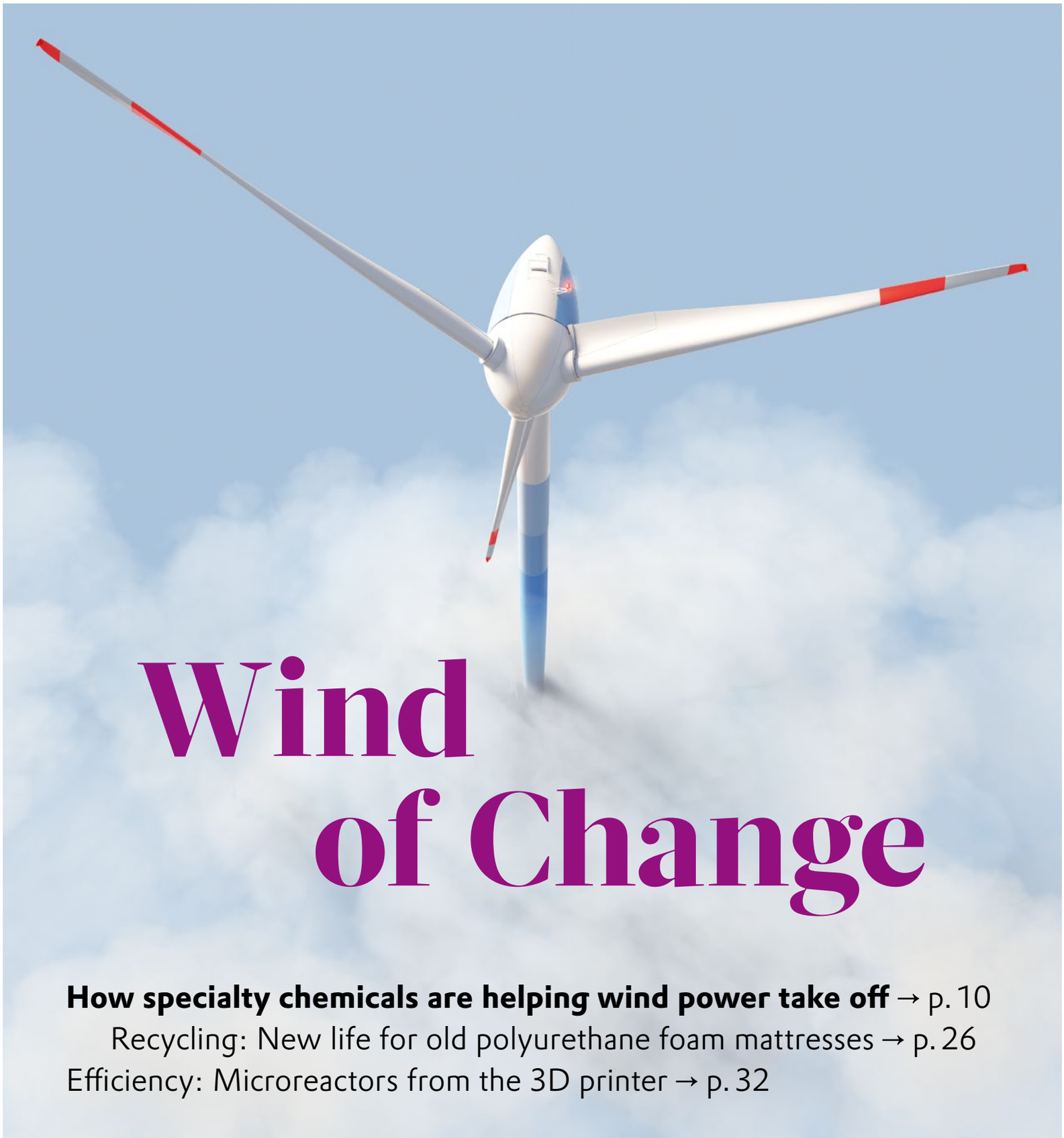
1/2022

EVONIK
Leading Beyond Chemistry

ELEMENTS

Research. Knowledge. The future.



Wind of Change

Offshore

At sea near a coast

"Offshore" refers to the location of constructions on the open sea. In many cases, this applies to drilling platforms for extracting petroleum or natural gas. It can also apply to wind farms. Placing these constructions on the open sea offers many advantages. Drilling platforms expand the extraction area for raw materials, and wind turbines benefit from stronger and more constant winds that enable higher electricity yields. As a rule, offshore wind farms are located no further than 200 kilometers from the mainland, because they depend on an expensive connection by means of undersea cables. At water depths of 50 meters or less, wind turbines that stand on a firm foundation are generally used. At greater depths, models with floating bases anchored to the sea floor are more practical. The world's biggest offshore wind farm is the Jiuquan Wind Power Base in China, which has a planned installed capacity of 20 gigawatts.

Wind farm An array of several wind turbines in one location.
Foundation The foundation provides the stable base of a wind energy plant. Offshore foundations can consist of concrete, steel pillars or multiple-leg structures.
Gigawatt A measuring unit for the output of a power plant. One gigawatt corresponds to one billion watts.

DEAR READERS,

The "arms race" between the USA, China, and Europe is in full swing. It's all about height, length and, above all, having the most power. Fortunately, it's not all about weapons.

On the contrary, it's all about climate protection and the power supply of the future. It's all about the next generation of wind power. Devices that used to be quaintly associated with pinwheels and windmills today deserve to be called wind turbines. These masterpieces of the engineer's art rise up to the sky at heights of way over 200 meters, and the individual rotors are over 100 meters long.

Their yield of power is not the only feature that increases together with their height. The wind turbines themselves are subject to forces that are increasing to dangerous levels. That applies especially to the wind parks on the high seas. Without new and innovative solutions from the specialty chemicals industry, these materials could no longer stand up to the permanent stress of seawater and storms.

But the wind turbines are standing up to the challenge—and delivering vast amounts of power around the clock. In this issue we explain how they do it and why the potential of wind power is far from being fully exploited.

And before we forget—we also explain why old mattresses made of polyurethane foam will no longer have to be incinerated in the future. Instead, they'll be repeatedly reborn. But that's another story.

I wish you a thought-provoking read.

Matthias Ruch
Editor in Chief

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

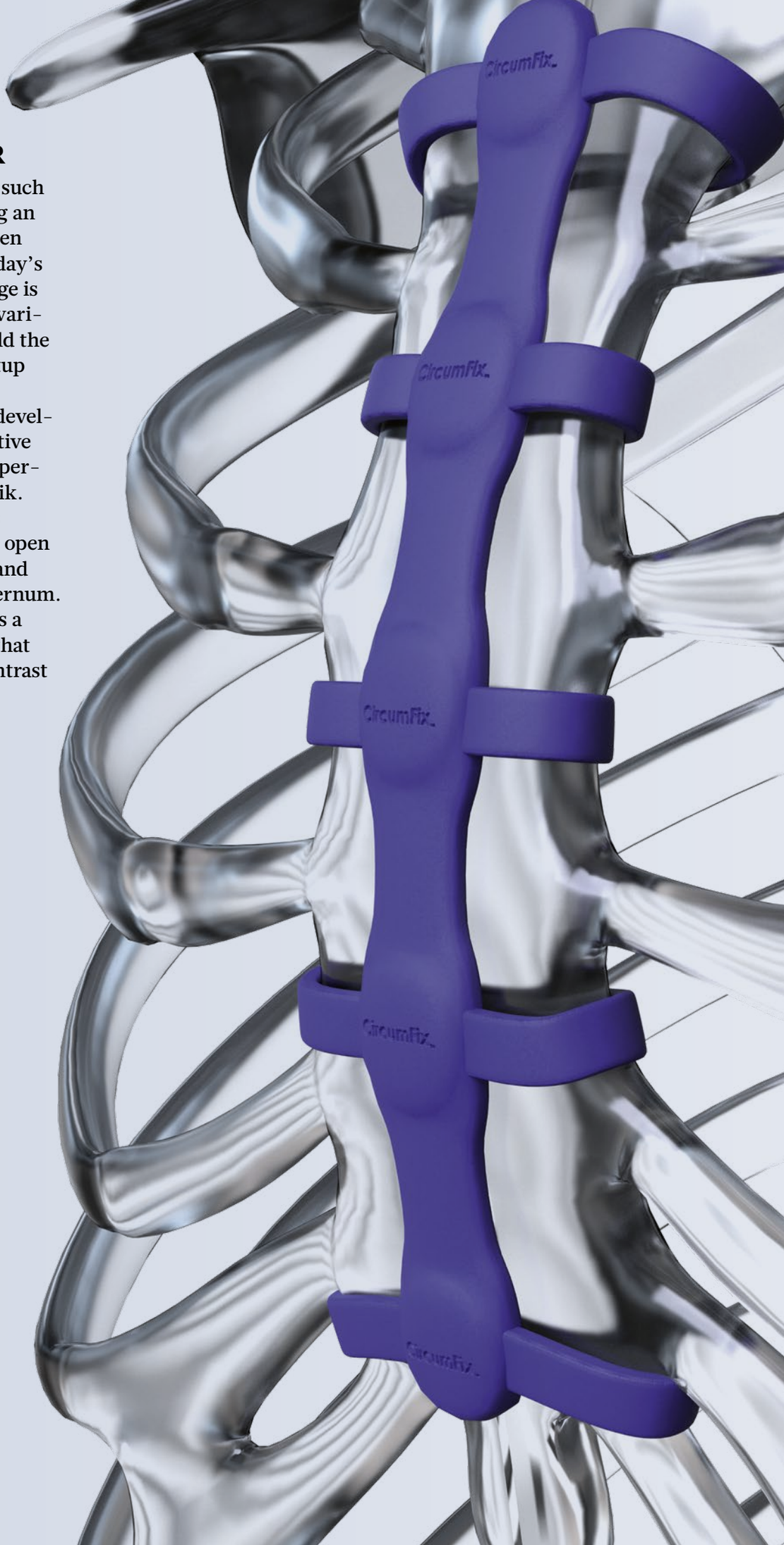
The future of wind energy is on the open sea—for example, here off Germany's Baltic Sea coast

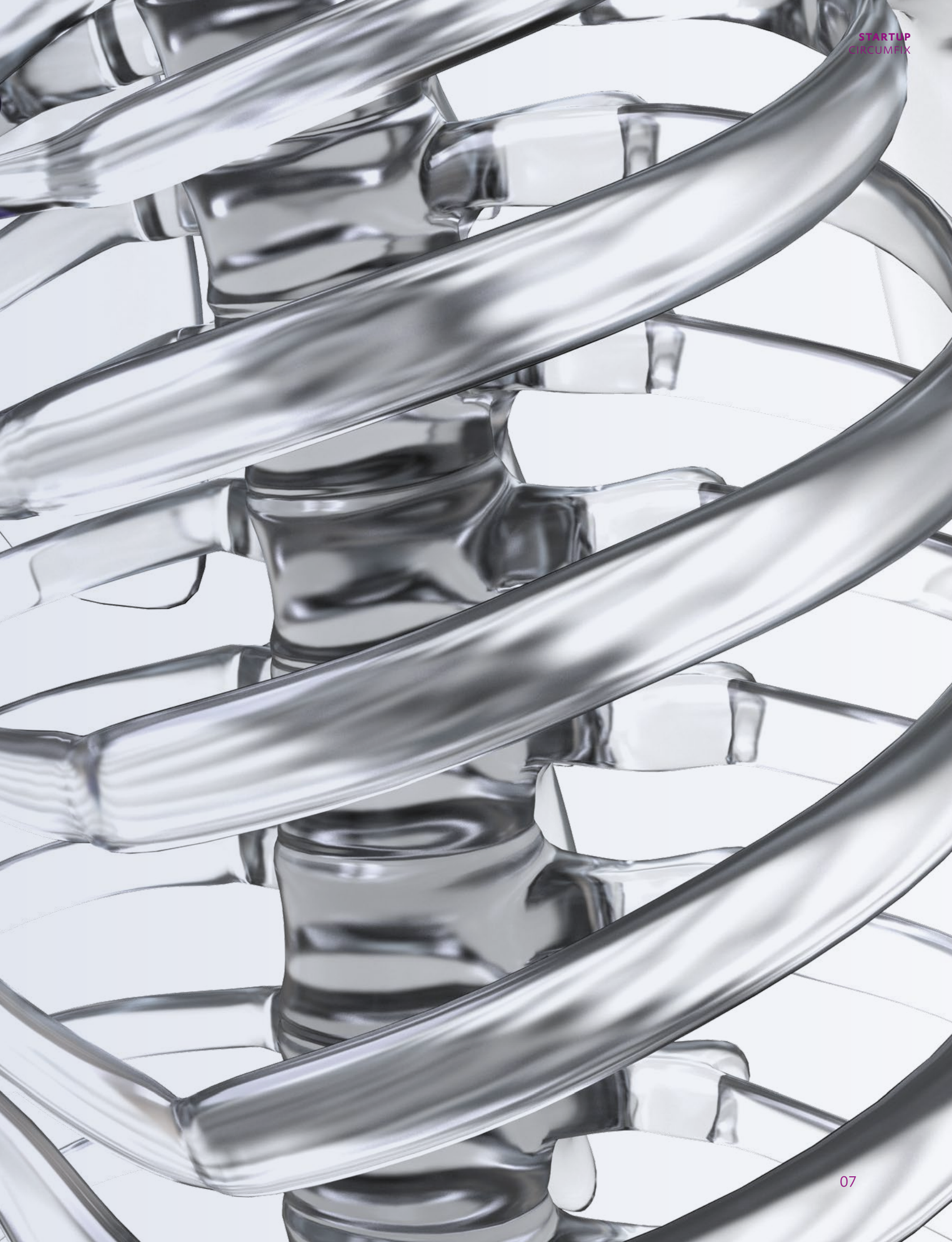
Annegret Terheiden and Michael Ferenz are researching processes for recycling foam for mattresses at Evonik

On the way to a reactor made by a 3D printer

HOLDING TOGETHER

In order to reach major organs such as the heart or the lungs during an operation, surgeons have to open up the patient's rib cage. In today's standard procedure, the rib cage is closed up again by means of a variety of metal structures that hold the sternum together. The US startup CircumFix Solutions, in which Evonik recently invested, has developed an alternative: an innovative rib cage closure made of high-performance polymers from Evonik. This medical product promotes healing after operations on the open rib cage by effectively closing and permanently stabilizing the sternum. The CircumFix locking device is a safe and comfortable implant that spares bones and tissue, by contrast to metal fasteners.





A pile of rubble makes history

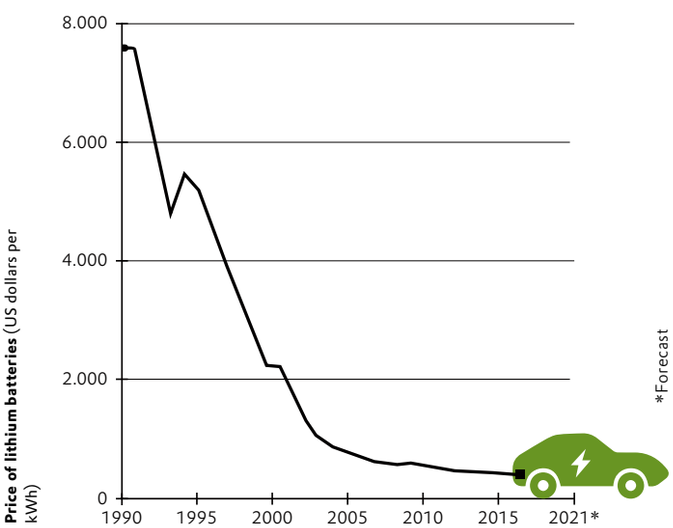
A Swiss startup is turning concrete rubble into high-quality limestone that also stores carbon dioxide

Recycled or fresh? The source of the ingredients has a big impact on the CO_2 balance of concrete

Concrete largely consists of cement, whose production accounts for around seven percent of global greenhouse gas emissions. The Swiss startup Neustark has now greatly improved the poor CO_2 balance of this ubiquitous construction material. The team headed by Johannes Tiefenthaler and Valentin Gutknecht has developed a technology that extracts carbon dioxide from the atmosphere and locks it up in concrete rubble, which is primarily created by the demolition of buildings. When CO_2 reacts with the calcium hydroxide in concrete, it results in new high-quality limestone that can replace newly produced cement in the production of fresh concrete. This technique enabled the company, which was outsourced from the Swiss Federal Institute of Technology (ETH) in Zürich three years ago, to improve the climate performance of fresh concrete by 10 percent. Neustark's next plan is to make climate-neutral concrete a reality by 2025.

THAT'S BETTER

Electrified



Inexpensive lithium batteries are making electric vehicles cheaper and thus more competitive against automobiles equipped with combustion engines. The cost of these energy storage devices has dropped by 98 percent over the past three decades. They currently cost around US$110 per kilowatt-hour. Things will get interesting once the price drops below US$100. According to the analytics firm BloombergNEF, this would enable electric cars to be offered at the same price as gasoline-powered vehicles. According to forecasts, this will become possible in 2024.

Source: BloombergNEF

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PERCENT

of all the steel ever produced worldwide is still in use, thanks to its durability and its material composition, which makes it ideal for recycling. Steel can be completely recycled without any decline in quality.

THERMOSETS...

