievement, the development team was awarded the Group's own Innovation Prize at the end of 2017. The facility not only reduces the integrated production network's dependence on crude C4 but also enables an increase in the production capacities for the C4-based chemicals, which are in high demand. The process is so successful that the purification facility is currently being expanded. By mid-2018, Performance Intermediates intends to substantially increase the amount of FCC-C4 that can be prepared by the newly developed purification process and further consolidate its position as a technological leader.

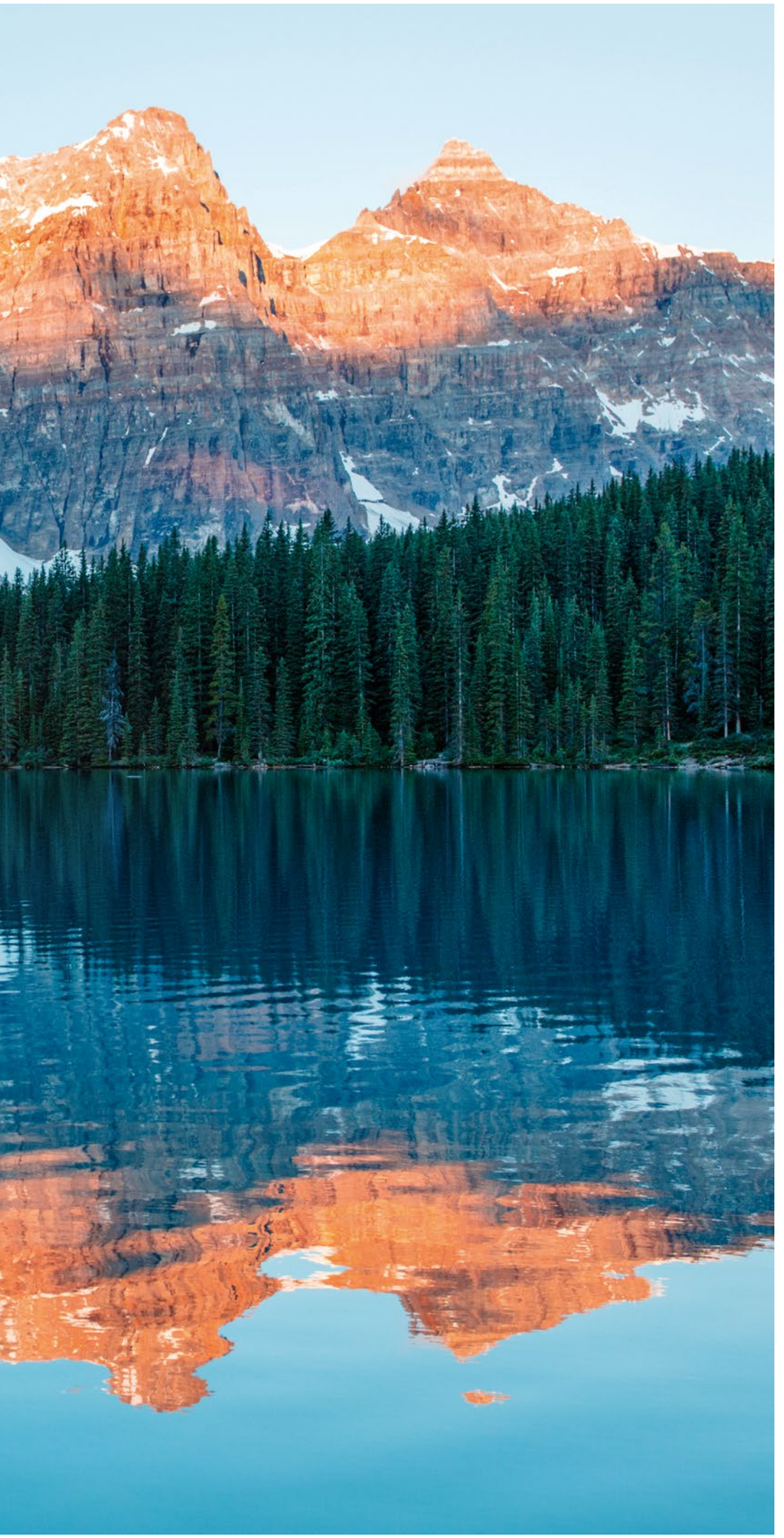
Dr. Markus Winterberg
was the project leader at Process Development

