2/2022

EVONIK
Leading Beyond Chemistry

ELEMENTS

Research. Knowledge. The future.

Infinite Loop

Critical raw materials

Important economic resources with a high supply risk

Critical raw materials are defined as materials that play a crucial economic role in areas such as microelectronics or the use of renewable energies, but that are not available always and everywhere—either because they are hard to extract or because they must be imported from a foreign country. In the European Union, the European Commission decides which raw materials belong in this category. The Commission reviews and updates its list of critical raw materials at regular intervals, most recently in 2020. One new entry on this list, which now encompasses 30 raw materials, is lithium. The list plays an important role in trade agreements and in the promotion of innovations, resource efficiency, and recycling.

Raw materials Natural resources that are either used directly or recycled
Lithium A silvery-white and very soft alkali metal that reacts rapidly with water and moist air and only occurs naturally in compounds
Recycling Processing consumed resources so that they can be reused

DEAR READERS,

At first glance, the term “white gold” certainly seems exaggerated. That’s because lithium, the lightest metal of all, can be found almost worldwide, in rocks as well as in water. But it’s precious nonetheless, because modern electric mobility would not be possible without lithium-ion batteries.

In 2019 the Nobel Prize in Chemistry was granted to the developers of these batteries. However, the place where the batteries end up is not so glorious: Most of them end up in the garbage. Evonik wants to end this waste, because the demand for lithium is growing rapidly. Besides, extracting lithium from its natural deposits is costly and clearly not sustainable. Plans call for the project, which is called “Blue Lithium,” to obtain ultrapure lithium from pulverized old rechargeable batteries with the help of an electrolyzer.

The US automaker Tesla pinned its hopes on rechargeable lithium-ion batteries early on, and in its Model 3 cars it is now installing leather seating that contains no leather. Instead, it’s using artificial leather that looks and feels exactly like the real thing. Evonik is also one of the drivers of developments in this field. Modern crosslinkers make it possible to produce polyurethane-based synthetic leathers that lack the “artificial leather smell” that used to be typical.

But before I get completely carried away, I’m going to change the topic. This issue is the last one I will be responsible for as the Editor in Chief. After 14 issues of ELEMENTS, I’m handing over the magazine to Jörg Wagner, who joined the development editorial team back in 2018. I will remain closely connected with ELEMENTS as its publisher. And one thing is certain: We will certainly not run out of fresh topics from the world of research in the years ahead.

It’s been a pleasure!