...are plastics that cannot be reshaped after they have hardened. They include resins and adhesives that are important for automobile production, for example. Thermosets are made from fossil raw materials and can be recycled to only a limited extent. Researchers at the University of Stockholm have now developed a new lignin-based material. Lignin is a waste material resulting from paper production. Its behavior is similar to that of a thermosetting plastic, but moderate heating allows it to be put back into its original shape. The material's properties can also be changed, depending on how much lignin is used. This increases its versatility.

On the trail of nature

The noses of camels inspired researchers to develop a sensor that can detect sources of moisture

Thanks to their unique properties, camels can survive in the hottest and driest places on earth. Their sensitive noses help them to detect sources of water, for example. This inspired a team headed by the Chinese researchers Weiguo Huang and Jian Song to develop an innovative moisture sensor. Previous models aren't very good at detecting the presence of water, and they are extremely sensitive to sunlight. In order to solve this problem, the researchers created a porous polymer network that imitated the large surface within a camel's nose. On this network, they placed moisture-attracting molecules, known as zwitterions, which have similar properties to the animals' nasal mucus. The result is a durable moisture sensor that helps identify water sources and can also detect fluctuations in humidity in hot industrial exhaust gases and the moisture emanating from the human body.

PEOPLE & VISIONS

"Artificial intelligence will play a key role for biotechnology"

THE PERSON

In her master's thesis, which has received two awards, the biotechnologist **Laura Helleckes** shows the potential of artificial intelligence (AI) for a more efficient development of bioprocesses. The researcher developed her fascination for microbial processes at school, which prompted her to study biotechnology at RWTH Aachen University. Important milestones in her career were a semester abroad in Helsinki and her final thesis at Forschungszentrum Jülich. There, as a member of the Microbial Bioprocess Lab, she is continuing this research in her doctoral studies with a focus on laboratory automation and process modeling.

THE VISION

In a bioprocess, microorganisms or their components are used to produce chemical or biological products. Helleckes wants to understand these processes in detail. For the researcher, the solution is **digitalization**. "AI and especially the sub-area of machine learning will be a key for biotechnology," she says. Laboratory robots supply so much data that manual evaluation becomes impossible. With the help of AI, this data can now be used in the course of a bioprocess and not just after it has been completed. Helleckes employs her models to analyze this data and then uses this knowledge to create optimized bioprocesses.

GOOD QUESTION

"Can we fuel cars with sugar in the future, Dr. Wang?"

The key to this are olefins—gasoline components that are, among other things, precursors for polymers, plastics, and lubricants. Until now, olefins have been derived almost exclusively from crude oil, but using new technology we are making them from glucose, which is produced naturally during photosynthesis. In a two-stage process, we first alter *E. coli* enterobacteria, which live in the large intestines of humans and many animals, so that they convert glucose into 3-hydroxyoctanoic acid and decanoic acid. In step two, the 3-hydroxyoctanoic acids are converted into olefins by means of heterogeneous catalysis. The goal is now to adapt the method so that we can also use it to produce alkanes, the main component of gasoline.

Dr. Zhen Wang, an assistant professor of biological sciences at the University at Buffalo (SUNY), co-authored a research paper titled "A dual cellular-heterogeneous catalyst strategy for the production of olefins from glucose."

OCEAN GIANTS

“We’ve managed to launch a green rotor blade on the market”

MARTIN GERHARDT, HEAD OF OFFSHORE WIND PRODUCT MANAGEMENT AT SIEMENS GAMESA

Huge offshore wind turbines are scheduled to spur the energy transition worldwide. Materials from Evonik are opening up new dimensions of electricity generation

TEXT **CHRISTOPH BAUER**

There’s almost always enough wind at sea. The latest generation of offshore power plants have capacities of over 14 megawatts

Cold Hawaii” is the name that wind surfers have given the 55-kilometer stretch of coast in northern Denmark that extends from Hanstholm in the north to Agger in the south. Here, in the Thy National Park, there is a steady and strong westerly wind that the surfers love. Thirty kilometers farther east is a hotspot for wind fans of a very different kind. At the test center in Østerild, seven huge wind turbines are being tested for their offshore use. The biggest of them, a model from Siemens Gamesa, is exactly 271.40 meters tall. As a result, it has replaced the 254-meter-high Storebælt Bridge as Denmark’s tallest structure. Since November, the turbine has been undergoing preparations for its commercial use, which is scheduled to begin in 2024.

Each of the record turbine’s three rotors is 108 meters long and covers a surface of 39,000 square meters with each sweep. That’s almost the size of six soccer fields. “The larger a rotor and its sweep, the more clean energy the turbine generates,” says Martin Gerhardt, the head of Offshore Wind Product Management at Siemens Gamesa. However, this record won’t last long. The world’s four largest offshore wind turbine companies—besides the German-Spanish company Siemens Gamesa, they are Vestas from Denmark, GE Renewable Energy from the USA, and Mingyang Smart Energy from China—are competing intensely with one another to erect the most powerful turbine. The winner is definitely the environment. Together with photovoltaic systems and hydropower plants, wind turbines contribute considerably to the global energy transition.

The performance data of the current turbines was still unthinkable a few years ago. For example, the wind turbine from Siemens Gamesa in Østerild has a capacity of 14 megawatts and can even achieve a peak performance of 15 MW. Vestas wants to present a model this year that will supply 15 megawatts in continuous operation. However, a lot of wind is needed to drive the huge rotors and this wind is mainly available on the high seas. “We have to make offshore wind power the backbone of decarbonization,” says Gerhardt. →

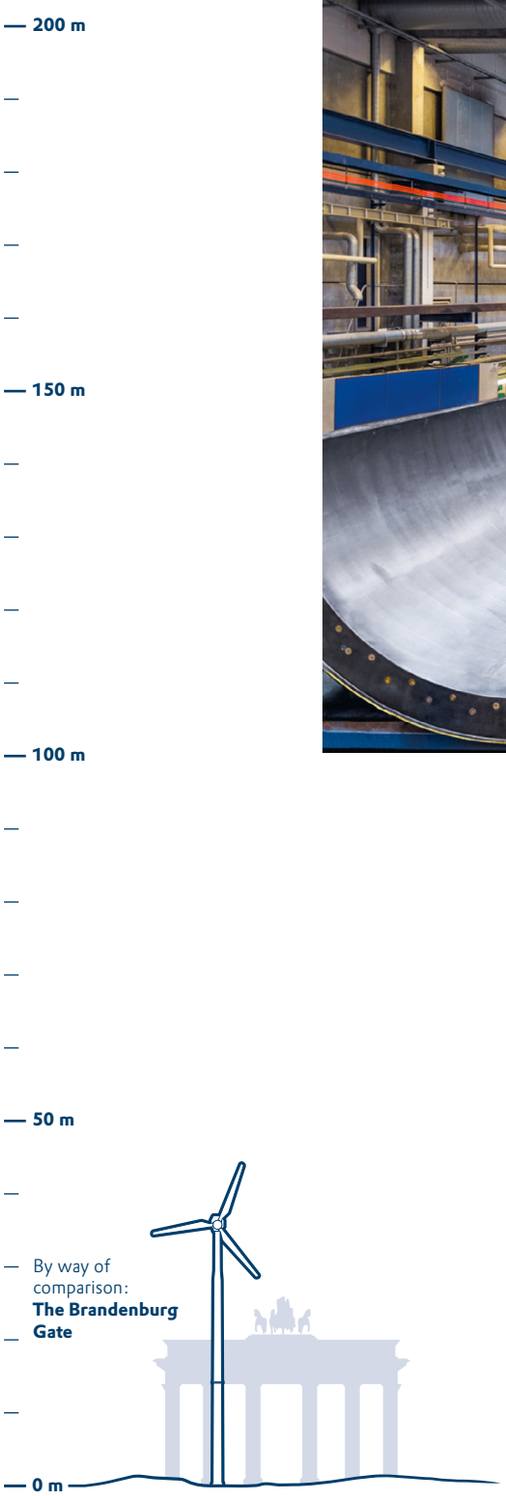
1990 on land

Tower height	**37 m**
Rotor diameter	**18 m**
Capacity	**80 kW**

Taller, bigger, more powerful

How the performance data of advanced wind turbines has changed from 1990 to 2024

The molds used to make the rotors of large wind turbines are more than 100 meters long, as is the case here at Vestas in Denmark



However, this is by no means easy. The turbines' great weight and the enormous centrifugal forces, as well as the rough conditions on the high seas, pose huge challenges for the structure and the materials. Moreover, offshore facilities have to be especially robust. Offshore repairs are complicated and very expensive; it's best if the giants operate maintenance-free.

Such demands can only be met with well-founded research. "The rotor blades, for example, are becoming bigger and bigger," says Christian Schmidt, who heads the Crosslinkers business line at Evonik. "That poses new challenges, not only during transport and construction but also earlier on, during production. We've developed customized products to deal with this."

Rotor blades are now technological high-performance products made of a variety of materials. Most of them are made in two half-shells. Each half of a blade is made of fiberglass mats impregnated with VESTAMIN® IPD. This resin provides the rotor blades with the required mechanical stability and ensures that the finished turbines have a long service life. The composite structure's service life can be extended further by applying silicon dioxide particles directly to the mats or mixing them into the impregnating resin. These particles are called NANOPOX® and were developed by Evonik. If 2,500 were piled on top of one another, they would be as thick as a human hair. The reinforced blade halves are connected to one another by carbon-fiber bars. This produces hollow spaces, which are

Testing titans: In Østerild, Denmark, the offshore wind turbines from a variety of manufacturers are tested on land for several years

then filled with foam. Weight is the most crucial aspect here. Evonik has developed the structural foam ROHACRYL™, which requires minimal amounts of resin and has a low density that enables it to be customized to meet the wind turbine industry's requirements and thus make weight-saving designs possible.

Huge amounts of adhesives are needed for the gigantic rotors. After all, the full length of both halves has to be glued together. This can be a technological challenge, given that the blades are up to 200 meters long. "In the past, the adhesive that was applied first would already have hardened while glue was still being applied to the other end of the blade," says Schmidt. "We solve this problem by using a special Ancamine that prolongs the gel phase, during which the adhesive hasn't hardened yet." This is extremely important for durability. That's because the adhesive doesn't just hold the two halves together, but also fills the production-related cracks and fissures and hermetically seals the rotor.

SWEEPING THROUGH THE AIR AT 400 KM/H

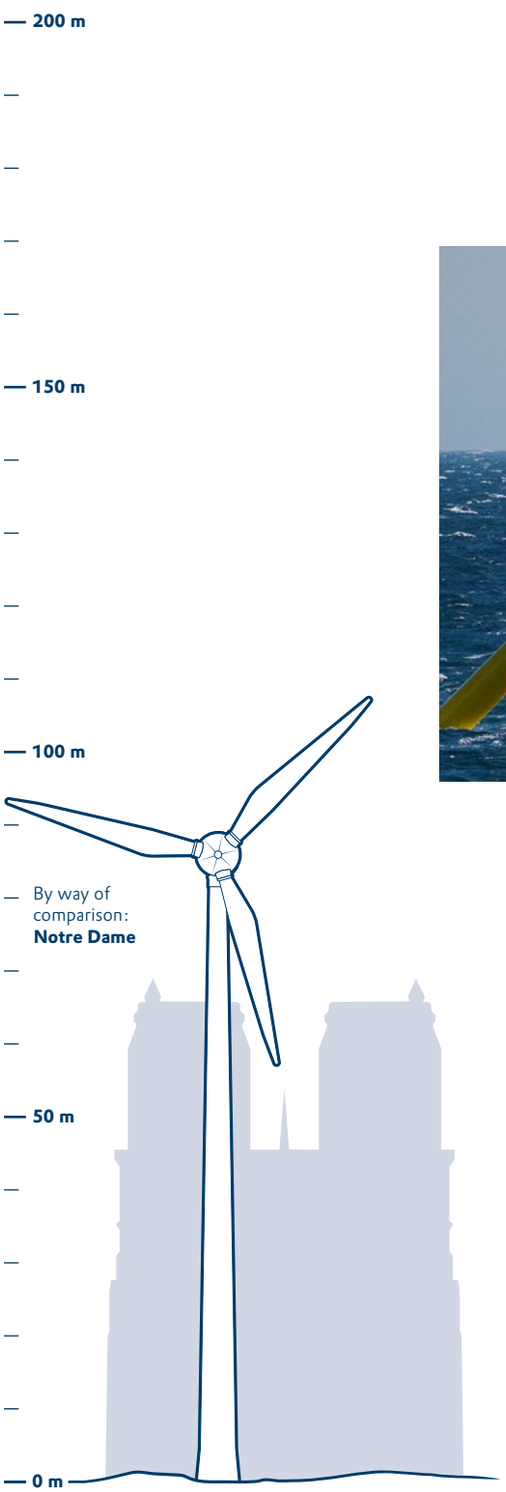
The last thing to be applied is the coating. Storms, hail, sand, and airborne salt—the rotors especially have to be protected against these extreme influences. To do this, many manufacturers use coatings that contain fumed silica from Evonik. This silica ensures that the protective coat can be applied to the blades with uniform thickness. In addition, it contains special crosslinkers that accelerate the drying of the coatings and make them more resistant to the effects of weather.

A blade's corners and edges are especially critical. The leading edge sweeps through the air at speeds of up to 400 kilometers per hour. A foam-like protective coating consisting of polyurethane is therefore applied to this edge. Additives from Evonik's toolkit ensure that this coating has the right structure. Without these protective coating, the rotor blades would be damaged in no time. →

A great feat of logistics: A special transport vehicle is used to take the rotor blade of a Siemens wind turbine to its destination

2000 on land

Tower height	89 m
Rotor diameter	59 m
Capacity	1 MW



Floating wind power platforms such as TetraSpar are intended to help offshore wind turbines achieve a breakthrough worldwide

However, even careful and technologically demanding manufacturing processes cannot prevent the rotors from experiencing extreme strain. For example, a gust of wind during a storm can make a more than 100-meter-long rotor blade bend by several meters. This occurs over and over again during the many years in which the turbine is in use. “It would be the beginning of the end for a rotor if the bending of the blades caused the protective coating to crack,” says Schmidt. “Our special crosslinker called VESTANAT® IPDI is used in many coatings and gives the resins both stability and flexibility.” This is the only way that the rotors can achieve the new size records, as also shown by the tests in Denmark.

But that’s not the only place where the offshore giants have to work well, because wind farms are currently being built at sea all over the world. In 2021 alone, the amount of offshore wind power generated worldwide increased by more than 25 percent to a total of 130.6 terawatt-hours. The Siemens-Gamesa turbine that is currently being tested in Denmark will go into operation in the Sofia Wind Farm on Dogger Bank off the northeastern coast of the UK. Beginning in 2024, a total of 100 such turbines will be installed here, boasting a total rated capacity of 1.4 gigawatts, which is the equivalent of a nuclear power plant. Additional projects will be implemented close by on this shoal, which connects Great Britain with the European continent.