Dr. Stephan Peitz
was responsible for carrying out the laboratory experiments

Undisturbed landscapes and ultramodern major cities, a traditional nation of immigrants, and a significant supplier of raw materials: Canada is a country of diversity

The "other America" is the world's tenth-largest economy and has the world's third-largest oil reserves. Evonik and its predecessor companies have been there since 1974

TEXT **NICOLAS GARZ**



Lakes, dense forests, and mountain ranges as far as the eye can see. Canada is a dream destination for lovers of adventure. It has approximately two million lakes and 11 percent of all the forests on our planet. It's the world's second-largest country, with an area as big as all of Europe. And with a population of 37 million, Canada is one of the least densely populated countries on earth

Ice hockey is Canada's national sport. "Team Canada," the national men's hockey team, have been the world champions 26 times and Olympics winners nine times—undisputed world records. On the ice, it's not just speed and technique that count. Having the right hockey sticks is also crucial. The ideal hockey stick is both robust and as light as a feather. Inside the hockey sticks made by Bauer, a Canadian company, ROHACELL® hard foam from Evonik provides this optimal combination

The salmon catch has fed Canadians for many generations. However, today it has shrunk considerably due to the massive overfishing of the Pacific and Atlantic Oceans. Instead, Canada is increasingly depending on sustainable salmon farming. In Maitland, Ontario, Evonik produces hydrogen peroxide, which is used as an active ingredient against sea lice—and is increasingly replacing other chemical agents against parasites

Lots of options for going out, hip pubs, and international flair: Vancouver offers young people in particular a high quality of life and is also a popular college town. More than 60,000 students are registered at the renowned University of British Columbia, with which Evonik has been cooperating for years on a variety of projects. This cooperation has been fruitful: Many college graduates are now working for the Group


vogue

Nature and high tech: The town of Mankota in Saskatchewan province is surrounded by endless fields of rapeseed, but that's not all. This is also the site of a unique gas separation plant that is used by the US-based Weil Group to extract ultrapure helium from natural gas. The plant was built by Linde Engineering, and the SEPURAN® membrane technology it uses comes from Evonik

REACHING CUSTOMERS QUICKLY IN SPITE OF LONG DISTANCES

Evonik has three production facilities in Canada. In Maitland and Gibbons, they produce hydrogen peroxide, which is used by the region's cellulose industry to develop sustainable packaging materials. In Morrisburg, the Group produces VISCOPLEX®, a resource-conserving flow improver for lubricants. In addition, Evonik is doing research in Canada, primarily on applications in the healthcare sector.

Evonik locations

1 Morrisburg
2 Maitland
3 Burlington
4 Gibbons
5 Burnaby - North Fraser Way
6 Burnaby - Northbrook Court

At

6

locations in Canada, Evonik has about

180

employees

Better than Real

TEXT **CHRISTA FRIEDL**

Artificial leather is booming, but its production is currently not very sustainable. Researchers have developed an additive that paves the way for environmentally friendly production processes

Even experts can hardly distinguish artificial leather from the real thing at first glance. The look, structure, and feel of this product now comes very close to its natural model. As a result, artificial leather has become an integral part of our daily lives. It can be found in sofas and dentist's chairs, luxury handbags and car seats, shoes and clothing. And sometimes it's even better than the original—in surfaces that are exposed to intense mechanical stress, ultraviolet light or saltwater, or in medical equipment that needs to be frequently disinfected.

High-quality material rather than a cheap imitation: The image of artificial leather is changing. It's also benefiting from people's heightened environmental awareness. Processors and consumers are increasingly attaching importance to production methods that harm neither people nor the environment—an expectation that is seldom fulfilled by genuine leather. "Vegan" leather is also popular with shoppers who reject animal products in general.

This has resulted in the steadily growing use of imitation leather. In 2016 the annual worldwide production of artificial leather amounted to about 3.5 million tons. If all of it were to be rolled out in a single piece, it would cover an area equal to the German federal states of Berlin, Hamburg, and Saarland. Asia is the Number One producer of artificial leather, with 85 percent of the annual tonnage coming from China.