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

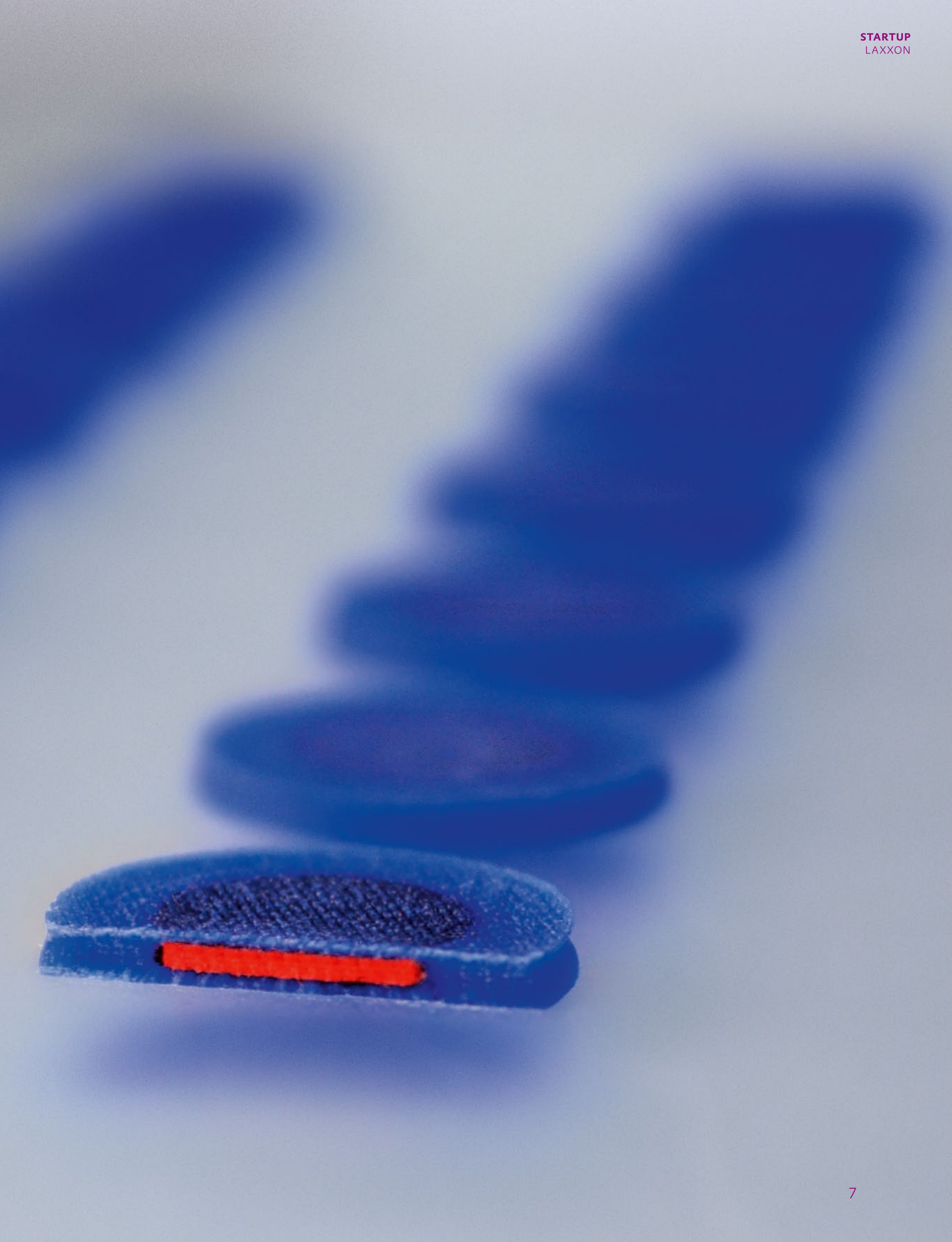
Basin building: Raw material suppliers extract lithium from brine in the Atacama Desert in Chile. However, recycling processes for recovering this raw material are drawing increasing attention

A wearable alternative: Modern artificial leather is hard to distinguish from leather made from animal hides—and that's why it's in great demand

Ready to go: "Rejuvenated" catalysts are especially effective at purifying oil products

EFFECTIVE PRINTING

They are round, oval or rectangular, colorful or white—the structured tablets from the US company Laxxon Medical, in which Evonik Venture Capital recently invested. Laxxon simply prints out the pills using a new type of 3D screen printing technology. The multi-layer structure enables the controlled release of the active pharmaceutical ingredients over an extended period of time. In addition, several ingredients can be combined with each other in this way. Polymers from Evonik ensure the targeted release of the active ingredients. “The technology is a great benefit for patients,” says Bernhard Mohr, the head of Evonik Venture Capital. “It reduces side effects and the number of tablets a patient has to take. This lowers the risk of forgetting an important medication.”



How long does a battery last?

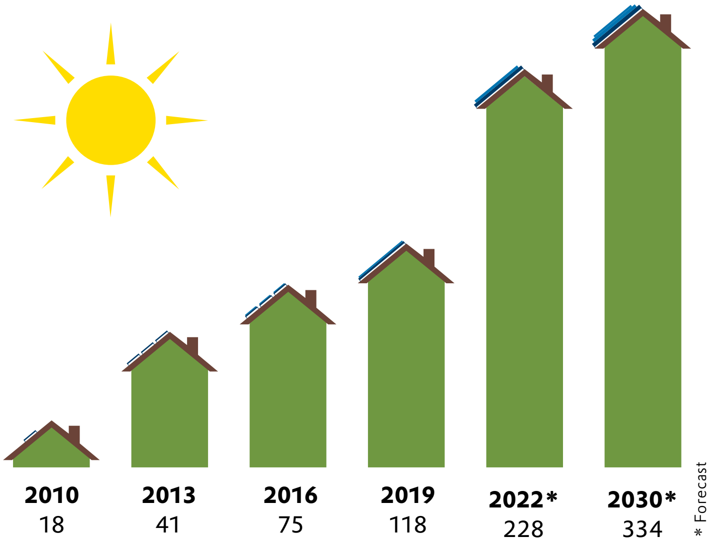
Machine learning makes predictions about the endurance of energy storage devices more reliable