Continued on page 16 →

A GOOD WIND

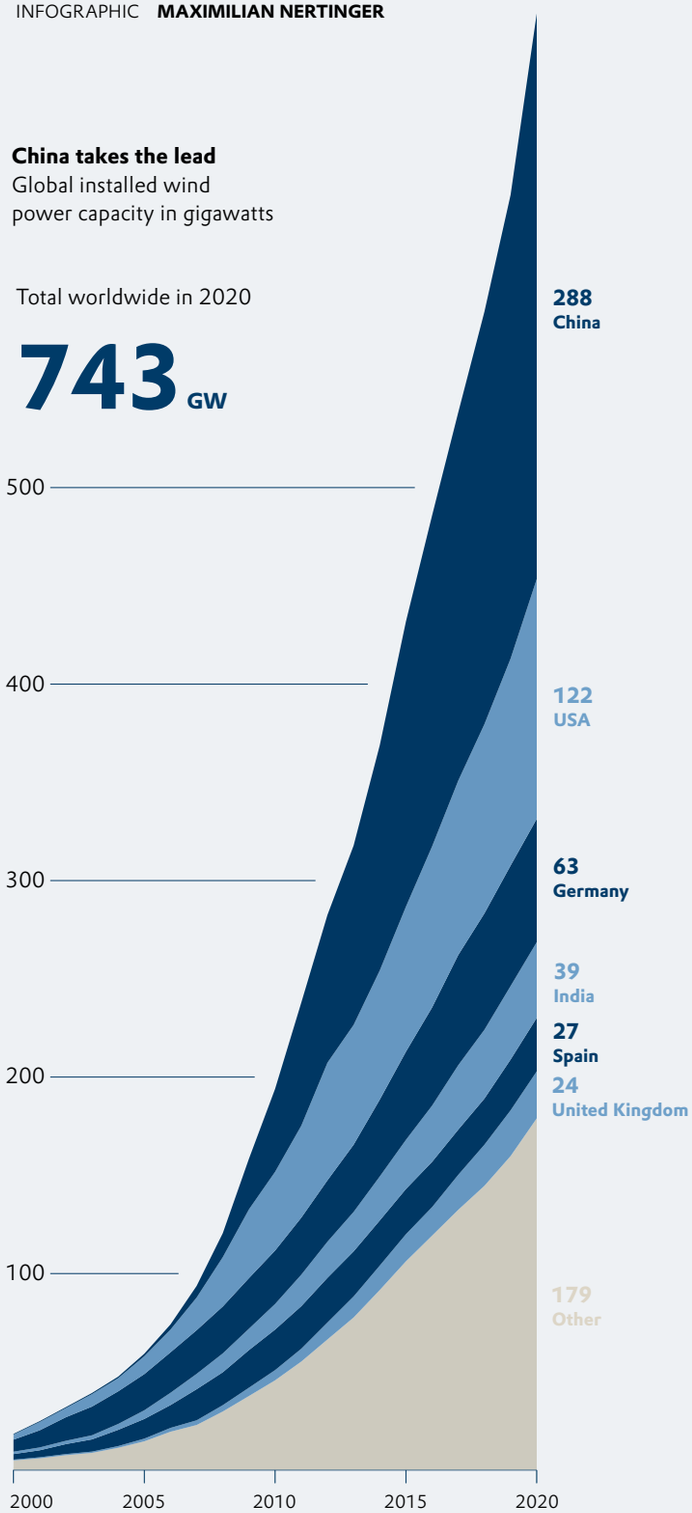
Renewable energies' share of global electricity production is growing. Wind turbines on land and at sea play an important role in this development. A glance at the numbers

INFOGRAPHIC **MAXIMILIAN NERTINGER**

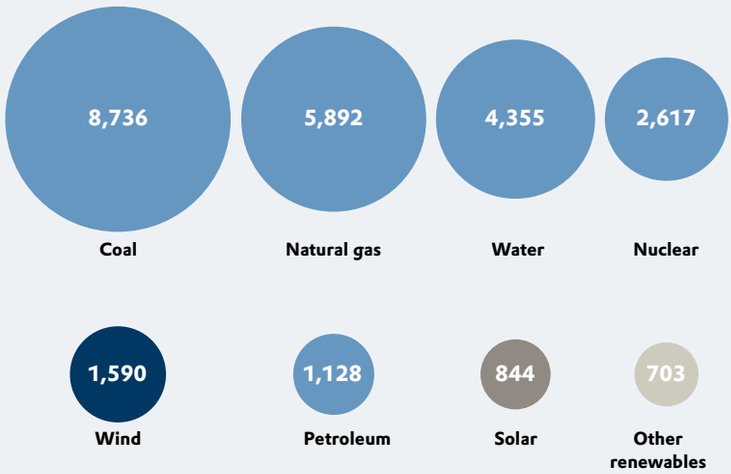
China takes the lead
Global installed wind power capacity in gigawatts

Total worldwide in 2020

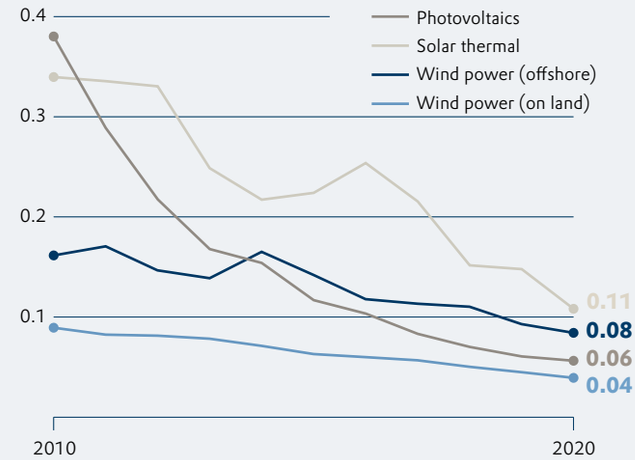
743 GW



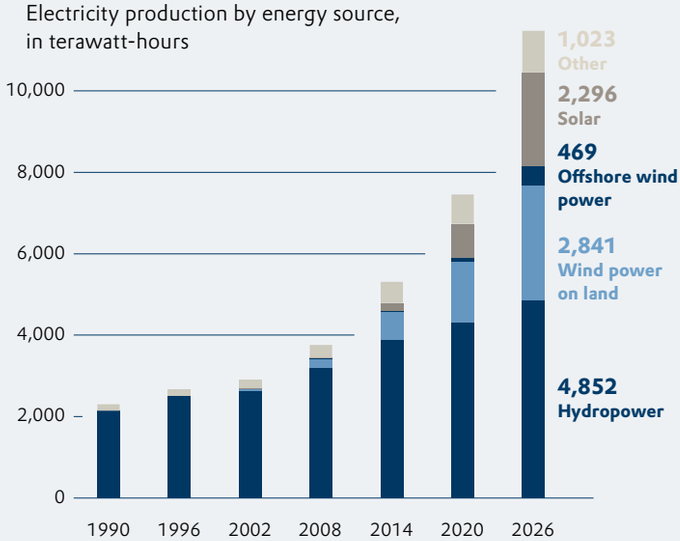
Wind beats petroleum
Global electricity generation by energy source in 2019, in terawatt-hours



Solar power is becoming less expensive
Average auction price of a kilowatt-hour of electricity by source of energy in 2020, in US$



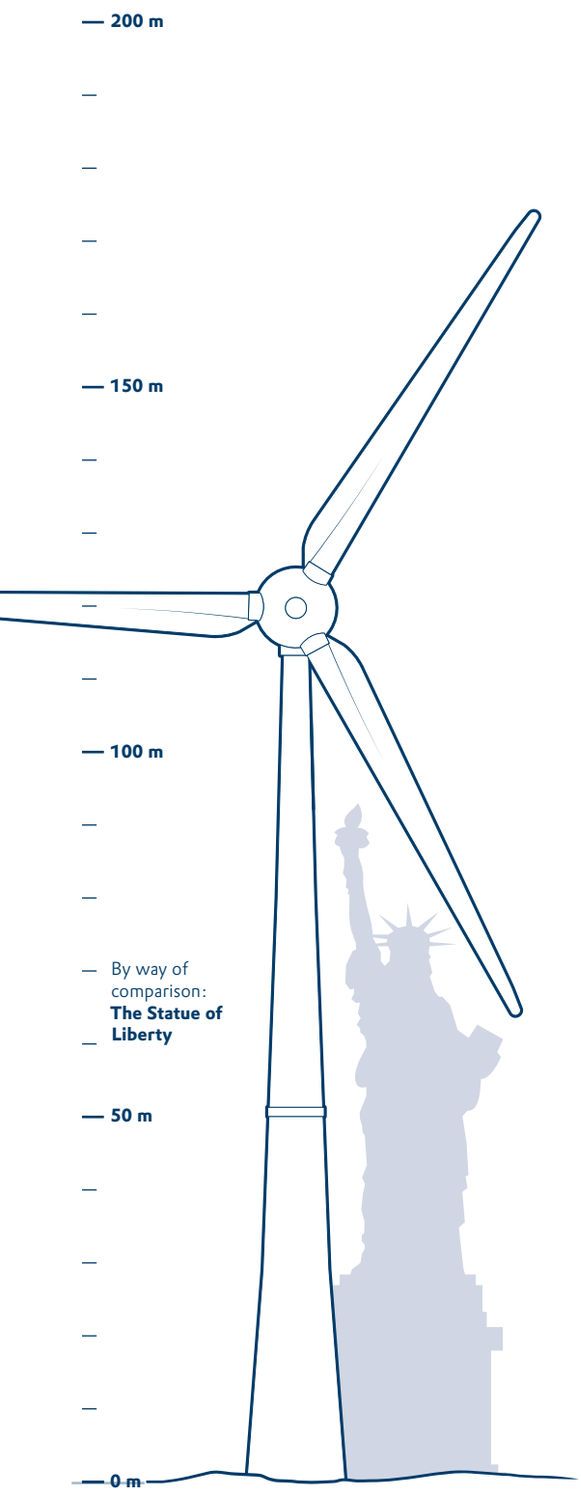
Sharp increase
Electricity production by energy source, in terawatt-hours



Source: Volker Quaschning, IRENA, IEA

2010 on land

Tower height	**135 m**
Rotor diameter	**127 m**
Capacity	**7.6 MW**



"The size of the rotor blades creates new production challenges"

CHRISTIAN SCHMIDT, THE HEAD OF EVONIK'S CROSSLINKERS BUSINESS LINE

FLOATING FOUNDATIONS

Such beneficial conditions, with water that in some parts is only 13 meters deep, are rather exceptional from a global standpoint and are primarily found in Europe and off the east coasts of North America and China. In other areas, the sea bed generally drops steeply so that the water is more than 60 meters deep only a few kilometers from shore. This depth is considered the limit at which a wind turbine can be built on a conventional foundation. "The next big step will be to make these deeper regions accessible with floating turbines so that wind power's potential can be exploited worldwide," says Gerhardt.

The thought of floating wind turbines might sound absurd, given the height and weight of these titans. However, a variety of concepts are already being tested. One such idea is to put each wind turbine on top of a huge submerged buoy. The upper part of the buoy is filled with air in order to give it buoyancy, while the bottom contains a counterweight to the wind turbine. Such structures have been used for more than four years at a wind farm around 25 kilometers off the Scottish coast. Due to their size, they can only be assembled out on the high seas. Elsewhere, the foundation is provided by relatively thin buoyant platforms that are attached to the seafloor by cables. However, they are unstable during assembly and the cables are subject to intense stresses. The companies Shell from the Netherlands, Tepco from Japan, RWE from Germany, and Stiesdal from Denmark recently presented a promising project in Norway. This project uses a structure called TetraSpar, which consists of the same steel elements as the wind turbine masts.

These are inexpensive to make, can be worked with existing machines, and use existing logistics paths. Underneath the floating platform is a triangular weight that is not lowered until the turbine reaches its destination, where the weight is sunk and anchored to the seabed. This makes it possible to attach the wind turbine to the platform while it's still in port, from where the completely assembled system is then tugged to its destination. Since December, a test facility has been in operation in 200-meter-deep water off the coast of Norway.

In normal operation these steel structures will float in saltwater for several years without getting a new coating. In the coatings, an additive from Evonik serves as a barrier against the saltwater. "Unlike a ship, for example, which can be put into dry dock, the substructures of wind turbines have to stay in the water for the facility's whole service life, which lasts for several decades," explains Schmidt. "The coating also protects the system against mechanical strain such as that caused during assembly or when service ships are moored to the platform."

EMERGING MARKETS BENEFIT

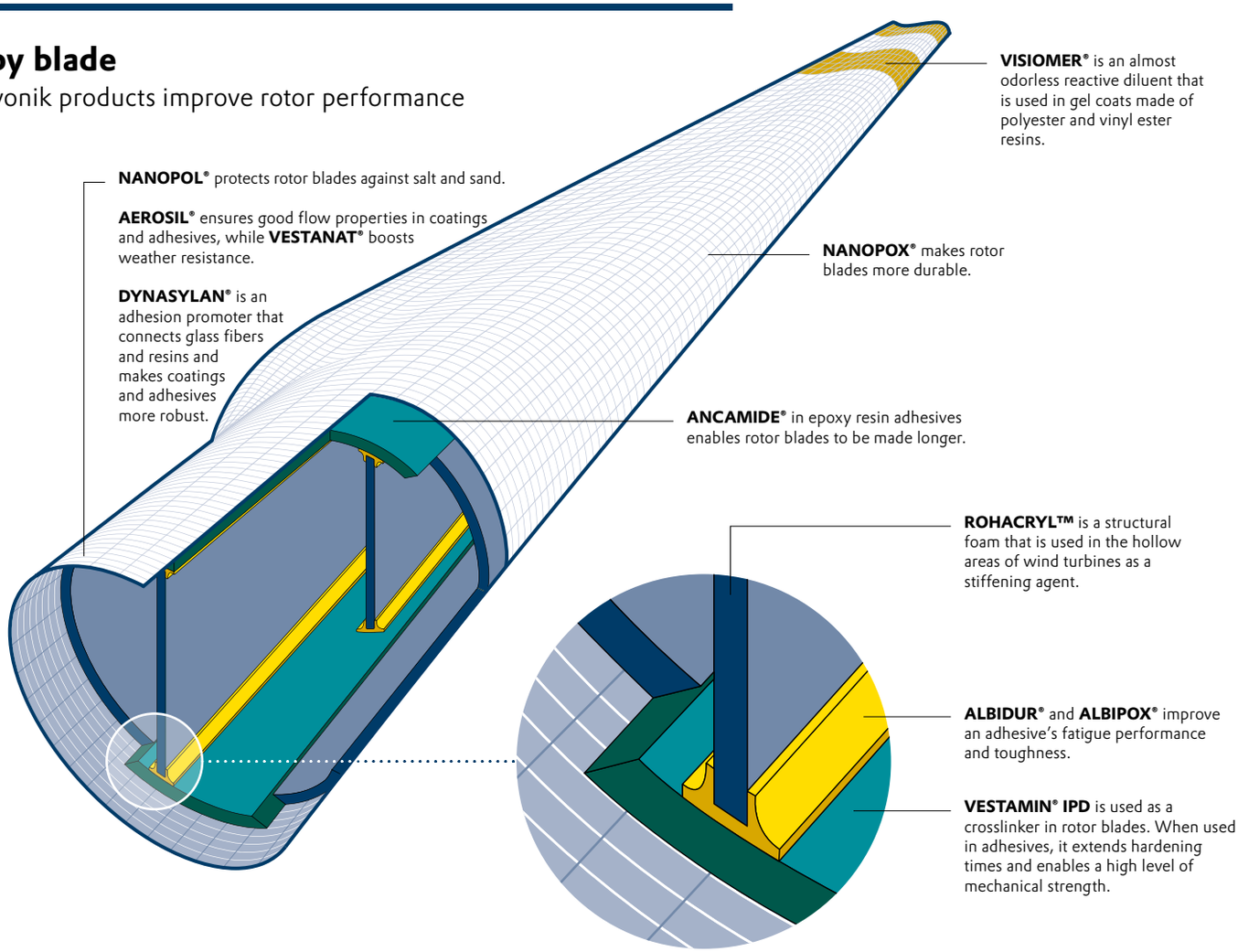
The new options for offshore facilities also make the use of wind power attractive for countries that until now have been unable to access renewable sources of energy. The International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) expect the amount of electricity from offshore wind turbines to increase immensely in the future. The global capacity might rise to 2,000 gigawatts by 2050, compared to slightly over 35 gigawatts at the end of 2020.

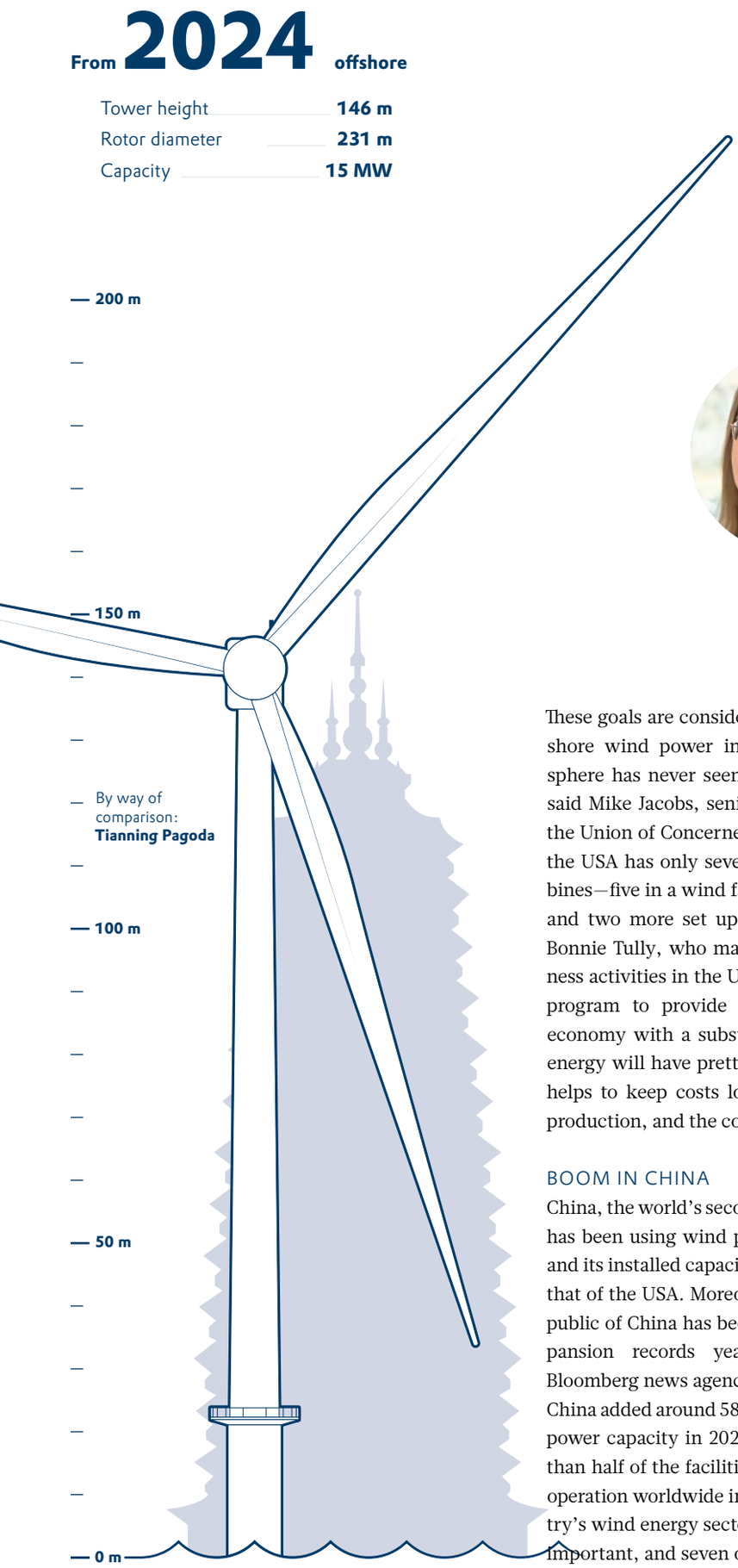
The main drivers of this development will be the rapidly growing developing countries and emerging markets, who can eliminate their dependence on imported fossil fuels and generate electricity more inexpensively than before. According to the Global Wind Energy Council (GWEC), an organization of 1,500 players from the wind energy sector in 80 countries, this could potentially have big benefits for the respective regional economies. Because wind turbines consist of very big pieces, it's not economical to transport them over long distances. The on-site assembly and subsequent maintenance create many qualified jobs.