A multilayered composite

Artificial leather is a multilayered composite material. It consists of a textile carrier covered with a layer of porous polymer—a type of foam that determines the thickness, feel, and durability of the material. The polymer layer is covered by a wafer-thin topcoat, which is responsible for the product's color and surface characteristics. In about two thirds of the artificial leather manufactured world- →

wide —or approximately 2.4 million tons— the porous layer consists of polyurethane (PU). Compared to the alternative material PVC, PU feels softer, offers a wider spectrum of characteristics, is lighter and more breathable, and regulates heat more effectively. For Evonik, which is the market leader for PU additives, the artificial leather market is thus an attractive sector.

More than 95 percent of the annual tonnage of PU additives is produced with the help of DMF coagulation. In this process, PU and the organic solvent DMF (dimethylformamide) are used to produce a paste that is spread onto the textile carrier. The PU content of the paste often amounts to 30 percent. The layered textile is soaked in a series of baths consisting of a mixture of water and DMF that wash the solvent out of the paste. During this process, the PU coagulates to create a firm porous layer. The material is then washed once again in order to remove the last DMF residue, dried, and covered with a topcoat. In 2014, more than 550,000 tons of DMF were used for the production of imitation leather in China. It is estimated that by 2019 that figure may increase to 660,000 tons per year.

A technological change has begun

However, DMF is not a good choice for human beings and the environment. According to the European Chemicals Regulation REACH, this solvent is a substance of very high concern and is classified as toxic for reproduction. DMF also presents risks because it is often not sufficiently recycled in artificial leather factories and thus can enter the environment. In addition, residues of this solvent remain in the end product in spite of repeated washing. And finally, the standard manufacturing process consumes large amounts of water and energy.

These negative side effects have motivated a shift to a different technology. The Chinese government aims to reduce the use of DMF by 30 percent by 2020. Pressure is also coming from the artificial leather processing industry, which is increasingly demanding DMF-free materials. Moreover, international initiatives are calling for a ban on hazardous chemicals in textiles or a further reduction of the permissible limit values for DMF in finished products.

This pressure to reduce the use of DMF is opening up corresponding space for environmentally friendly non-toxic alternatives—also in countries other than the main producer, China. Water-based production processes in particular, which have so far represented a niche market, could experience an upswing. According to some forecasts, water-based processes could take over at least 20 percent of the artificial leather market in the coming four to five years.

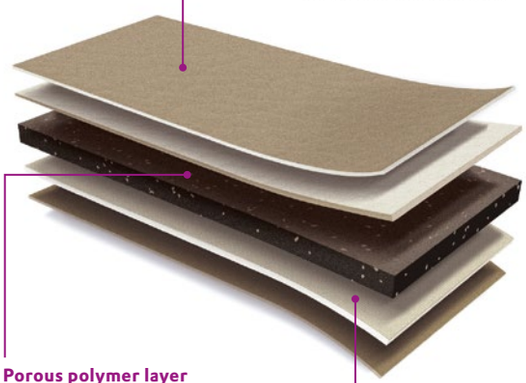
More environmentally friendly alternatives

From Evonik's perspective, the PUD process is especially interesting. It begins with the manufacture of an aqueous PU dispersion (PUD) with an approximately 50 percent proportion of polymer microparticles. The dispersion is foamed, and the foam mass is then spread onto the carrier at room temperature. The material is then dried within a few minutes at a temperature of 100 °C, covered with the topcoat, and finished.

But so far this alternative, which is much more environmentally friendly, has only played a subordinate role in the market. One →

MULTIPLE LAYERS

Artificial leather is a multilayered composite material. Each of the layers is responsible for certain properties of the material



Topcoat
This provides the color and the surface characteristics

Porous polymer layer
The polymer foam determines the thickness, feel, durability, breathability, and heat conductivity of the material

Textile carrier
This gives the artificial leather the desired stability and flexibility

Artificial leather can be used almost everywhere—for car seats, handbags, the outer material of shoes, or a comfy spot for the family pet. It is used for the same applications as leather, but it's less expensive, more robust, more weatherproof, and easier to clean. It dries out without hardening—an especially important advantage for products used outdoors, such as shoes.