It's hard to predict how long a lithium-ion battery in an electric car or a cell phone will last. The forecasting methods used today are based on measuring current and voltage during the charging and discharging of the battery, but not all the relevant parameters can be recorded. Now researchers at Argonne National Laboratory at the US Department of Energy have succeeded in predicting the capacities of a wide range of different chemical battery types. They did this by means of a machine learning algorithm. To train the computer program, the scientists collected data from experiments with hundreds of batteries. In a very short time, the simulation provides insights that would take several years with real cycles. Based on the research results, the scientists plan to develop higher-performance battery materials in the future.

THAT'S BETTER

Sunrise

Photovoltaic systems
Installed capacity worldwide in gigawatts



The energy transition continues to pick up steam. Photovoltaic systems with a total output of more than 200 gigawatts are expected to be installed for the first time this year—representing a more than fivefold increase within one decade. According to Bloomberg New Energy Finance, the fastest-growing product segment is roof-mounted solar modules, with China as the main customer. For 2030, the analysts expect volume to grow to more than 300 gigawatts.

Source: BloombergNEF

300

TIMES
their own weight. That's how much weight objects from a 3D printer can bear when made from a new type of polymer that is combined with quartz sand. Compared to conventional binders, the polyethylenimine used in the tests doubles the strength of the sand components. The technique was developed at Oak Ridge National Laboratory in Tennessee (USA).

PETASES...

...have raised hopes in the scientific community that global plastic pollution can be tackled biologically. These enzymes were first isolated in 2016 from the bacterium *Ideonella sakaiensis*. With the help of a PETase, this microbe breaks down the plastic polyethylene terephthalate (PET) in order to metabolize it. Researchers from the United States and the UK managed to modify the enzymes in such a way that, together with another enzyme, they further break down PET into its basic building blocks, ethylene glycol and terephthalate (TPA). The scientists have now characterized an enzyme that breaks down TPA and could be used by bacteria in the future to produce raw materials for new plastic.

Electricity vs. viruses

A new mode of action uses an electrically charged polymer to prevent the entry of infectious structures into cells

Diseases caused by bacteria can be treated with broad-spectrum antibiotics. In the case of viral diseases, a comparable universal approach has so far been lacking. However, an international research team led by the Universities of Ulm and Aarhus has succeeded in chemically optimizing polystyrene sulfonate so that it can be used for antiviral prophylaxis and the treatment of viral infections. "We have developed a negatively charged polymer that can prevent viruses from entering the cells," explains Rüdiger Groß, one of the authors of the study. According to the researchers' hypothesis, the polymer wraps itself around viral envelope proteins and its charge disrupts the interaction with the cell's receptor proteins. In cell culture, the principle was successful with herpes viruses, HI viruses, and the SARS-CoV-2 coronavirus, among other things.

PEOPLE & VISIONS

"The nature of the scallop shell could serve as a model for materials that have to function at particularly low temperatures"

THE PERSON

Dr. Konrad Meister grew up far away from the wilderness, in the Ruhr region. In his doctoral thesis, the biochemist and physical chemist investigated antifreeze proteins that ensure the survival of fish in the Antarctic. "A collaborator invited me to go on a polar expedition," he says. Since then, Meister, 39, has been to the Antarctic four times, including during his time at the Max Planck Institute for Polymer Research in Mainz. Today, Meister lives in Alaska and teaches at the university in the state capital, Juneau.