Naturally, the big economic powers have also recognized this sign of the times. In the United States, the Biden administration announced a program in October 2021 for the massive expansion of offshore wind power. The turbines will supply green energy for ten million households and create 77,000 new jobs in the wind energy sector. The aim is to create a total of seven huge offshore wind farms in the Gulf of Mexico and along the US East and West Coasts in order to supply economic centers in the coastal areas with electricity. "We're at a turning point for domestic offshore wind energy development," US Interior Secretary Deb Haaland said. "We must seize this moment." →

Blade by blade

Where Evonik products improve rotor performance





"Wind energy will have a dynamic impact on the US economy"

BONNIE TULLY, EVONIK NORTH AMERICA

These goals are considered ambitious. "Offshore wind power in the western hemisphere has never seen anything like this," said Mike Jacobs, senior energy analyst at the Union of Concerned Scientists. To date, the USA has only seven offshore wind turbines—five in a wind farm off Rhode Island and two more set up as tests in Virginia. Bonnie Tully, who manages Evonik's business activities in the USA, now expects the program to provide the world's biggest economy with a substantial boost. "Wind energy will have pretty dynamic effects. It helps to keep costs low in supply chains, production, and the construction sector."

BOOM IN CHINA

China, the world's second-largest economy, has been using wind power for some time, and its installed capacity is twice as large as that of the USA. Moreover, the People's Republic of China has been achieving new expansion records year after year. The Bloomberg news agency has calculated that China added around 58 gigawatts to its wind power capacity in 2020 alone. That's more than half of the facilities that were put into operation worldwide in that year. The country's wind energy sector is correspondingly important, and seven of the world's top ten wind turbine manufacturers are from China. Evonik responded to this growth early on and opened an isophorone diamine plant in Shanghai in 2014. The company has extensive experience with isophorone chemistry, which has been in use for 60 years and serves as the main technological basis for preventing materials in wind turbines from becoming brittle or fragile. Today Evonik manufactures isophorone products on three continents. In addition to the facility in Shanghai, these products are also manufactured in Marl and Herne (Germany), Antwerp (Belgium), and Evonik's biggest US location, in Mobile, Alabama. Recently the company also began to make these products from renewable raw materials. Evonik has developed a procedure for turning such materials into the precursor product acetone. This is part of Evonik's "eliminate CO_2" mass balance approach, which aims to substitute fossil carbon with renewable or recycled carbon (see the report beginning on page 50).

Iris Zhen, who manages Evonik's crosslinker business for China and Southeast Asia from the location in Shanghai, expects further growth. "China wants to become carbon-neutral by 2060. The first step toward achieving this goal is to generate a

A wind farm in the German Bight: Offshore turbines improve wind energy yields and impact the environment less than power plants on land

large part of the electricity from emission-free and renewable sources and thus accomplish the transition to sustainable and clean energy sources and a carbon-free economy." Zhen also thinks that wind will play a crucial role in a clean energy future, and she expects "Asia, and China in particular, to continue to dominate the global wind energy sector."

GIVING ROTORS A NEW LEASE ON LIFE

There's no doubt that the carbon-free electricity from wind power benefits the environment. But how durable are wind turbines and how are they disposed of? "Our wind turbines are designed to last at least 25 years," says Gerhardt. A turbine's service life is mainly determined by its rotor blades. "We have made progress here with new concepts and materials that have considerably improved durability under the harsh offshore conditions."

The recycling of steel, concrete, and metal is already no problem, adds Gerhardt. However, the recycling of the rotor blades is more difficult. The rotors consist of a mixture of plastic and carbon fibers as well as of balsa wood. These materials can be separated from one another only with great difficulty. "However, we recently launched a truly green rotor blade on the market for offshore use: the RecycableBlade," says Gerhardt.

Creavis, the strategic innovation unit at Evonik, has the same aim and is now pooling the expertise from a variety of business lines in order to make wind power a part of the circular economy. The structural foam ROHACRYL™ is already reusable. As a result, Martin Gerhardt's plans for the future might become a reality. "Our goal for 2040 is to build only turbines that are fully recyclable," he says. Once that goal is achieved, it won't just be the huge rotors that will go in circles for as long as possible, but also the materials that they are made of.

Christoph Bauer is a journalist who works at Evonik's Communications department

"Renewables are the cheapest type of energy supply"

The transition from fossil fuels to renewable energies is a massive endeavor for the economy and society. The engineering scientist Volker Quaschning explains why he believes nonetheless that the transition to wind power and photovoltaics is succeeding

INTERVIEW **CHRISTOPH BAUER** & **CHRISTIAN BAULIG**

The USA led by President Joe Biden has rejoined the Paris climate protection agreement, China is building wind and solar power plants at record speed year after year, and in Germany the new national government has stepped up with a very ambitious energy policy. Is humanity now moving in the right direction?
VOLKER QUASCHNING Things are moving somewhat, but unfortunately they're still not up to speed. One way or another, we will have one hundred percent renewable energy in the year 2100. There's only one question: Will we have destroyed the climate by then, or will we have managed to change course before that?

Do you think it's still possible for us to change our energy generation systems in time?
It's a technological challenge, but it's doable.

And will we be able to pay for it?
Today renewables are the cheapest type of energy supply. Continuing to depend on coal-fired power stations and gasoline or diesel-powered cars is the far more expensive option.

Can the necessary changes be implemented at the social and political levels?
I hope the majority of the population agrees to utilize a technology that is affordable and will save us from drastic consequences.

What about the minority that opposes it?
There's a lot of talk about "getting people on board." But some people are sitting on their sofas at home and don't want to get on board. We live in a democracy, so the majority should decide, and a very big majority wants to protect the climate. We can't continue the discussion until the final holdout has been convinced. That's also true of wind power.

Some people oppose new wind turbines precisely because they are supporters of nature conservation. For example, they claim that the rotors are endangering our population of birds of prey.
We have a split in our society. Many people have realized that we're facing a huge problem, and they are sinking into depression because society is still acting so slowly. At the same time, there's a minority that is denying the problem and saying, "If we're bent on protecting the climate, then please let's do it without any wind turbines in my neighborhood." It's astonishing that in Germany the strongest resistance to wind turbines is in regions where hardly any wind turbines exist.

How can we solve this dilemma?
We have to give the local people a share of the proceeds. In Germany, wind turbines were initially built →

Tilting at windmills: Many opponents of wind turbines argue that they harm the environment. However, the biggest threat to nature is climate change

“We can’t continue the discussion until the final holdout has been convinced”

VOLKER QUASCHNING

mainly by idealists and citizens’ cooperatives. Some municipalities have dozens of wind turbines and there’s no opposition at all. These people say, “When the rotors are turning, they’re not disfiguring the landscape. Every rotation earns us a euro.” Sharing can also take the form of models in which the people who live near wind turbines receive a ten percent discount on their electric bills, for example.

It’s also possible to move energy production to the open sea, where nobody lives and the wind is always blowing.

It’s true, we have fewer discussions there than we do on land. And the wind turbines in the North Sea produce almost twice as much electricity as the ones on land. The UK could cover all of its energy needs with offshore electricity. But from an international perspective, it’s an exception. In general, we can’t use offshore wind turbines to compensate for the turbines that we need but prevent being build on land. Besides, offshore wind energy has to compete with solar energy that is produced on land. If wind energy costs twice as much as solar, it will have only moderate success.

Some inventors are promoting wind turbines whose rotors turn on a vertical axis rather than a horizontal one. They claim that they are quieter than conventional ones. What’s your opinion?

This technology isn’t new, and after all these decades it still hasn’t caught on. Their efficiency is lower and their mechanical stress is higher. On top of that, most of today’s vertical-axis turbines are relatively small. There would probably also be resistance to a land-based five-megawatt wind turbine of this type.

In addition, wind power plants are often criticized because people claim they are not sustainable. In particular, they object to the fact that they cannot be sufficiently recycled. Are they in the right?

The concrete foundations, the tower, and the generator can be recycled well. The challenge is the rotor blades, which are often made of composite materials. Ideally, in the future the producers of these components should stop using petroleum-based plastics—and, as with almost all other products, here too we have to become part of the circular economy. However, engineers will certainly find solutions for this problem.

Which countries can give us some good ideas about the energy transition?

Norway is the leader in the field of electric mobility, France will soon no longer permit any combus-

tion-engine vehicles to enter Paris, and Denmark is doing a great deal in terms of wind energy. But no country is perfect. In the climate protection ranking of Germanwatch—where Germany is in the middle range, incidentally—the first three places are vacant, because no country is prepared to implement adequate measures. And there are also states that have no great climate-related ambitions, yet can demonstrate successful progress toward the energy transition.

Can you give us an example?
Take Texas. It's the US state that is doing the most to promote wind energy. It's an oil state that has been governed by the Republicans since way back! But Texans have realized that wind energy means big business. For them, climate protection is only secondary.

How important is the role of the economy in changing energy policy? Obviously major consumers such as the steel sector and the chemical industry have tremendous leverage when it comes to forcing decisions.
The mindset of many companies has completely changed in recent years. They are trying to establish environmental standards, and they've realized that they can do good business in this new world. I couldn't believe my eyes when the Federation of German Industries criticized the results of the climate conference in Glasgow as being inadequate and said it had wished for more. I'm glad that companies are trying to structure the necessary transformation in positive ways. Many companies have understood that an industrialized country such as Germany can only stay big and strong thanks to new technologies like these.

Isn't there a risk that energy-intensive companies could migrate to countries that are continuing to work with old and written-off coal-fired power plants?
Absolutely not. After all, coal is certainly not cheap, especially by comparison with solar energy. In sunny countries, a kilowatt-hour of solar power costs less than two cents. For that amount of money I can't even buy the necessary coal on the world market. Of course the companies operating old written-off power plants have an advantage. However, if we're talking about greenfield sites, solar power plants are more economical, even in countries such as India. A very likely scenario is that energy-intensive sectors will migrate to countries where solar and wind energy can be generated cheaply. Thirty years from now, will Germany still have the same steel mills it has today? I don't think so.

We could import inexpensive solar energy from the favored regions, for example in the form of hydrogen that is produced climate-neutrally with the help of solar or wind energy.
After all, the right question is "Which is cheaper? Bringing green hydrogen to Europe, or taking the steel mill or at least the energy-intensive parts of it to Morocco?" I would choose the second alternative. Of course that would mean losing jobs in traditional sectors here in Germany. But on the other hand, so many jobs are being created by the energy transition that we should instead be thinking about where we'll find the workers we need.

Evonik produces specialty chemicals. You can't move them easily, because they require know-how that you can't find just anywhere in the world.
That's absolutely right, and it's also a question of costs. If 70 percent of the product costs are due to energy, you'll have to think about moving your production plant. However, if most of the costs are due to know-how, production will continue to be located in Germany. And for that we will also need hydrogen, that's absolutely clear.

China has left the rest of the world behind when it comes to expanding renewable energies, both wind and solar. Meanwhile, it's continuing to invest in coal-fired power plants

The big job upswing in Europe due to the solar power business is a thing of the past. Today European companies are hardly playing any role in this industry. Production is mainly taking place in China. Is this fate looming for us in the area of wind power as well?
China committed itself to technologies such as solar and wind energy early on, and thus it helped to cause the drastic drop in prices. Without China, photovoltaics would probably be about three times more expensive on the world market. This effect is not so →

great in the case of wind turbines, because they are not as easy to transport. A rotor blade doesn't fit into a Euro container. Because transportation costs tend to increase, in the future it won't pay off to produce everything in China.

China is by far the Number One country when it comes to expansion for its own purposes. In recent years, more than 50 percent of all wind turbines have been built in China.
Yes, this expansion is impressive. However, China's hunger for energy is also very huge. As a result, the expansion is insufficient to roll back the use of coal. The Chinese would have to actually double their ambitions once again.

There has been a huge drop in the price of photovoltaics over the past ten years. At the same time, the performance level of solar modules has seen a spectacular increase. Will this development continue—and possibly cause wind power to become less important?
The costs of wind power will also continue to decrease, just because of economies of scale: If I build 20,000 wind turbines instead of 1,000, I can manufacture each one of them more cheaply. However, in the short run prices could also rise, because the demand is rising quickly at the moment and it takes a while for production to catch up. I no longer expect the prices of photovoltaic systems to decrease significantly in the years ahead, largely because of the higher labor costs for their installation.

And how much can their performance still increase in the future?
Wind energy is close to its physical limits. In theory, we can reach an efficiency of almost 60 percent, and good wind turbines already reach more than 50 percent today. For photovoltaics the theoretical efficiency is more than 80 percent, but in series production we've only reached 20 percent. However, we're basically facing the problem that photovoltaic systems hardly produce any electricity in the winter, whereas wind turbines do. That's why there will always be a market for wind energy.

Some skeptics fear that the security of the power supply will be at risk if all conventional power plants have been taken off the grid. Is there any cause for concern?
Well, if people believe that our current energy supply is invulnerable, we have to disabuse them of this idea. If two or three major power plants were to break down simultaneously, we would have an extensive blackout today. By contrast, renewable energies operate in a more distributed fashion. If you were to cut down three wind turbines, nothing would happen. Besides, some of these assumptions are quite far-fetched. Of course if everyone recharges his or her electric car at the same time, things will go dark. But something like that will never happen.

What can we do when there's no sunshine and no wind? In addition to batteries, pumped-storage power plants like this one in Goldisthal in the German state of Thuringia act as buffers during fluctuating power production

Volker Quaschning, who was born in Leonberg in 1969, has been a professor in the field of renewable energy systems at the HTW Berlin – University of Applied Sciences since 2004. Together with his wife, Cornelia Quaschning, he actively posts on various social media platforms in order to inform the public about the opportunities offered by renewable energies. He is the author of many scientific publications, including the reference work *Understanding Renewable Energy Systems*, which was first published in 1998, has been translated into several languages, and has been continuously updated. The beginning of 2022 marked the publication of *Energie Revolution JETZT!*, in which the Quaschnings present facts relevant to the current discussion of renewable energies in a lively format

Nonetheless, in the new world of energy we will have more extreme fluctuations in production volumes, and we will need more storage capacity.
That's right. But I'm not too worried that we'll never solve this problem. The electric cars that were registered last year in Germany alone have a storage capacity via their batteries that is bigger than the largest German pumped-storage power plant.

Electric cars won't solve the problem alone. Don't the storage facilities harbor a tremendous cost risk?
Battery technology is roughly at the same point today as photovoltaics were ten or 15 years ago. In the case of lithium batteries in particular, automation and rationalization will lower the costs in the future.

You operate a photovoltaic system yourself on the roof of your house. Are you toying with the idea of purchasing a private wind turbine as well in order to have the optimal energy mix?
I own shares in a wind farm, because small wind turbines are not practical. In the case of solar panels, it doesn't matter whether I set them up on my roof or they are in a field in Brandenburg—they always produce the same amount of energy per square meter. That's not the case with a wind turbine. The wind becomes much stronger as you go higher. A wind turbine on your own roof wouldn't produce very much power. Besides, you might get into trouble with your neighbor complaining that the thing makes a lot of noise.

It's no exaggeration to say that the recycling project that Annegret Terheiden and Michael Ferenz are working on could soon prevent thousands of tons of waste

THE DREAM OF FOAM

Evonik has developed an innovative method for recycling foam mattresses. The new process achieves a very high yield saving a lot of energy and fossil raw materials. The aim is now to build a pilot plant.

TEXT **JOHANNES GIESLER**

On average, we throw away a worn-out mattress every five to ten years. This causes a huge environmental problem, because some 40 million mattresses have to be disposed of each year in the EU alone. If they were laid on top of one another, the resulting pile would be 8,000 kilometers high. This amounts to around 600,000 tons of waste, of which more than 300,000 tons is polyurethane foam. Remove So far and replace with Currently, the mattresses have mostly ended up in landfills or are "thermally recycled"—i.e. burned in power plants or waste incineration plants. Obviously, this is not environmentally friendly. With every end-of-life mattress, the raw materials and energy used for production and transport go up in smoke or are converted to heat.