Smell

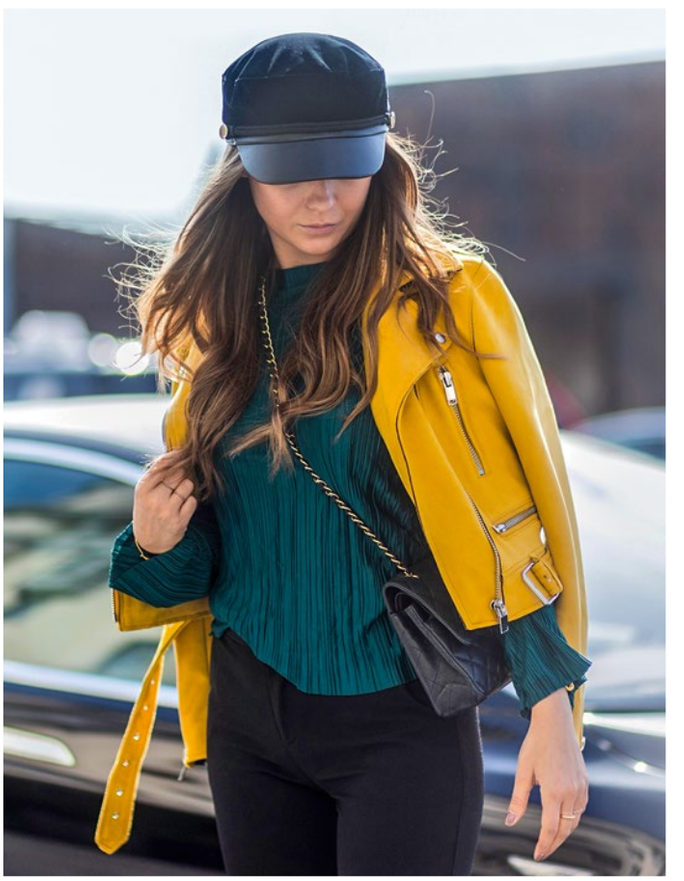
For years, artificial leather was characterized by its chemical smell, but today it's hard to distinguish between it and real leather.

Durability

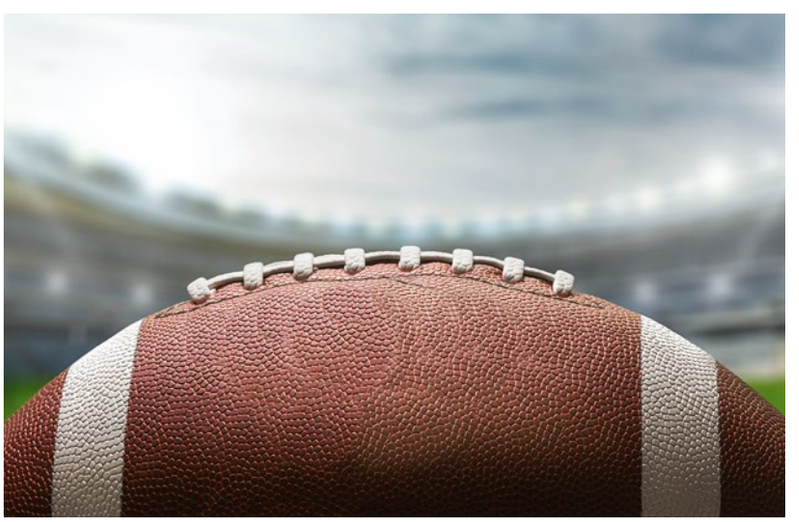
Most high-quality artificial leathers are resistant to water, coffee, and dirt.

Processing

Stable, tear-resistant, and easy to process: Artificial leather is easy to sew and glue.



We want artificial leather to be a perfect imitation of genuine leather. For clothing, we mainly want soft material that is pleasant to wear, supple and, above all, machine-washable.



Feel

High-quality artificial leather generally feels exactly like real leather.

of the reasons for that is the inadequacy of the necessary process additives—surfactants and foam stabilizers—which are added to the production process in only small amounts but play a key role in determining the quality of the final product. The additives that are used most often today react sensitively to hard water, are incompatible with certain crosslinking agents, and migrate to the surface of the material, where they form unsightly spots or an unpleasant greasy film. In addition, the surfactants that have been used to date often result in very course foam structures and do not sufficiently stabilize this foam during the production process.