THE VISION

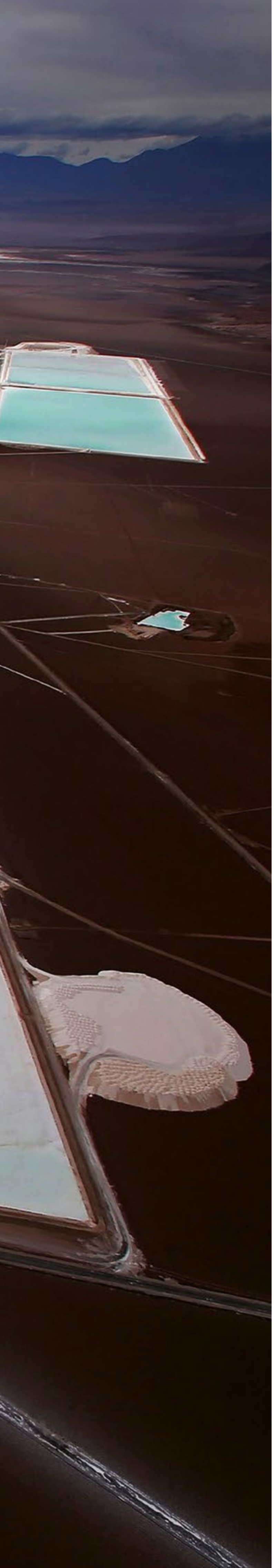
Icing causes problems in many types of technology, such as aircraft wings and solar cells. As a bionics scientist, Konrad Meister recognized the potential of a phenomenon that he happened to observe with colleagues in Antarctica: The scallop *Adamussium colbecki* has a surface with a **particularly fine structure** to which ice crystals do not stick. "The nature of the shell could serve as a model for materials that have to function at particularly low temperatures," says the researcher.

GOOD QUESTION

Can manure stop climate change, Professor Hacker?

Yes, to a certain extent. Green hydrogen can be obtained from pig manure in biogas plants, and no CO_2 is produced when it is burned. However, production has so far been uneconomical due to the high costs. Two years ago we developed a chemical looping process with which we can produce high-purity compressed hydrogen cost-effectively and decentrally. In the plant, biogas is first reformed into synthesis gas, which then reduces iron oxide to iron in a reactor. In a further step, steam is added, which oxidizes the iron again. This releases hydrogen. The generator is only as big as a freight container and can be used on farms, for example. The possibility of using renewable energy locally is extremely important for mitigating climate change.

Viktor Hacker is a professor at the Institute of Chemical Engineering and Environmental Technology at Graz University of Technology in Austria. In cooperation with a startup he is promoting the commercial use of the hydrogen generator.



POWER FOR THE PEOPLE

The aim of expanding electric mobility is to help save the climate. Nonetheless, the extraction of the lithium that is needed for this effort is leaving highly visible tracks on the earth. Recycling this raw material, which is crucial for battery production, is mitigating this strain on the environment. High-performance membranes from Evonik could soon be at the center of this trend

TEXT **CHRISTOPH BAUER**

Water in the desert: The Atacama salt flats in northern Chile with their gigantic saline pools harbor one of the world's largest lithium deposits

Green, turquoise, yellow—the gigantic basins glow in countless nuances of color under the blazing sun. The salt flats in the seemingly endless plains of the Atacama Desert in Chile are one of the chief sources of "white gold": lithium. In Australia, even larger volumes of lithium are extracted from hard rock minerals in open-pit mines that are more than a hundred meters deep. Along the sides of these pits, trucks slowly make their way upward and downward on narrow spiraling tracks. →

Far from the users: Workers prepare for the construction of a pilot plant for lithium extraction at the Uyuni salt flat in Bolivia

The gigantic extraction sites are a widely visible sign of the global transformation of transportation: away from combustion engines and toward electric drive systems with rechargeable batteries that contain large amounts of lithium. Some of the factors that benefit the environment on the one hand are leading to considerable damage on the other. In the Atacama Desert the sun causes the water to evaporate, increasing the concentration of lithium without any additional input of energy. But the extraction process requires huge amounts of water, and that causes the already scarce groundwater to sink to even deeper levels. More and more often, open-pit mines like those in Australia are leading to conflicts with the local inhabitants. Evonik is working to find a solution to this dilemma—on the basis of the company's membrane expertise.

ELECTRIC MOBILITY IS THE DRIVER

Experts agree that electric mobility will not make any progress in the decades ahead if there is a lack of the relevant battery materials such as lithium, cobalt, and nickel. On the contrary, the need for lithium carbonate and lithium hydroxide, which are crucial raw materials for the production of lithium-ion batteries, will grow by leaps and bounds. Up to ten kilograms of these materials are used in each electric vehicle. In 2018 the global demand for lithium carbonate equivalents amounted to 59,000 tons. According to calculations by the US lithium provider Albemarle, by 2025 this amount will already have grown to 650,000 tons—more than 11 times the previous figure. Lithium is also needed for other applications, such as the production of ceramics and lubricants (see Data Mining on page 19). "However, the crucial driver of the demand for lithium will be electric mobility," says Dr. Elisabeth Gorman, who is responsible for new business development in the field of lithium recycling at Creavis, Evonik's strategic innovation unit and business incubator.