Annegret Terheiden wants to change this. More than three years ago, Terheiden, who has a PhD in chemistry, teamed up with colleagues at Evonik's business incubator Creavis to initiate a recycling project. Their aim is to break down used mattresses into their chemical components and make them recyclable. The process should be so good that the quality of the recyclate can be compared with conventional raw materials. This goal now appears to have been achieved. What is more, a few weeks ago colleagues from Evonik's Life Cycle Management examined the ecological footprint of the new recycling process in detail. The review showed that the process reduces the carbon footprint by more than half in comparison to mattress production using fossil raw materials. "And we want to improve it further," says Terheiden.

On a cloudy, cold January morning, Terheiden and other researchers from the project team are working on the process at the Essen-Goldschmidtstraße location. Building E-18—red brick on the outside, bright neon on the inside—is home to the Comfort & Insulation business line, which focuses a lot on foam. "Our recycling project was initially a small spin-off topic," says Terheiden. It emerged from her main job of developing additives for the foam industry. Terheiden, who is now 50, has been working in this area since she joined Evonik in 2006. "I translate the requirements of our customers—we call them foamers—into chemical ones," she says.

Terheiden's job is to provide technical customer support and manage the development of new additives. After all, the precisely tailored additives should meet the customers' requirements. These additives make car seats dimensionally stable, and mattresses and sofa upholstery particularly comfortable. Terheiden is now in charge of Evonik's technological unit for flexible foams worldwide. →

In order to fill his five-liter hydrolysis reactor with reactants, Michael Ferenz must turn the cranks vigorously

DURABLE—BUT HARD TO SEPARATE

The material she deals with the most is polyurethane (PU). It is used in the manufacture of mattresses and upholstered furniture, among other things. Typical PU foam for mattresses is created by the reaction of isocyanate (TDI) with polyether polyol and water and with the addition of various additives (see the infographic on page 30). Carbon dioxide is released as a by-product, causing the mixture to bubble up like a hot spring. Instead of collapsing again afterwards, PU retains its wide-meshed web-like structure. PU compounds are wear-resistant, which benefits the lifespan of the end product. However, this property is a hindrance for recycling, which requires these compounds to be broken up.

"Developing the recycling process completely anew was uncharted territory for us," says Terheiden. "In the case of the additives, we work with molecules that we are familiar with. We are experienced in this area, and our business line is the world market leader in the field. However, our expertise at Creavis, for example, makes it possible to also tackle completely new innovation projects."

The time for her idea came in 2018, when Evonik decided to focus more on the circular economy and sustainable production. From now on, new products, but also those from the existing portfolio, should be compelling not only because of their concrete benefits, but also in sustainability analyses. Terheiden was also encouraged by a meeting with experts from the furniture chain IKEA, one of the most powerful voices in the foam industry. "They told us at the time that by 2030 all their mattresses should be made entirely from reclaimed and renewable raw materials. That was challenging and gave us a nudge," Terheiden recalls.

GOVERNMENTS DEMAND A RECYCLING SOLUTION

The processes that had been commercialized until then did not allow PU to be completely broken down back into polyol and isocyanate. Instead of individual molecules, the processes create mixtures of short-chain oligomers, which lead to far poorer foam properties than the original ingredients. A maximum of 20 percent of fossil polyol can be replaced with this process in the manufacture of new mattresses; otherwise the product properties will suffer. Terheiden wants to achieve a better result. The research work began back in early 2019, and Creavis was involved in this work from the very start. It is responsible for exploring business ideas for Evonik in new areas and markets. Thus, Terdeiden can concentrate on the chemistry and the application of the end product.

Before the hydrolysis starts, all lines must be checked and the sensors must be calibrated

“This is a key milestone to achieving a circular economy.”

IAN W. ROBB, CEO VITA GROUP

As a “flexible foamer,” as chemists in this field call themselves, she knows that European Union regulation requires a recycling solution for PU foams. The “Directive (EU) 2019/904 of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment”—also known as the “Plastic Directive” for short—stipulates that by 2025 many plastic products must consist of a quarter of recycled material. Manufacturers must also present a plan for recycling their products at the end of their useful life. “PU is not yet regarded as strictly as single-use plastic,” says Terheiden. “But it’s not a question of whether that will happen, but when.”

In her office on Goldschmidtstraße, Terheiden puts on a white lab coat and makes her way to Michael Ferenz’s lab. Ferenz, who is an experimental chemist, joined the recycling project a year ago and has been responsible for the experiments in the laboratory in Essen since last summer. Behind a raised pane of safety glass is a shiny silver head-high apparatus: a hydrolysis reactor with a capacity of five liters. “In there I separate the PU foams with the help of additives,” says Ferenz.

The list of ingredients is constantly being optimized. “First we used finely ground PU ‘snow’,” says Ferenz. “However, this has a very low bulk density, which made it significantly more difficult to fill the reactor. So we are now working on other dosage forms.”

After loading, Ferenz sets the parameters for the experimental setup. The reactor has a laptop wired to it. This laptop depicts colorful curves from the last experiment and enables Ferenz to command and control everything. The temperature in the housing is shown in red, the temperature in the reactor in orange, and the pressure in blue. The last curve shows the stirrer rpm. It ensures that all reactants are mixed well.

If you ask Ferenz what exactly happens in this pressure cooker, you will get a quick refresher on chemistry. After clicking on his pen and getting out a notepad, he writes down the key to recycling success. It was discovered during research and employs hydrolysis, one of the fundamental reactions in organic chemistry, by using a catalyst. “We don’t yet know exactly how it works,” Ferenz admits. “The working hypothesis is that the catalysts bring our reactants together better.” →

The hydrolysis produces a dark brown liquid in which the polyol and toluene diamine (TDA) are dissolved

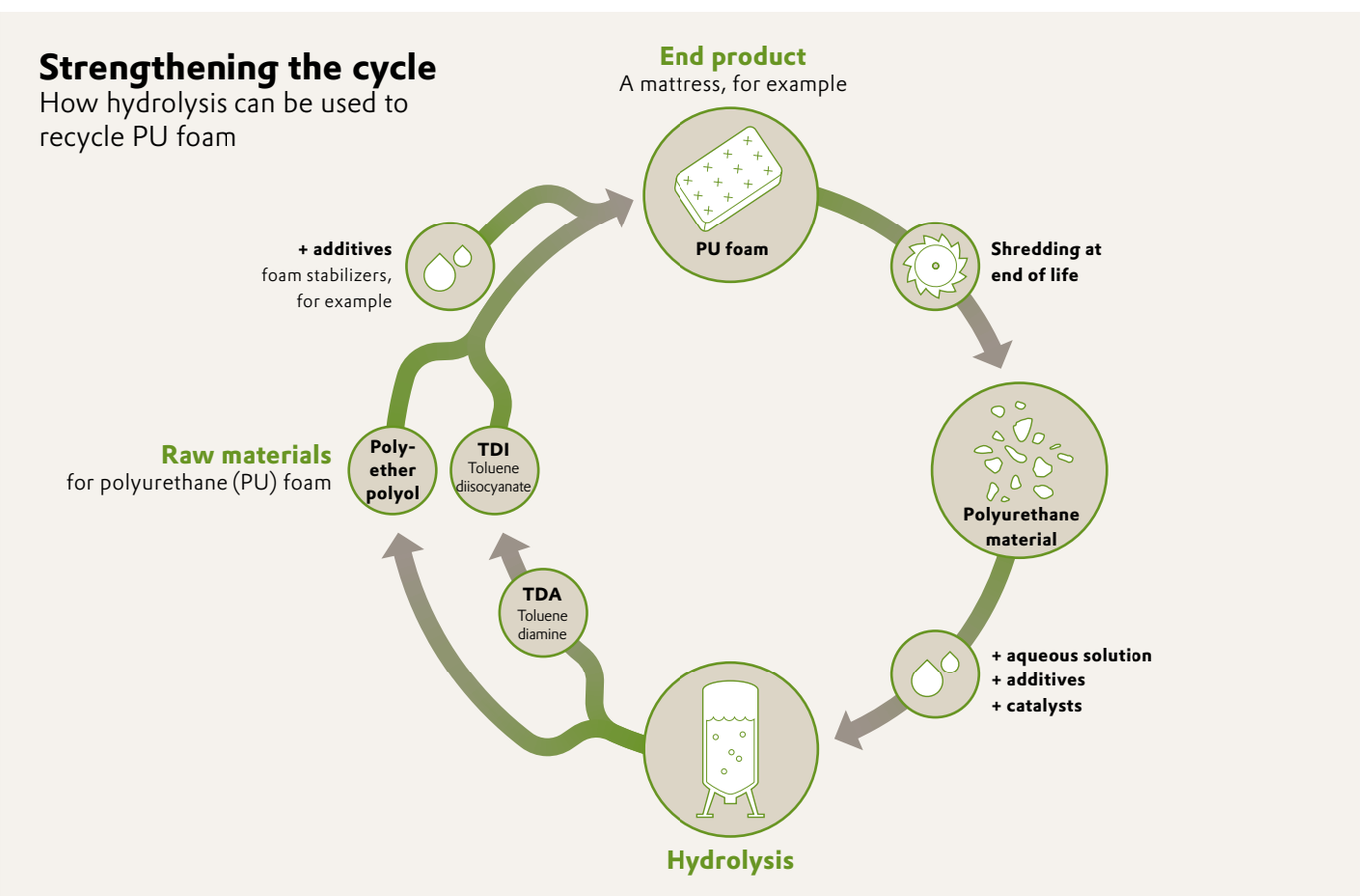
TACKLING THE URETHANE FUNCTION

Ferenz and his colleagues use a catalytic system to split the polyurethane. By using a catalyst, the reaction can proceed under milder conditions. The catalyst ensures that the necessary chemical bonds are broken quickly and efficiently and that the reaction can take place within an acceptable period of time.

Ferenz shows what the result looks like in a small bottle. It contains what remains after the successful hydrolysis of PU foam: a deep brown liquid containing pure polyol and an amine (TDA). The latter can be converted into the isocyanate (TDI) in a subsequent reaction, resulting in precisely those substances that are required for the production of polyurethane. In order for the molecules to be suitable for foaming again, they have to be cleanly separated from one another.

"It took us a long time to get this far," says Ferenz. Countless experimental setups provided useless parameters. Lots of catalysts and additives proved to be unsuitable. It was basically the normal life of a researcher. However, the proof of concept has now been achieved: a completely closed circuit without the addition of fresh polyol.

That was the starting signal for many experts at Evonik, especially in process engineering. Particle technicians are clarifying how mattresses can be shredded better, fluid process technicians are looking for a solution to separate the dark brown liquid into its components more quickly and cleanly, digitizers, measurement and control technicians, environmental technicians, and safety technicians are all solving problems relating to the process. The result is still not completely perfect. Although the foams made from the recycled



“Developing the recycling process completely anew was uncharted territory for us”

ANNEGRET TERHEIDEN, GLOBAL TECHNOLOGY MANAGER FOR THE COMFORT PRODUCT LINE

Annegret Terheiden at the technical center of the foam specialists at the Essen-Goldschmidtstraße location

molecules behave flawlessly, they are brownish in color. Polyol derived from fossil sources is colorless, unlike its recycled chemical twin.

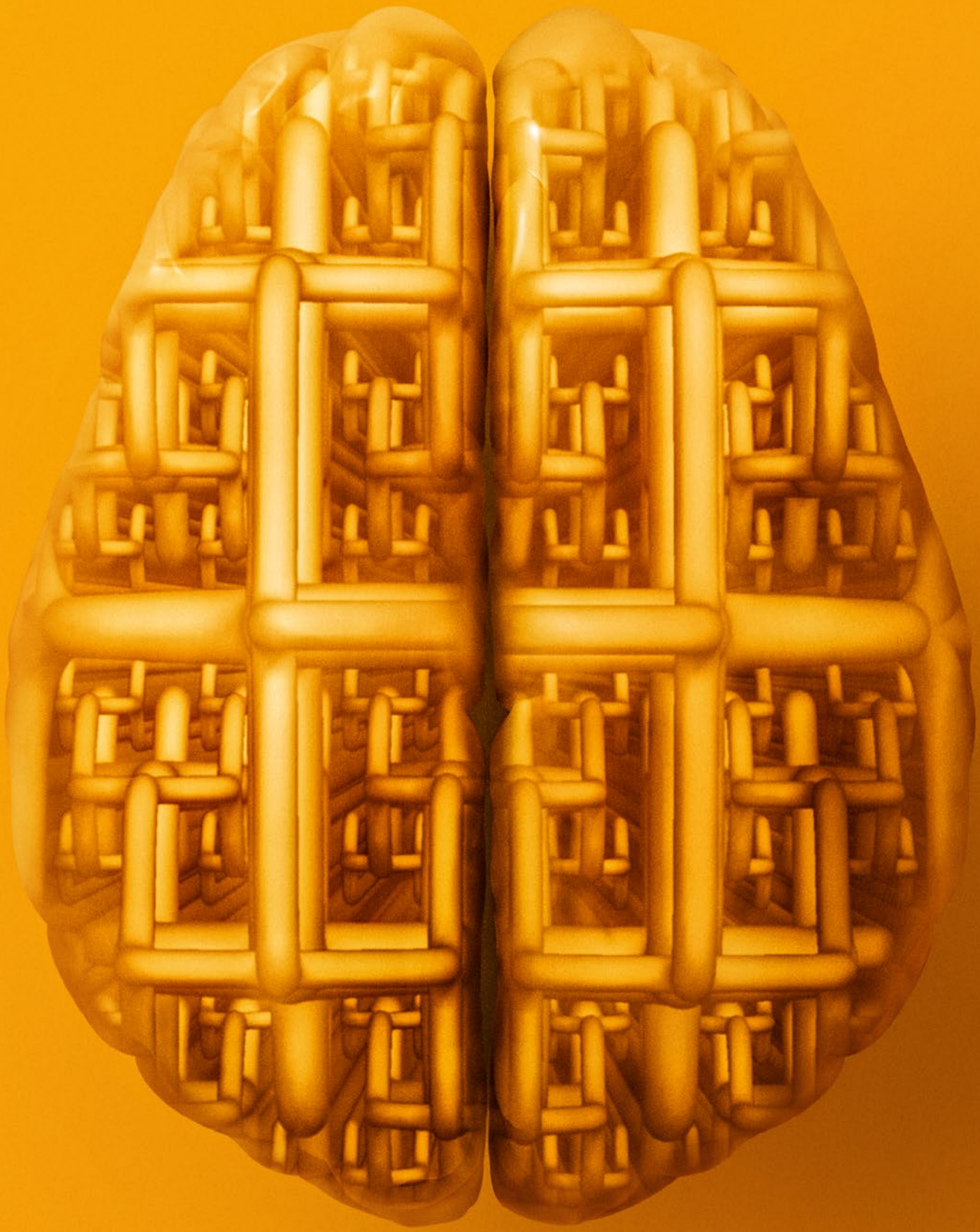
A MILESTONE FOR THE FOAM INDUSTRY

Despite these challenges, partners from industry are already very impressed by the process—for example the British flexible foam manufacturer The Vita Group, which produces high-quality mattresses and works closely with Evonik. “We have trialled Evonik’s recycled polyols in several of our flexible foam formulations and the outcome has been very positive,” says Vita CEO Ian W. Robb. The company considers itself a pioneer in the environmentally friendly production of mattresses. The outstanding environmental balance of the recycling project is therefore a decisive factor for Robb. “We see it as our responsibility to be at the vanguard of the development of eco-friendly technology (within our industry),” he says. “This partnership represents a key milestone on our journey to achieving a circular economy.”

At Evonik, the recycling project now resembles a huge mosaic that is being worked on in parallel at several locations. Business lines beyond Comfort & Insulation’s foam experts support the project. For example, colleagues from the Crosslinkers unit made their facilities available at the Marl Chemical Park. However, the big picture should be visible in Hanau in a few months. A pilot plant is being built there in which the components of polyurethane are to be obtained in larger quantities. The plant is the responsibility of process engineering project manager Andree Blesgen, who joined the project in 2020. Instead of five liters, as in the previous reactors, the new plant should produce a multiple of that amount. “We hope to go into operation in 2022 and to advance into the tonnage range with the new plant,” says Blesgen.

That would be extremely rapid progress. “From patent research to the miniplant in three years—that’s really quick,” says Blesgen. One of the reasons for this is the enthusiasm within the company for the project. “It’s great fun to do something that is so environmentally beneficial. This generated an incredible amount of team effort,” he says. The project is even paying off for Blesgen, 45, at home. “When I used to talk about my job, my children were only moderately interested. However, they find it really exciting that I’m now helping to make mattresses recyclable,” he says.

Johannes Giesler works as a freelance science journalist in Leipzig. Thanks to his research for this article, he now knows what makes a good mattress



A SMART SOLUTION

How can chemical reactions be carried out as sustainably and efficiently as possible? A team from Evonik is researching this question in cooperation with external partners and taking advantage of the possibilities of 3D printing

TEXT **KARL HÜBNER**

If Dr. Senada Schaack has her way, the chemical reactor of the future will be small, custom-tailored, and homemade. "It's disruptively different," says Schaack, a process engineer who is researching a new generation of minireactors for Evonik in Hanau. The metal contraption is only about as big as a shoebox, but it promises great advances. Its abilities aren't apparent from the outside. However, its inner workings are designed so that a chemical synthesis requires as little energy as possible and causes less CO_2 emissions. Some reactors contain extremely thin tubes through which the reaction mixture or a cooling medium can be pumped during operation. Others contain intricately branched systems, which help to distribute flows from one tube to several.