These are the issues that were addressed by the researchers at Evonik. They have now developed an additive that does not have any of these negative side effects, but instead offers additional advantages. "It optimizes the pore structure of the polymer, accelerates the production process, conserves energy, and lends the artificial leather the desired high quality," explains Dr. Michael Klostermann, who is responsible for the technical product development of the new additive.

Fine and uniform pores

The new additive, which is being marketed as ORTEGOL® P 1, is an organic non-ionic surfactant—a product group about which Evonik possesses extensive know-how. Among other things, organic non-ionic surfactants are used as highly effective emulsifiers for skin creams and lotions. Emulsifiers have functions that are very similar to those of surfactants: They disperse materials and stabilize one phase in another. This results in large surface areas that play a key role in determining the characteristics of the end product. Through ORTEGOL® P 1, Evonik has now made the way in which these surfactants work usable for the production of artificial leather too.

The new additive is added to the PUD dispersion before the foaming process in quantities of just a few percent of the total mass. The function of the additive is to keep the foamed dispersion on the carrier stable until it has completely dried into a foam. That's the only way to create the fine and uniform pores that make artificial leather soft, smooth, and supple. Tests carried out in cooperation with artificial leather manufacturers have shown that ORTEGOL® P 1 is equal to this task. It stabilizes not only the individual air bubbles but also the continuous phase of the aqueous foam.

Energy use is reduced by 50 percent

"The additive can do even more. During the production of artificial leather, it significantly improves the balance of energy, raw materials, and emissions," says Dr. Kai-Oliver Feldmann, who is responsible for coordinating the contacts between product development and technical customer support. Compared with the DMF coagulation process, the new procedure saves producers about half of their energy consumption and also drastically reduces emissions. The new additive is based on renewable raw materials, and that's a further advantage by comparison with DMF.

ORTEGOL® P 1 has been produced in Duisburg since the end of 2017 and is already being used by the first group of customers in Germany and China. And P1 is only the beginning. Evonik is currently working to develop additional types of ORTEGOL® P that enable customers to precisely adjust the pore size, density, and flow properties of the foam and thus determine the performance of their artificial leather. The aim is to ensure that the ORTEGOL® P family can cover the entire spectrum of applications in the artificial leather market.

Evonik is launching the new additive on the market at a time when the artificial leather industry is changing and searching for alternatives. ORTEGOL® P 1 is the first successfully tested candidate from a group of surfactants that make water-based processes practicable and environmentally friendly. As a result, Evonik is successfully addressing the requirements of manufacturers and consumers who set great store by high-quality artificial leather and also expect that its production will not harm people and the environment.

"The additive optimizes the pore structure of the polymer and lends the artificial leather the desired high quality"

MICHAEL KLOSTERMANN

Glossary

Dimethylformamide (DMF) is an organic solvent that is often used in the production of polymers such as polyurethane

DMF coagulation is a process of layering in which a paste made of polyurethane resin and DMF is spread onto a textile carrier and the DMF is then washed out in a series of baths. The polyurethane continues to adhere to the textile and hardens there