RECYCLING IS BECOMING MORE ATTRACTIVE

In order to cover this increased need for lithium in the future, companies are investing in the expansion of lithium extraction and facilities for processing this raw material. In the future, recycling will provide another important way to obtain lithium. At its Hanau and Marl locations, Evonik is working on a development project for extracting ultrapure lithium from battery wastes.

The recycling of lithium from old batteries would solve two problems at once: the need to meet the rapidly growing demand for lithium, and the responsible disposal of the batteries, which still have enough residual charge in them to spark fires if they are not properly handled. Today the recycling of lithium is complicated and costly. As a result, at the end of the batteries' life cycle almost all of this material ends up in the trash. Even the proportion of lithium that remains in the recycling facility together with other residues after the recovery of cobalt and nickel is often chemically bound with the process slag. This slag is simply used by the construction industry as a mineral aggregate in ready-mixed concrete—a shameful end for the "white gold."

“The crucial driver of the demand for lithium will be electric mobility”

ELISABETH GORMAN, BUSINESS DEVELOPMENT MANAGER AT CREAVIS

And the amount of lithium that ends up in landfill today is only a hint of the challenge we will face in the future. We are still only at the beginning of the age of electric mobility. Several stages on the road to recycling are becoming apparent. Batteries that are now in use will remain on the road for a number of years. In many cases, when the vehicle that they powered is scrapped at the end of its life cycle, the rechargeable batteries are still capable of 70 to 80 percent of their original performance. They can be removed and interconnected in containers to form electricity storage units. Mercedes-Benz launched pilot projects with “second-life” batteries of this kind at various locations years ago in order to safeguard production plants from fluctuations in the power grid.

However, the use of these rechargeable batteries will eventually no longer be worthwhile. At that point, the focus will shift from battery disposal to recycling. The recycling of lithium and other battery components is becoming increasingly attractive from an economic perspective. The prices of cobalt and nickel have more than doubled over the past two years. It’s true that the price of lithium carbonate decreased slowly and continuously until the beginning of 2021, but since then it has increased almost tenfold. As a result, all the essential components of a lithium-ion battery have become so expensive that reuse is not only practical from an environmental perspective but also pays off in economic terms.

“Meanwhile, many countries are increasing the regulatory pressure,” says Elisabeth Gorman. By 2026, companies in the European Union will be required to recover at least 35 percent of the lithium in used batteries. That figure will increase to 70 percent by 2030. “The EU is also defining minimum standards for the processing of batteries,” adds the Evonik expert. “By 2030, new batteries will have to contain at least 12 percent recycled cobalt, 20 percent recycled nickel, and four percent recycled lithium.” Back in 2018, China required its domestic automobile production plants to find solutions for batteries that have completed their first life cycle. The USA →

Samples of the ceramic membrane are measured at the Evonik laboratory in Hanau

Elisabeth Gorman is responsible for the development of new business in the area of lithium recycling at Creavis

More than 6.5 million electric cars were sold all over the world in 2021. New production plants are being built in many countries. Even heavy pickups like the Ford F-150 are now being offered with electric drive

still has not passed a nationwide regulation in this area, leaving the problem to be solved by the individual states.

In order to meet the EU's quotas in the future, recycling capacities must be rapidly expanded. According to predictions, old batteries with a total weight of 100,000 tons will be ready for recycling in the European Union by 2023. The number of electric vehicles that have already been sold leads to estimates that by 2025 that figure will already be 300,000 tons in the EU and a million tons worldwide. Efforts to extract lithium from used batteries are increasing everywhere. Another reason for this is that the transportation of freshly extracted lithium salts from distant regions such as South America and Australia is energy-intensive and thus increases companies' CO_2 footprint. Shipping raw materials is expensive in itself, and in some countries customs duties are imposed as well. It seems logical that if a raw material is already available in a given region it should be used there for as long as possible.