"If we do this well, we can achieve a high degree of purity in the desired product and save energy that previously had to be used for cooling or complex material separations, such as distillation," explains Schaack, who runs the Simulation and Additive Manufacturing competence center, or SAM 3D for short. Together with her employees, she develops concepts for the design of reactors—and then manufactures them from stainless steel powder using 3D printing.

These reactors could be used in many applications, for example in the production of methanol for solar or wind energy storage. The team is currently working on a new type of reactor for a synthesis step that often plays a role in the manufacture of active pharmaceutical ingredients: ortho-lithiation. "We designed the apparatus in such a way that it not only delivers the product with higher purity but also requires less cooling for the reaction than the conventional process," says Schaack.

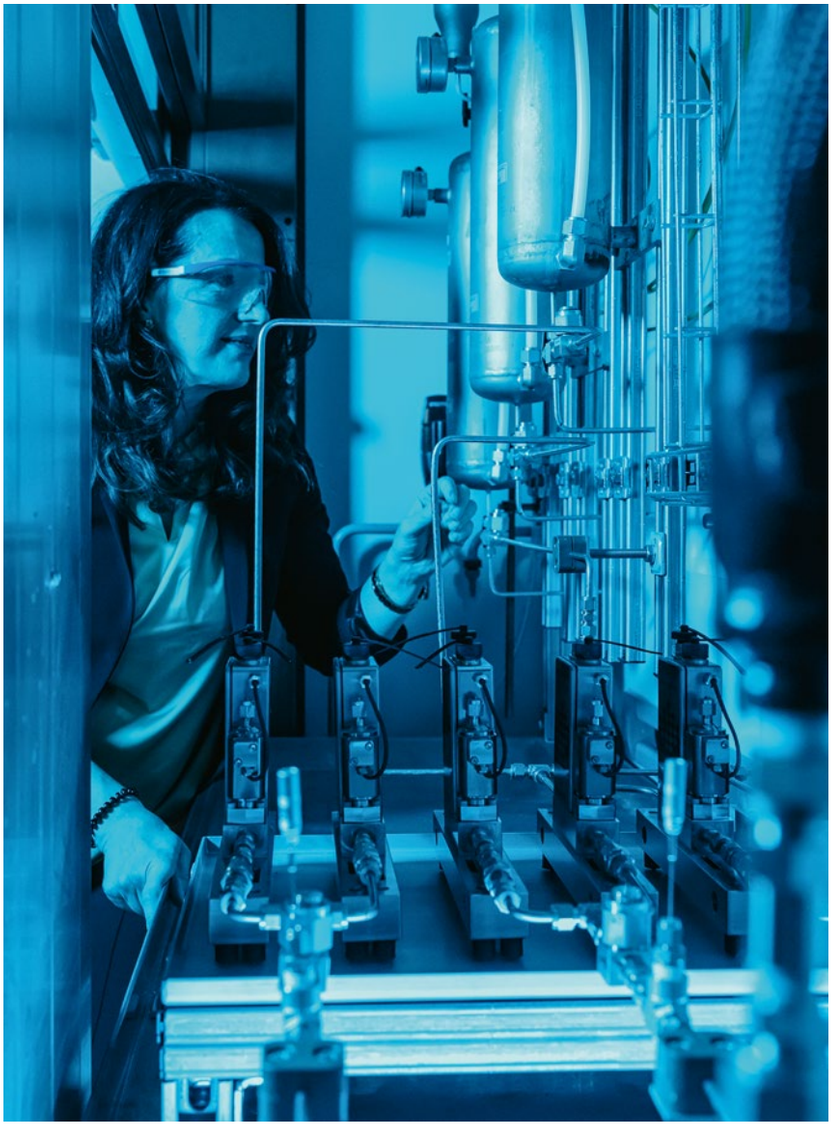
This development is part of the 3D-PROCESS project funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) (see box on page 39). The project is devoted to disruptive reactor concepts. These devices are digitally planned, manufactured in 3D printers, and optimized with the help of empirical process data and artificial intelligence. "We are completely rethinking the processes in chemical engineering," says Schaack. Together with the project partners, she has set herself the goal of making chemical production more sustainable.

The potential for this seems enormous. Prior to the pandemic, in 2019, the chemical industry consumed 200 terawatt hours of energy in Germany alone in the form of natural gas, petroleum products, coal, and electricity—eight percent of the total demand.

COOL INSTEAD OF ICE-COLD

Ortho-lithiation, for which the 3D-PROCESS team in Hanau is developing a reactor, is a case in point where a lot of energy can be saved with a better design. In this synthesis step, a lithium atom is temporarily introduced into an organic molecule. This releases so much heat that the reaction vessel has to be cooled down to at least minus 50 degrees Celsius. This technique uses liquid nitrogen, which requires a lot of energy to produce. A cooling temperature of -20 degrees Celsius could be sufficient for the new approach with the small metal block. The cooling could be carried out with an electrically temperature-controlled liquid, which would reduce energy consumption by 80 percent compared to the nitrogen variant. →

Mind meets electricity: The arrangement of the cooled reaction tubes in the printed microreactor is optimized with the help of artificial intelligence



Senada Schaack inspects the ortho-lithiation apparatus. Plans call for the lines to soon lead to the first self-printed test reactor

"The microreactor will deliver products of higher purity and require less cooling"

SENADA SCHAACK, THE HEAD OF THE SAM 3D COMPETENCE CENTER AT EVONIK

The enormous savings are made possible by the innovative design of the reactor. It differs significantly from the conventional tank reactors commonly used in the chemical industry. In the latter reactor, the reaction heat is dissipated by cooling coils in the interior or in the double-walled outer shell. Because the cooling surface is relatively small in relation to the reactor volume, the cooling medium has to be very cold. The new reactor is a much smaller system known as a flow reactor. In the simplest case, the reaction mixture is passed through a linear reaction tube, which is wrapped in a cover containing the cooling medium. The ratio of the cooling surface to the reactor volume is significantly larger, which means that the medium does not have to be that cold. The heat dissipation becomes even more effective if the reaction mixture is not just passed through one tube but distributed over several channels.

COMPLEX STRUCTURES HAVE AN ADVANTAGE

This is exactly how the experts at Evonik designed their microreactor. "In the first prototype, we distribute the flow of the reaction mixture over a total of 256 tubes," explains Dr. Hendrik Rehage, a process engineer on Schaack's team. The advantages are obvious: More tubes increase the flow rate while making cooling more efficient at the same time, because each tube is surrounded by its own cooling channels (see diagram on page 40). The experiments are intended to show whether the cooling temperature of -20 degrees Celsius calculated on the computer is actually sufficient.

The 256 reaction channels are each 0.8 millimeters in diameter. With conventional methods of metal processing, this would be an immense effort or not possible at all. But the situation is different when you use a 3D printer. "It doesn't matter at all whether we manufacture a reactor with one or 256 channels," says Rehage, explaining why additive manufacturing also makes very complex reactor geometries accessible. The decisive advantage of 3D printing compared to the classic production of microreactors is that the printed items can have any shape. Luckily, it's long been possible to carry out 3D printing with metals such as aluminum, titanium, and stainless steel. The metal is fed in in finely powdered form, melted by a laser beam, and then deposited layer by layer on the workpiece to be manufactured.

"The dimensions and also the structural design of the test reactor are the result of the simulations that we performed beforehand," says Rehage. The experts simulated how different geometries and process parameters affect where in the reactor it gets hot and to what extent, as well as how quickly the heat is dissipated. However, many of the mathematical descriptions are only approximations of reality. Therefore, it's still important that an experiment be conducted afterward.

A SELF-OPTIMIZING SYSTEM

This was the case with the first prototype for ortho-lithiation. The team wants to use the possibilities of 3D printing to provide the components with integrated connections for the installation of sensors. These record temperatures, pressures, flow rates, and substance concentrations during operation. "This data lets the system know whether it is getting too hot somewhere in the reactor or whether unwanted byproducts are being produced," explains Rehage. The engineers absolutely want to avoid both, because they reduce yield and product purity. If the product has to be laboriously separated from other molecules, this also increases energy consumption.

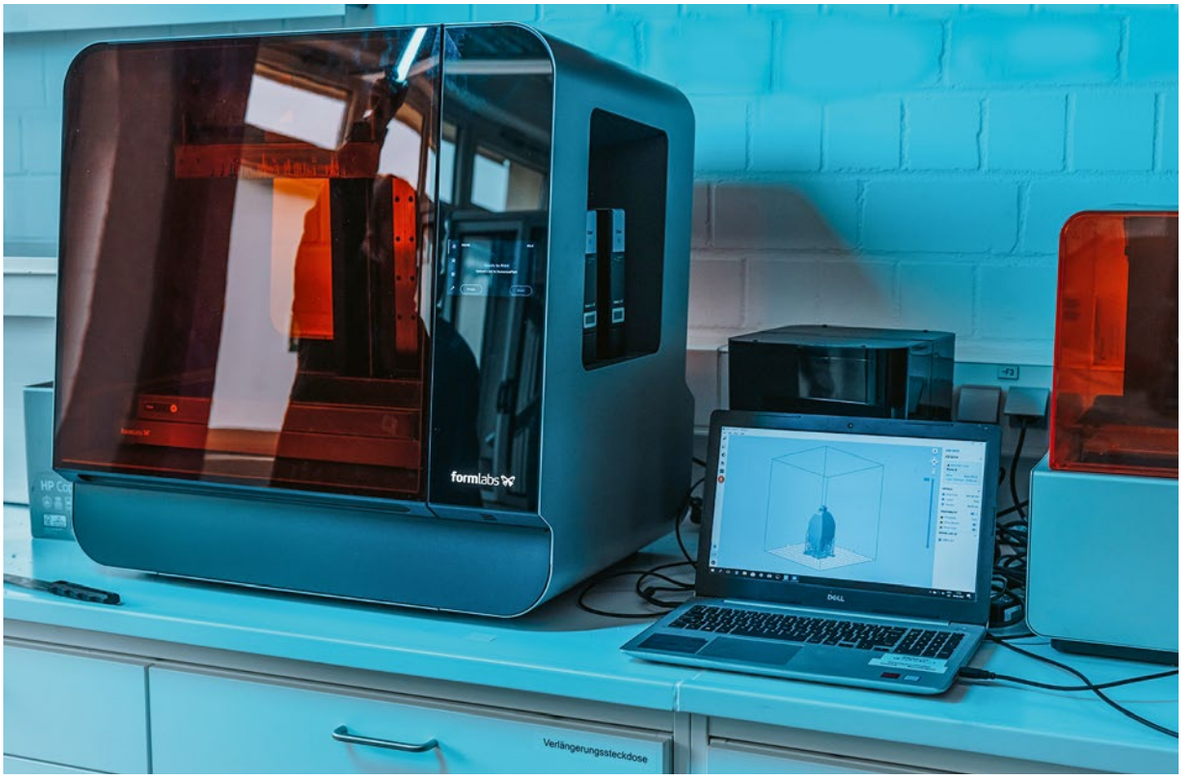
The 3D-PROCESS team uses methods of artificial intelligence to determine the parameters for which the yield and purity are as high as possible and the energy required for cooling is as low as possible. "On the basis of the sensor data, the system is able to adjust the process control and thus gradually get closer to optimal conditions in a self-learning loop," explains Schaack. If this optimum cannot be achieved with the existing reactor, the data provide information on how the design should be changed, Schaack adds.

Dr. Stefan Randl is also enthusiastic about such visions. As the head of research in the Health Care business line, Randl is following the experiments with the test reactor with great interest. He considers ortho-lithiation to be "a model example for many other syntheses in the pharmaceutical environment that previously had to be cooled or heated with a great deal of energy."

Evonik produces active pharmaceutical ingredients and their precursors for external customers. It often happens that Randl's team still has to develop the associated synthesis process. Wherever possible, attempts are made to implement a continuous process in a small flow reactor. "There is currently a trend in the industry away from classic batch production in large stirred tanks," reports Randl. Continuous processes in microreactors enable temperature, pressure, and safety to be controlled much better. The miniaturized processes also require less solvent because more concentrat- →

"We can produce the reactor for every new idea within two days"

CHRISTOPH KLAHN, ADDITIVE MANUFACTURING EXPERT FOR PROCESS ENGINEERING AT KIT



The team carries out test runs with the 3D printer for plastic components before the components are printed in stainless steel. The monitor shows an experimental design for ortho-lithiation

ed liquids are fed into the reactor. In addition, the catalyst required for the reaction can be used in the form of a much finer powder, which in turn leads to better product yields.

"For us, it's always important to develop new processes as quickly and reliably as possible, and in such a way that they are economical and offer customers in the pharmaceutical industry products of the highest and consistent quality," says Randl. It's a great help that reactor concepts can be simulated in advance and that the reactor that is best suited for an application is printed in the end.

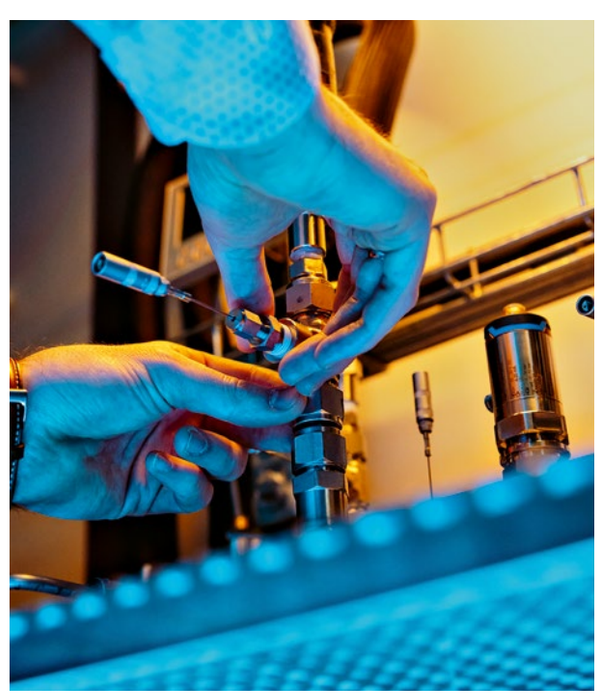
METHANOL MADE OF GREEN HYDROGEN

However, the printed microreactors should also bring their disruptive properties to bear in other areas. In another subproject of 3D-PROCESS, Evonik is working with researchers from the Karlsruhe Institute of Technology (KIT), Siemens Technology, and the KIT spin-off INERATEC. The partners are working on a reactor for the conversion of hydrogen and carbon dioxide (CO_2) into methanol or dimethyl ether. Both substances are important basic chemicals and can also be used as fuels. While the CO_2 comes from biogas or exhaust gases, the hydrogen can be obtained through water electrolysis—preferably when excess renewable electricity is available.

"Our goal is to create decentralized systems made up of standardized modules that can be set up next to a wind farm or a large-scale solar power system, for example," says Professor Roland Dittmeyer from the KIT Institute for Micro Process Engineering. A corresponding reactor must be simple and robust and also meet a number of requirements, one of which is to separate the resulting methanol directly from the reaction mixture. In fact, 3D printing allows defined porous structures in the reactor wall. Thanks to these structures, this can now be achieved in connection with a suitable temperature control.

FROM THE IDEA TO THE REACTOR

Initial trials in a test reactor have been promising. When all the small-scale studies are complete, the consortium will start to develop design rules to scale up the reactor to an industrial scale. Professor Christoph Klahn, who works on additive manufacturing in process engineering at KIT, praises the acceleration of the



The heart of the test apparatus: The front horizontal tube (left) will soon be replaced by the 3D-printed version

3D-PROCESS

The project "Disruptive reactor concepts by means of additive manufacturing: From the digital design to industrial implementation—3D-PROCESS" kicked off in June 2021 and will conclude in May 2024. It has a budget of €9.8 million. It is funded as a joint project by the Federal Ministry for Economic Affairs and Climate Action under the funding code 03EN2065A-E. The consortium leader of the project is Evonik. Other partners include Siemens, the Karlsruhe Institute of Technology (KIT) with the Institute of Catalysis Research and Technology, the Institute for Chemical Technology and Polymer Chemistry, and the Institute for Micro Process Engineering, as well as INERATEC. The aim is to develop process engineering components for more energy-efficient chemical processes that cause fewer emissions and are more sustainable.

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Process engineer Hendrik Rehage is a project manager in the 3D-Process project at Evonik

development process. "Thanks to the well-prepared design and manufacturing workflows, we can produce the corresponding experimental reactor for every new idea within two days," he says.

The software modules for these end-to-end workflows come from Siemens and include simulation, design, and digital control of the 3D printers for reliable production of the fine structures. Dr. Christoph Kiener, Principal Key Expert Functional Design at Siemens, says than the 3D-PROCESS research project is an important contribution to the energy transition. He thinks that the new possibilities will transform the concept of chemical reactors. "Until now, this has been the place for a chemical reaction," he says. "In the future, we will be able to bundle all the important process steps, i.e. mixing, reacting, separating, and so on, in a tailor-made way through simulation in one apparatus so that they then take place highly efficiently in defined zones." The test reactor, in which the synthesis and separation of methanol are now combined in a very small space, gives an idea of what is possible.