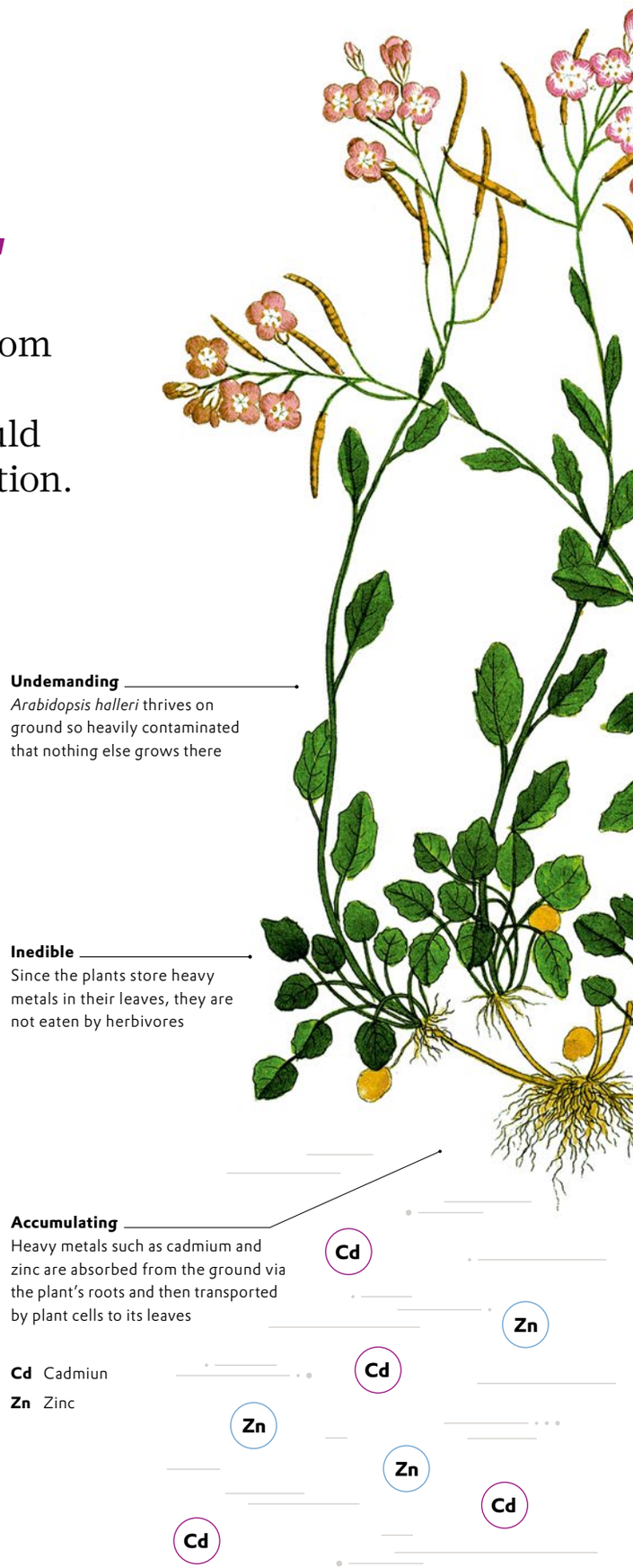
Polyurethanes (PUs) are versatile plastics or artificial resins. Today they are used in the production of high-quality artificial leather, among other things

PVC (polyvinyl chloride) is one of the most important polymers for the production of plastics. Since the 1940s it has also been used to produce artificial leather

FRESHLY PICKED CADMIUM AND NICKEL

Harvesting nickel? Extracting cadmium from contaminated soil with a simple ecological trick? Certain plants can do this. They could simplify land remediation and metal extraction. That's why researchers are very excited

TEXT **BJÖRN THEIS**

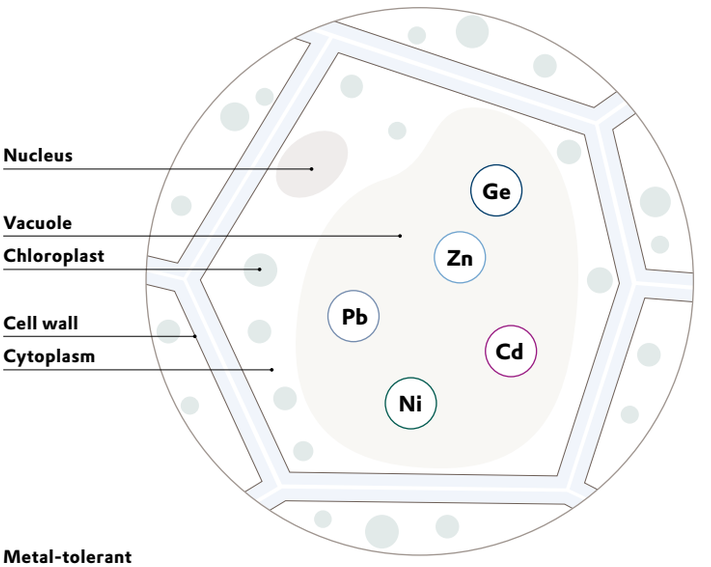


Mining is not usually associated with green fields. The classic picture is of winding towers, strip mines, scarred landscapes, and contaminated ground. In Germany alone, substantial tracts of land on and around disused mine workings and former industrial sites are heavily contaminated with nickel and cadmium. Nationwide, it is estimated that about 20 percent of Germany's land surface contains such high levels of heavy metals that it would be unsafe to grow fruit or vegetables.