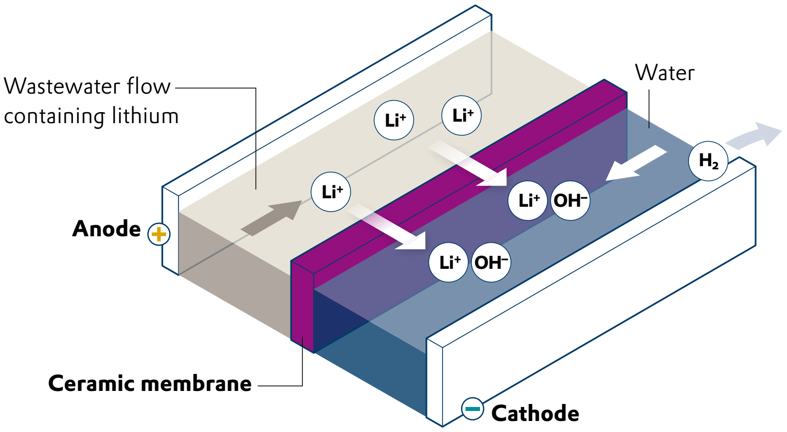
LITHIUM FROM "BLACK MASS"

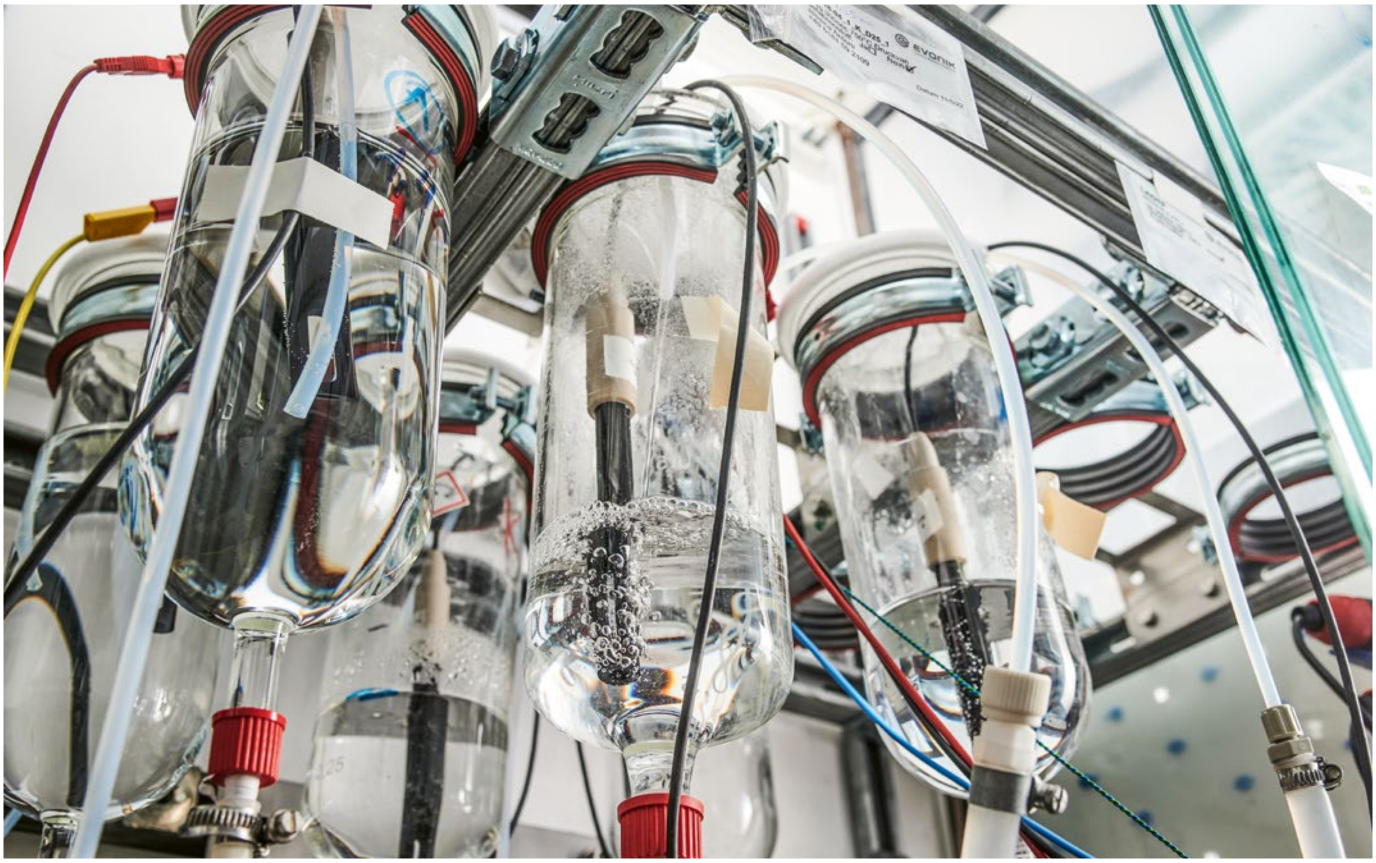
Evonik has been watching this development with growing interest for years now. The winner of the in-house idea competition Ideation Jam in 2019 was the Blue Lithium team. The team originally came up with the idea of extracting lithium from seawater, but it eventually switched to a technology that filters the residues from recycling facilities. This process was developed further within the company for one year; since then, the development process has been driven by Creavis. The basic objective is to extract lithium from "black mass" using the smallest possible inputs of energy and chemicals. By "black mass," the experts mean the material that is left after the plastic components of rechargeable lithium-ion batteries have been removed and the remainder has been shredded.