The image of chemical parks could change in the future if small flow reactors were increasingly used instead of large tanks. But do these minisystems actually supply sufficient quantities? "That's definitely the case for active pharmaceutical ingredients," says Stefan Randl from Evonik. With a throughput of one liter per minute, the small reactors can produce tens to hundreds of tons of active ingredients per year. Moreover, the concept can easily be scaled. Depending on the desired product quantity, the necessary number of reactors can be connected in parallel.

The concept is a viable alternative even for large-scale chemical production operations, says Schaack. She sees the potential for radically smaller systems and processes that—thanks to precise data, better simulation, and precise control, require less steel, less solvent, and ultimately less energy. That, in turn, would also lead to less CO_2 emissions. This really would be disruptive and enable chemistry to be more sustainable.

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

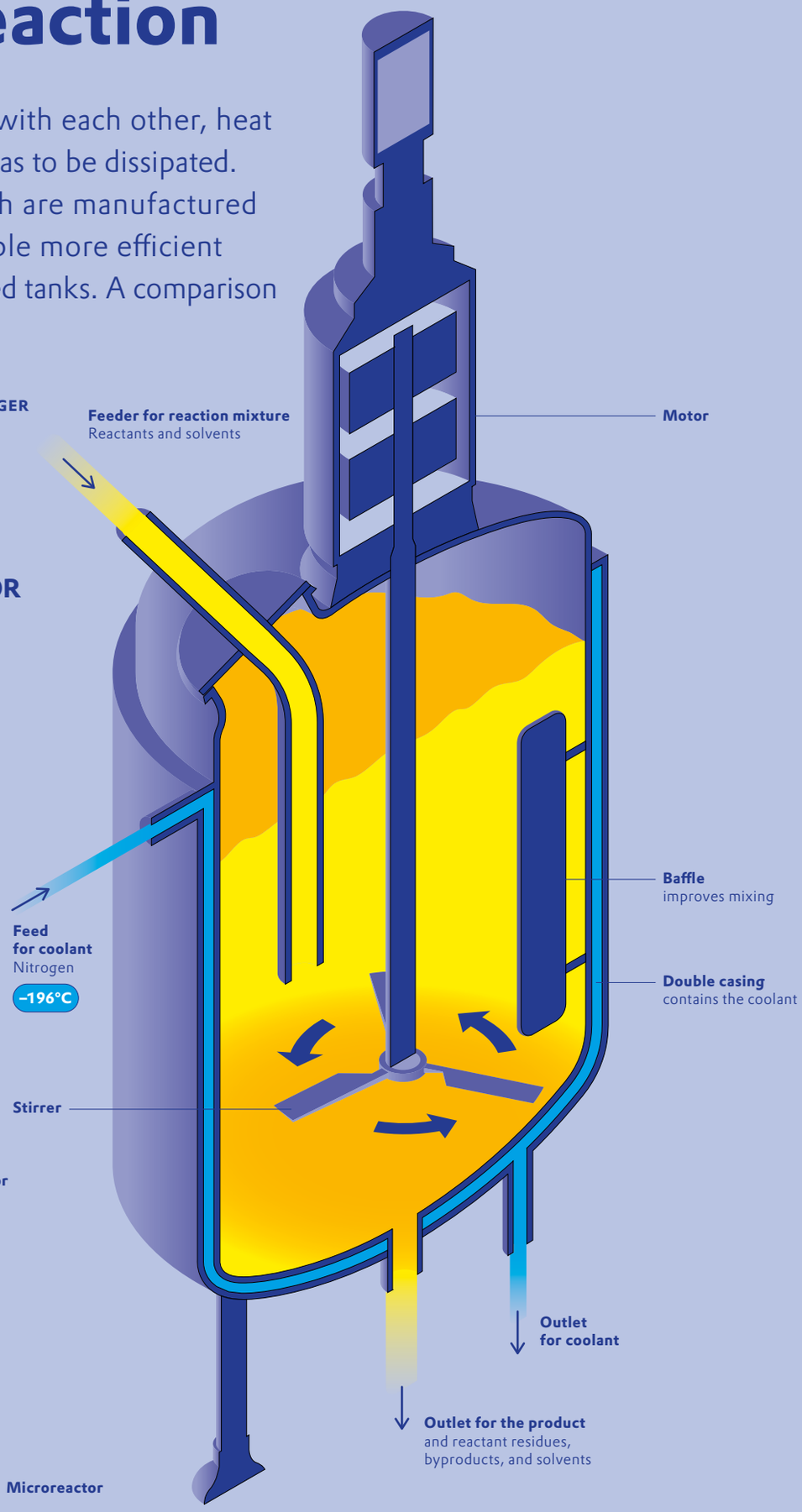
A cool reaction

When chemicals react with each other, heat is often generated and has to be dissipated. Small flow tanks, which are manufactured using 3D printing, enable more efficient cooling than classic stirred tanks. A comparison of the two systems

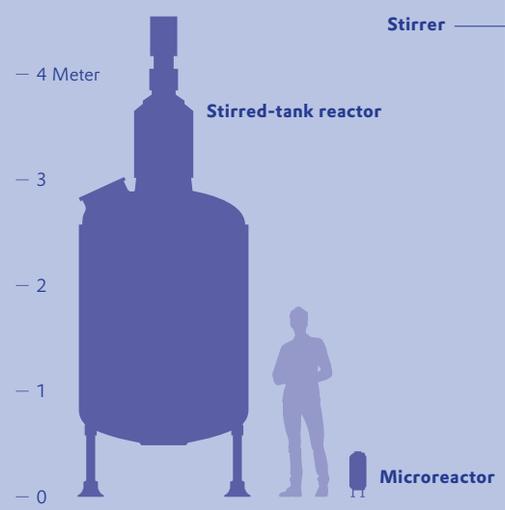
INFOGRAPHIC **MAXIMILIAN NERTINGER**

STIRRED-TANK REACTOR

The large reactor volume generates a lot of heat. A very cold coolant (nitrogen at -196°C) has to be pumped through the reactor casing to ensure that no part of the tank gets too hot.



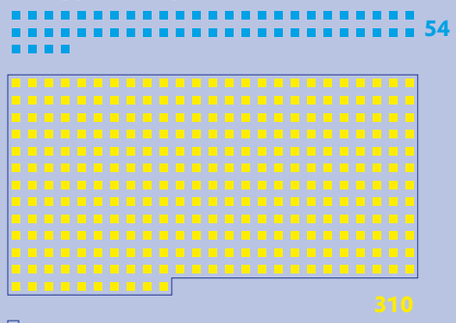
Size comparison



Comparison of the efficiency of the reactor types*

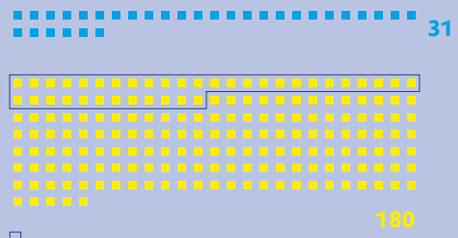
Microreactor **Stirred-tank reactor**

Energy consumption in MWh



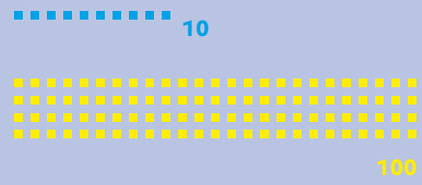
□ = ø annual electricity consumption of 100 German households: **310**
Source: destatis.de

CO_2 emissions in t



□ = CO_2 emissions of an Airbus A320 on a flight from Munich to Berlin: **37**
Source: atmosfair.de

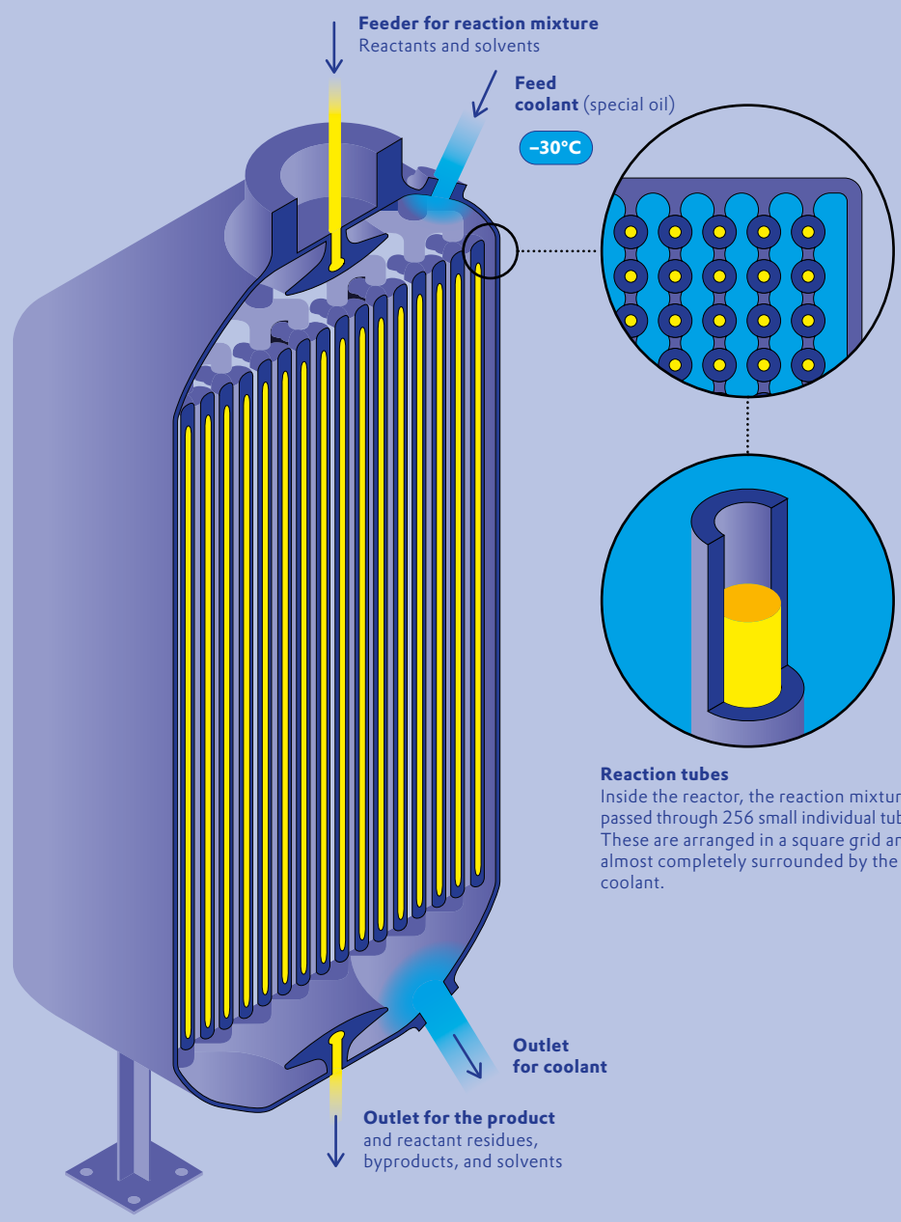
Space needed in m^2



*Relative to the cooling requirement for a production volume of 150,000 tons per year for ortho-lithiation

MICROREACTOR

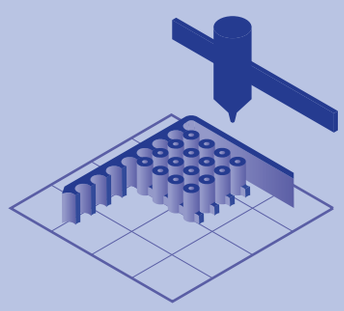
Many thin reactor tubes ensure that the local temperature stays lower. Because all the tubes are surrounded by a cooling medium, the heat is also better dissipated.



Reaction tubes
Inside the reactor, the reaction mixture is passed through 256 small individual tubes. These are arranged in a square grid and are almost completely surrounded by the coolant.

New production process

3D printing enables reactor components to be manufactured in shapes that would be very expensive to make using conventional production processes such as injection molding.



An anchorage for traditions

Belgium is a meeting point for politicians, businesspeople, and tourists from all over the world—not only because of its delicious pralines. It's impressive because of its trilingual culture, its historical cities, and its function as the center of European politics. Belgium may be small, but its time-honored traditions combined with its openness to the world give it unique perspectives

TEXT **PAULINE BRENKE**

Like a cruise ship, the dazzling superstructure towers above the former fire department barracks in Antwerp Harbor. The Havenhuis building, which was designed by Zaha Hadid Architects, is today the headquarters of the Antwerp Port Authority. It symbolizes both the history and the future of Europe's second-largest port. Goods from all over the world are transshipped in this harbor, which covers 25 square kilometers. That makes this northern Belgian city not only a center of trade but also an outstanding location for chemical production—and Evonik is one of the beneficiaries. The company's huge production location in the middle of the harbor is not only globally connected but also part of a multi-location C4 production network along with Evonik's biggest location, which is in Marl, Germany. C4 chemicals are byproducts of crude oil processing that are transformed by Evonik into high-quality chemical products.

Precise craftsmanship and a love of detail: Belgian pralines are renowned for their high quality and outstanding flavor. So it's no surprise that the world's biggest trading center for chocolate is located at Brussels Airport, outside the gates of the capital city. Here 1.5 kilograms of chocolate and pralines are sold to travelers every minute. One of the materials used by the *chocolatiers* to maintain the high standard of these tiny delicacies is potassium carbonate from Evonik. It gives the chocolate its perfect consistency and intense color.

Homage to Blondin and Cirage: Since 1991, many facades and house walls in Brussels have been dedicated to popular heroes from the comics. Pedestrians taking a stroll along the Comic Strip Route can view a total of 50 works of art. Comics are an important element of the Belgians' identity. World-renowned comic book series such as *Les aventures de Tintin* (The Adventures of Tintin), *Les Schtroumpfs* (The Smurfs), and *Lucky Luke* owe their existence to the fantasy of Belgian comic-strip artists. But what would our favorite childhood heroes be without their colorful appearance? Evonik supplies products for high-quality printing inks and hydrogen peroxide for bleaching paper.

When you're on a street in Brussels, a French fries stand is never far away. From tiny stands to exclusive multi-star restaurants, Belgian cuisine would be unthinkable without the famous Belgian *frites* (this is the French word; in Flemish or Dutch it's *Fritten*). The secrets behind the unique flavor of this specialty include the choice of a specific potato variety, the use of beef fat, and the fact that *frites* are fried twice. What happens to the fat after it has completed its mission of frying these crunchy potato sticks? Evonik converts it into biofuel with the help of the alkoxyde potassium methylate and directs it toward its next intended purpose.

De Ronde van Vlaanderen—the Tour of Flanders—is a traditional cycling event. Every April, professional cyclists are invited to complete the 230-kilometer-long route from Antwerp to Oudenaarde, pedaling along nearly impassable cobbled streets and stretches with a gradient of almost 20 percent. (Highly motivated amateurs can also participate in a subsequent race.) Evonik often takes part—for example, by providing Ultrasil brand silica, which gives tires their ideal composition, and Rohacell structural foam in lightweight components. In Belgium, a bicycle is not only a piece of sport equipment but also a popular means of transportation. About a fourth of Evonik employees cycle to their workplace.

TREMENDOUS DIVERSITY

The Evonik facility in Antwerp is the company's biggest production location outside Germany. Evonik has used this 109-hectare factory site, which is home to 11 production units, since 1968. The spectrum of products is just as extensive as the location itself. It ranges from raw materials for the electric and communication industry to binders for paints and coatings and environmentally friendly herbicides.

Evonik locations
1 Antwerp
2 Brussels
3 Ostend
4 Leuven

The

4

locations have

1,128

employees

IT'S ALL ABOUT CARBON

TEXT **TOM RADEMACHER**

"Energy and mobility can be decarbonized, but not the chemical industry"

JEROEN VERHOEVEN, VICE PRESIDENT PRODUCTION PARTNER MANAGEMENT, RENEWABLE POLYMERS AND CHEMICALS AT NESTE

For the chemical industry, the carbon atom is irreplaceable—but the fossil sources of carbon are not. Renewable carbon is being utilized more and more, and its proportion in products can now be precisely measured

Energy and mobility can be decarbonized, but not the chemical industry," says Jeroen Verhoeven. Carbon is much too important a component of chemical compounds to be replaced. There's hardly any product that contains no carbon atoms at all.

Verhoeven works at Neste, a Finnish company that is the world's biggest producer of diesel and aviation fuel based on renewable sources. The company has worked together with Evonik in the past to develop lubricant formulations. By its own account, through its products Neste prevented the emission of about eleven million tons of greenhouse gases in 2021 alone. In recent years the company has increasingly turned to alternative sources of carbon for chemistry.

The demand is tremendous. According to a study conducted by the nova-Institute, a German think tank, the chemical products manufactured all over the world every year contain about 450 million tons of carbon. This amount will more than double by the year 2050.

That's why the chemical sector is searching for alternatives to natural gas and petroleum with increasing urgency. It is examining all kinds of materials, ranging from used tires to cellulose waste, that can keep carbon in circulation and stop the extraction of new carbon from the earth.

Evonik has developed a material from renewable sources: TROGAMID® myCX eCO, a transparent polyamide that was specially formulated for eyeglass lenses. The BOSS brand is now presenting the first collection of sunglasses made with this product. The abbreviation eCO stands for "eliminate CO_2." This climate-friendly innovation generates only half as much carbon dioxide emissions as conventional polyamide, because its production uses renewable energy and 40 percent of the fossil raw materials are replaced with renewables. "We want to help shrink Evonik's CO_2 footprint," says Dr. Florian Hermes, the expert responsible for the topic at the High Performance Polymers business line at Evonik.