Were it up to Alan Baker, a retired English botany professor, these areas would have long ago been restored to a clean, green, and fertile state. It was as a student, while exploring the site of a disused mine, that he first noticed that some plants were thriving despite the heavily contaminated soil. He began to investigate and, together with the US agronomist Rufus Chaney, identified what came to be known as hyperaccumulators: plants that absorb heavy metals from the soil and store them in high concentrations in their leaves. An example is a species of rock cress known as *Arabidopsis halleri*. This plant stores cadmium and zinc in such large quantities that it can be used to remediate industrial wastelands.

RECULTIVATION AND PHYTOMINING

Baker and Chaney recognized at once that these plants do more than make contaminated ground fit for recultivation. That's why they coined the term "phytomining." What these plants also do is to extract metals from the soil. In other words, they offer a simple, sustainable, and cost-effective way of producing raw materials. In an



Metal-tolerant
The heavy metals accumulate in the central vacuoles, which are present in all plant cells. The plants are unharmed by the poisonous metals

experiment conducted in the 1990s, the two scientists extracted 100 kilograms of nickel from 500 kilograms of plant ash. In the face of rising prices and restricted access to some heavy metals such as rare earths, phytomining could well become a lucrative business.

Years passed before an industrial use of hyperaccumulators became an option. That's because Baker and Chaney's research was financed by an investment company, Viridian Environmental, which secured the rights to all patents resulting from their work. Despite major interest from the business community, Viridian consistently blocked any commercial exploitation of phytomining.

RENEWED INTEREST FROM RESEARCH

But now the patents have expired and researchers are once again examining the potential of hyperaccumulators. Given the growing need for certain metals, especially in the electronics sector, and ever stricter environmental regulation of the mining industry, phytomining is becoming an increasingly attractive commercial proposition. The agronomist Guillaume Echevarria, for example, has shown that the plant yellowtuft (*Alyssum murale*) accumulates nickel salts and nickel oxides. Similarly, the chemistry professor Marie-Odile Simonnot is searching for plants that accumulate precious metals such as platinum and palladium.

Evonik retains an interest in the mining business via its subsidiary Cyplus, one of the world's leading companies in the production and use of cyanides, which are used to extract heavy metals such as gold and silver from their ores. Given its major economic and ecological potential, the Corporate Foresight team at Evonik's innovation unit Creavis has taken a closer look at phytomining as part of its game-changer analysis "Low-impact Mining." Who knows, one day the scarred landscapes of former strip mines may be decked in a carpet of flowers.

Björn Theis is the Foresight Manager at Evonik's innovation unit Creavis. An ethnologist by training, he also teaches in the master's degree course in Future Studies at FU Berlin.

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Hydrogen

“My Fate Depends On Hydrogen”

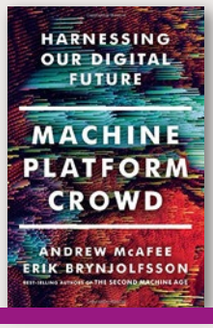
PROTOCOL **NADINE NÖSLER**
PHOTOGRAPHY **RUBEN WYTTENBACH**

Kurt Frieden
has been ballooning with his teammate Pascal Witprächtiger since 2008. As a child, he was fascinated by hot-air balloons, often chasing after them for hours and hours on his bicycle. Indeed, his obsession even caused him to miss school at times

My most exciting balloon trip to date was from England across the North Sea and on to Finland. It’s a trip that takes you across a huge expanse of water. Sometimes you look down and think: If we were to plunge out of the sky, we wouldn’t survive—my teammate, Pascal Witprächtiger, and I. It makes you shiver. Our fate depends entirely on a balloon filled with hydrogen. Hydrogen is the lightest element on earth, much lighter than air. It is this property that enables a hydrogen balloon to take off from the ground and fly through the air. The thing about ballooning is that the only way of steering is by means of ballast. This is how you regulate altitude so as to find the right current of air to take you forward. This is the great challenge in the Gordon Bennett Cup, the world championships in gas ballooning. The team that covers the greatest distance wins the contest. One time, we covered 3,500 kilometers, which took us 77 hours. There are two of us in the basket, and we each do four-hour shifts piloting the balloon. Apart from that, there’s plenty of time to enjoy the peace and quiet—and of course the spectacular view. It’s moments like these that make ballooning so enjoyable. After a race, when we’re back again on firm ground, the first steps always feel a little bit funny. Of course we’re also relieved that everything has gone well. But our dream is to stay up in the air for 100 hours. Nobody has ever achieved that, and that’s our goal! Despite the great distances you cover and the long hours you spend in the air, time just “flies” by when you’re up in a balloon.

On the next phase of digitalization, the opportunities offered by blockchain technology, and the power of mathematics

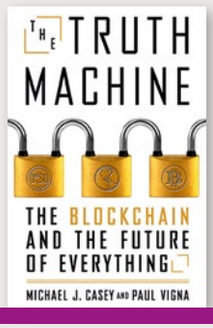
TEXT **NIELS BOEING**



The Age of Machines

Andrew McAfee and Erik Brynjolfsson, economists at the MIT Sloan School of Management, foresee a technological tsunami more dramatic than the rise of the Internet. Unleashed by the breakthrough in machine learning, the development of global platforms such as Amazon, and the global crowd of users able to access a huge fund of information at a moment's notice, it will revolutionize the way we do business. Ingenuity, great products, and an expert team will no longer suffice to guarantee commercial success. McAfee and Brynjolfsson already caused a stir in 2012 with *Race against the Machine*. Now they are plotting the next chapter in the story of digitalization.

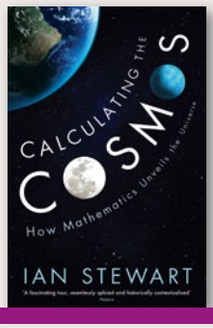
Andrew McAfee & Erik Brynjolfsson
Machine, Platform, Crowd: Harnessing Our Digital Future
W. W. Norton & Company, 2017



The Age of Trust

Everyone's talking about bitcoin, but the technology behind it is much more revolutionary. For Michael Casey and Paul Vigna, blockchain technology marks a break in economic history. That's because it replaces an accounting practice—double-entry bookkeeping—that had shored up faith in financial transactions for over 500 years—until, that is, the financial crash of 2008 revealed that the banks had been fiddling their books. In the age of globalization, Casey and Vigna argue, blockchain could help restore this trust—and, in the process, make diverse things like land registries, supply chains, and copyright more transparent and secure. *The Truth Machine* offers a pleasingly reflective view of one of the most important new technologies of our time.

Michael Casey & Paul Vigna
The Truth Machine. The blockchain and the future of everything
St. Martin's Press, 2018



The Age of Equations

Our picture of the universe is like a huge jigsaw puzzle. Over the past 300 years, scientists have found an impressive number of pieces and inserted them in the right places. Many of these pieces bear the names of brilliant physicists. Less well known is how mathematics has contributed to determining just where these pieces fit. "Mathematics is a very powerful inference engine," writes the British mathematician Ian Stewart, a master in works of popular science. He shows how the investigation of the stars gave rise to powerful mathematical tools such as differential calculus, and how mathematicians can use equations to discover things that remain invisible to a telescope, such as black holes and gravitational superhighways. Not an easy read, but very stimulating.

Ian Stewart
Calculating the Cosmos
Basic Books, 2016

Masthead

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Location, the holy grail of innovation

…was recently praised by the US magazine *Wired*. Evonik too believes that the conditions offered by certain locations promote creativity, and that face-to-face communication is needed in order to develop innovations.

This new issue of ELEMENTS focuses on innovations and on regions—specifically, on an all-rounder plastic from Marl, a technology leader in 3D printing from Leuven, Belgium, and an innovation cluster in Singapore. Creative teams in certain places drive developments that then go on to benefit many sectors and people. That's what Evonik means by innovation.

2/2018 **Polyamide 12**