Today, in the sector as a whole, 85 percent of the carbon in chemical products comes from fossil sources. Over three fourths of this comes from petroleum and one fourth comes from natural gas. Only a tenth of chemical products are bio-based, and one twentieth are recycled. This mix must be fundamentally changed by 2050. According to the nova-Institute, by then more than half of all carbon should come from recycled materials; the rest should come from cultivated plants and directly from the air.

That sounds like a revolution. However, these changes will be carried out step by step. Completely rebuilding global industries such as chemistry, with its complex material flows and gigantic production networks, would not be a viable option. Nor would it make sense from an environmental perspective. The transformation →

Renewable raw materials Plants are part of the natural carbon cycle. The carbon contained in rapeseed, castor oil, and other useful plants has been previously extracted by them from the atmosphere. As a result, using them as chemical raw materials can offer advantages for the climate. Whether a finished product is actually climate-friendly depends on other factors, such as the source of the energy that is used to produce it

must be achieved by means of the production plants that already exist, by incorporating renewable raw materials in ever greater volumes into the existing processes.

One important method that will help us reach this goal is called the "mass balance approach." According to this approach, the renewable carbon that is fed into the beginning of a chemical value chain by means of a raw material can be assigned to a certain carbon-containing product at the end of the value chain. In very simplified terms, this is how it works: One ton of vegetable oil that replaces a ton of petroleum in a refinery is credited, for bookkeeping purposes, to a ton of finished plastic that is produced from the refinery's products. In this process, the vegetable oil and the petroleum do not need to remain separated. The mass balance approach makes it possible to process fossil materials and renewables together. The final balance is calculated at the end of the process.

ATOMIC MASSES INSTEAD OF KILOWATT-HOURS

This is very comparable to the way we deal with renewable electricity. Wind turbines and photovoltaic systems feed electric energy into the same power grid as power plants fired with coal and natural gas. Customers who pay for green electricity don't know where the electrons streaming out of their sockets really originate. However, they pay for the fact that the amount of electricity they use is equal to the amount of electricity from renewable sources that is fed into the grid.

In the chemical industry, this is somewhat more complicated. Instead of kilowatt-hours, we need to trace atomic masses. And we need to trace them through many complex reactions, some of which are closely guarded trade secrets. In order to ensure that this process is carried out correctly and transparently, binding regulations and international standards are necessary. One of the standards is ISCC PLUS.

ISCC stands for International Sustainability & Carbon Certification, an organization based in Cologne. Its PLUS standard ensures that the amount of carbon in the product that is declared as renewable in the calculations is exactly the same as the amount of renewable carbon that was fed into the process. Possible process losses are thus taken into account.

Standards such as ISCC EU have been legally binding for biofuels for a long time now. ISCC PLUS was developed for the chemical industry, among other sectors. Compliance with this standard is still a voluntary self-commitment. However, the number of valid ISCC PLUS certificates has recently been doubling year after year. Major producers of consumer goods are already attaching the ISCC PLUS label to packages of baby pacifiers, potato chips, and shampoo. As a result, demand is increasing all along the supply chain.

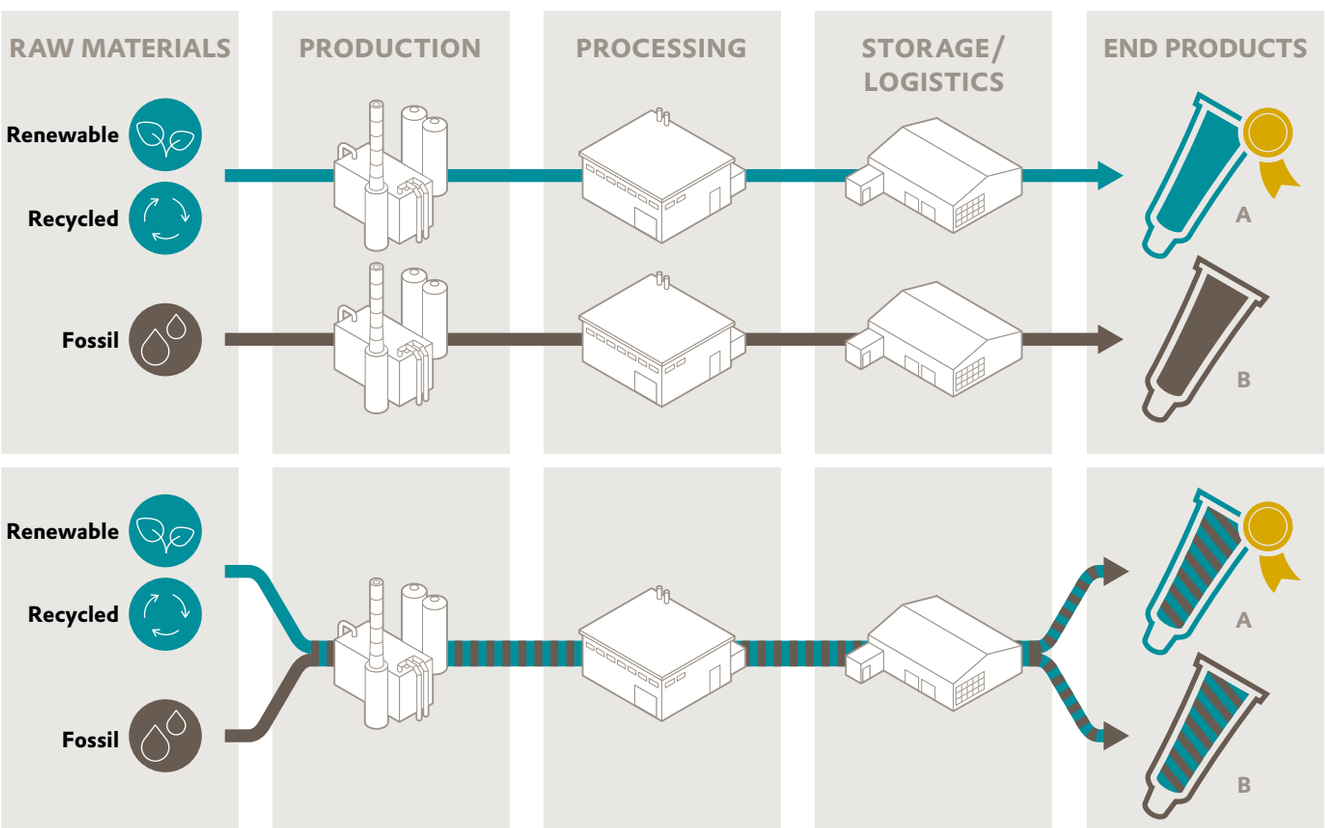
CRACK-C4 FROM SUSTAINABLE SOURCES

Evonik facilities in Marl and Antwerp have had ISCC PLUS certification since November 2021. They are part of the Performance Intermediates business line, whose products include plasticizers, additives, and intermediates for everything from detergents to shoe soles—around two million tons per year. The most important raw material for these products is called crack-C4. Its molecules, which contain four carbon atoms, are created when crude oil products are cracked. In the future, plans call for more and more of these molecules to be supplied by renewable residue materials from refineries. Whether it's butadiene for rubber applications or butene for plastics, these substances can be extracted from renewable or recycled sources—and they will be chemically identical to the compounds made from scratch. This is confirmed by the mass balance approach. "Certification according to ISCC PLUS enables us to increase the proportion of sustainable products in line with availability and demand," says Hendrik Rasch, who is responsible for Business & Sustainability Transformation at the business line.

Demand for certified products of this kind is also increasing within the company itself. For example, butadiene and butene are processed in the Coating & Adhesive Resins business line. The first eCO product made →

A clean sweep

How the mass balance approach makes it easier to use renewable raw materials



Whereas conventional production processes (top) require fossil and alternative raw materials to remain separate in the value chain, the mass balance approach (bottom) allows different material streams to be mixed. This reduces additional cost and effort in production, processing, and logistics. At the end of the process, the amount of renewable raw materials in the products can nonetheless be precisely assigned.

“We want to help shrink Evonik’s CO_2 footprint”

DR. FLORIAN HERMES, EVONIK HIGH PERFORMANCE POLYMERS

of a defossilized cracker product is already on the market: VESTOPLAST® eCO is processed in the hot-melt adhesives—or hotmelts, in technical jargon—that hold baby diapers together, for example. In this case, reliable adhesion is a must, and people are increasingly demanding sustainability as well. “Today the millennials have kids in diapers, and they’re watching out for eco-labels,” says Dr. Sabrina Mondrzyk, the head of Technical Marketing for Hotmelts. Adhesion is also important in the production of furniture, beverage cartons, and automobiles. And companies such as IKEA are demanding that recycling products be used even for adhesives. “Nonetheless, no company is making compromises when it comes to adhesion performance and processing,” says Mondrzyk. VESTOPLAST® eCO is chemically identical to the conventional variant, but in terms of the mass balance approach 97 percent of it is based on renewable raw materials.

Evonik’s Crosslinkers business line is also ready to manufacture eCO products. The division for crosslinkers, which promote the hardening of coatings, industrial flooring, and fiber components, for example, had its complete production line in Herne certified in March. In the future, all of its products will be available as eCO variants. That’s because acetone, on which all of its products are ultimately based, can be 100 percent produced from renewable sources in terms of mass balance approach. (see the report on page 10)

Nothing needs to be changed in the plants to enable them to process the renewable raw materials. Instead, the technological obstacles to the replacement of fossil carbon lie at the beginning of the value chain. Companies such as Neste need to answer questions such as “What raw materials are available, and how can they be transformed into precursor products that are chemical-

Fossil raw materials Petroleum, natural gas, and coal are currently by far the most important sources of energy and raw materials in the chemical industry. The carbon they contain was biologically bound in the course of millions of years and sealed in underground layers. The utilization of these deposits launched the modern age of industrialization. As we move toward climate neutrality, fossil raw materials should stay underground

Circular raw materials Substances that today are still waste materials could soon serve as valuable raw materials for new products, thanks to new and improved refining and recycling processes. In addition to mechanical recycling, the chemical recycling of plastics can play a much bigger role in the future.

ly identical to the conventional ones?" "Not everything is technically and economically feasible just yet," says Verhoeven. "However, many processes are proceeding faster than expected, even for us. And you have to leave room for innovation."

PYROLYSIS: A FUTURE PROJECT

Neste uses many different renewable raw materials today. In the past it mainly used vegetable oils, but today more than 90 percent of its starting materials are residues and waste. For example, the company cooperates with the McDonald's burger chain in the Netherlands. McDonald's used frying oil is converted by Neste into biodiesel for McDonald's supply trucks.

Wood scraps, residual waste, sewage sludge—the more inferior the waste, the better the life cycle assessment can be. Moreover, renewable "second-generation raw materials" of this kind do not compete with food production. Plastic waste will play a much bigger role in the future. One path toward this goal is called pyrolysis. In this process, plastic waste that cannot be sufficiently separated out for mechanical recycling is heated to a temperature of several hundred degrees Celsius in the absence of oxygen. The result is a thick black-ish-brown liquid. It not only looks like crude oil but can also be processed in a very similar way.

In 2021 Neste invested in a US recycling company that has its own liquefaction technology. The Finns want to process more than a million tons of plastic waste annually by 2030. Shell is building a plant for processing pyrolysis oil in Singapore. Total has announced that it will build the first industrial pyrolysis plant in France. BP is thinking of setting up a pyrolysis plant in Germany. Its refinery in Gelsenkirchen is connected via a pipeline with Evonik's nearby Marl Chemical Park. That opens up the possibility for closing the cycle for renewable carbon.

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

PUSH-BUTTON RAIN

TEXT **BJÖRN THEIS**

Precipitation by means of electroshocks? Algae that bind carbon dioxide and serve as the basis for fuels? Scientists are now extensively researching a variety of geoengineering technologies that could be vital for humanity's survival

Since the beginning of the industrial revolution, human beings have been changing global systems such as the climate and the earth's surface more than ever before. For example, we are emitting greenhouse gases and releasing long-lived man-made materials such as aluminum and plastics into the environment. Around the beginning of this millennium, the chemist and Nobel Prize winner Paul Crutzen and the biologist Eugene Stoermer proposed a new geological epoch in which human beings have become the biggest influence on the development of the earth's biological, geological, and climatological conditions. They called it the Anthropocene.

The International Panel on Climate Change (IPCC) also describes the serious consequences of our actions. In August 2021, this panel published a report that evaluated around 14,000 studies and came to the conclusion that humanity has clearly caused global climate change and that we can expect this change to lead to severe climatic, economic, and social upheaval. In order to prevent this from happening, the scientists at the IPCC state that mankind will have to not only substantially reduce emissions but also promote innovation in geoengineering.

COOLER THANKS TO REFLECTION

Geoengineering refers to technologies that enable people to intervene in the earth's geochemical and biochemical cycles on a large scale. Crutzen had already realized that such technologies would be necessary. As a result, he suggested in 2006 that sulfur dioxide be distributed throughout the stratosphere. His idea was that this would lead to the formation of sulfate particles large enough to reflect sunlight and thus reduce global warming.

Reflection is also the principle used by a group of researchers at Purdue University in the USA, who presented the world's whitest white last year. The paint that they developed reflects more than 98 percent of the light incident on it. Roofs on which this paint is applied would cool buildings more effectively than power-guzzling air conditioners.

REACHING FOR THE CLOUDS

Other technologies want to utilize clouds. In the case of cloud seeding, for example, airplanes, cannons or rockets disperse a substance (generally silver iodide or potassium iodide) into clouds. These chemicals serve as condensation or ice kernels for initiating precipitation. In 2008, rain was specifically caused in some areas of China in order to keep the venues of the Summer Olympics dry. In the future, some people even want to use laser beams or electric shocks to cause clouds to rain.

ATMOSPHERE SWEEPERS

Another important geoengineering concept is carbon capture and utilization (CCU), which aims to eliminate carbon dioxide from the atmosphere. In direct air capture, for example, air is sucked in and the CO_2 is extracted from it. Other initiatives utilize algae. The German startup Carbon Biotech wants to use algae as a biological means of binding carbon dioxide that is then converted into food or fuel. According to the company, one ton of *Spirulina* algae can absorb 1.8 tons of CO_2.

At Evonik, the Foresight team at Creavis is pursuing geoengineering approaches as part of the focus topic Sustainable Food Futures 2040. These approaches could be used in the production of food. Among other things, the Creavis incubation cluster Defossilation is investigating the possibilities of carbon capture.

Many of these technologies are still in their early stages. Their environmental, energy, and cost efficiency are still unclear, as are the consequences of their large-scale application. However, it's becoming increasingly clear that they will probably become indispensable. And who knows, maybe we will someday have sunshine or snow at the push of a button—and then the weather forecast will also be right all the time.

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

49 114,818
In
Indium

"We need a large enough quantity to recycle indium"

Dr. Daniel Goldmann is a professor at Clausthal University of Technology. He heads the Institute of Mineral and Waste Processing, Waste Disposal and Geomechanics. He and his team have worked on ways to recover indium.

LOG **KAROLINA FÖST**
PHOTOGRAPHY **RAMON HAINDL**

As a professor of recycling, I'm always on the lookout for new materials that we can recycle. About ten years ago I became aware of indium, a rare, silvery-white, soft, heavy metal that is about as common in the earth's crust as silver. At that time, indium was scarce on the world market and demand was increasing. That's because in conjunction with tin indium has two special properties: It is conductive as well as transparent, and it becomes a highly efficient semiconductor for LCD flat screens, which took the world by storm around the turn of the millennium. Today it is found in almost all televisions, computer screens, and touch screens. It's used in smartphones as well.

As indium became scarcer, prices rose, and I was commissioned by the then-leading flat-screen manufacturer and a large electronic waste recycler to develop a recovery process. We succeeded from a technological standpoint, but our process is not used commercially. China, the largest indium supplier, suddenly threw three years' worth of global production onto the market—around 2,000 tons.

The prices nosedived, and with them the willingness to invest in our recycling technology. However, I am sure that indium will be recycled in the future. The only question is when this will become economical.

Demand is expected to increase in the years ahead. More and more areas of life are becoming "smart" and the demand for screens is rising. Indium is also used in the latest photovoltaic systems. However, there is still a lack of used devices. We need a large enough quantity to make the process worthwhile. Until now, only 45 percent of electronic waste has been recycled in Germany, and the rate is even lower internationally. In my more than 35 years of recycling research I have dealt with many aspects of recycling. I'm now viewing it from the standpoint of behavioral psychology: How can we motivate people to hand in their old electronic devices?

Masthead

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“Of all the forces of nature, …

… I should think the wind contains the largest amount of motive power—that is, power to move things,” said Abraham Lincoln in 1860. That was only a few months before he began his first term of office as the President of the United States. And it was approximately three decades before the first wind turbines for producing electricity were erected in Europe.

Lincoln, who was self-educated in many fields of knowledge, realized even back then that wind power was an important source of energy alongside fossil fuels. ELEMENTS presents the contribution made by state-of-the-art materials and processes to the optimal use of wind turbines’ potential.

1/2022 **Wind power**