Some processes for reprocessing the finely ground contents of "black mass" are already being implemented. They are based either on smelting processes (which are known as pyrometallurgical processes), the use of alkaline solutions (hydrometallurgical processes) or a combination of the two. These processes have proved their worth in the case of cobalt and nickel, which today are

LITHIUM PRODUCED VIA ELECTROLYSIS

Wastewater containing lithium from the recycling facility flows between the anode and the ceramic membrane developed by Evonik. The positively charged lithium ions are attracted by the negative cathode and move toward the membrane. The membrane also contains lithium ions (Li^+), and as a result the lithium ions from the wastewater flow can hop from one localized point in the membrane to the next. By means of this "hopping mechanism" the membrane always releases exactly as many lithium ions on the cathode side as it receives on the anode side. At the same time, the water reacts with the electrons at the cathode to form hydrogen (H_2) and hydroxide ions (OH-), which react with the lithium ions to form lithium hydroxide—the desired product.





Thanks to the ceramic membrane, lithium can be filtered out of wastewater in such high purity that it can be directly used for the production of new batteries

already being isolated with high yields and reused as secondary raw materials. However, the residue that remains still contains lithium, whose recovery has so far hardly been economically worthwhile.

A MORE SUSTAINABLE PROCESS

However, Evonik is now working together with other companies that specialize in the ongoing use of the materials in “end-of-life” batteries. The aim is to develop more advanced technologies for extracting the white gold from the black mass. These companies are experienced in the recycling of lithium-ion batteries that are used in typical household and industrial applications. So far they have been recovering aluminum, copper, steel, and stainless steel.

However, the current processes for recycling lithium are not efficient enough, so this metal is being recovered only in small quantities. Together with the recycling companies, Evonik now aims to find a better process that will close the gap in the circular economy of lithium as a raw material for batteries. Many of the processes that have been commonly used to date for recovering lithium from battery residues work with a complicated precipitation process. In this process, the concentration of the lithium salts in an aqueous waste flow is increased and the lithium is then precipitated with sodium carbonate, which is also known as soda. The lithium carbonate thus produced must be expensively separated from the other reaction products, and it must then be converted into lithium hydroxide through the addition of calcium hydroxide. Only at that point is it once again available as a raw material for the production of rechargeable lithium-ion batteries. The entire process is cost-intensive, requires additional chemicals, and uses large amounts of water. As a result, it is not very appealing to battery recycling companies in economic terms.

The experts at Evonik are working to develop a simpler and more sustainable process. Their aim is to recover the lithium in a continuous process using a single step. They are backing an electrochemical process for purifying the lithium salts contained in the aqueous waste flows. Patrik Stenner is an expert in this field. He works as a process engineer in the Process Technology & Engineering unit at the Hanau location, where he is the head of the Electrochemical Processes & Exploration group.

In his laboratory, Stenner is developing an innovative electrolysis cell whose special feature is a lithium-selective ceramic membrane between the anode and the cathode. The aqueous waste flow from the recycling facility is channeled through the cell. Lithium ions react with the hydroxide ions (OH^-) that are created in the process to form lithium hydroxide and hydrogen (H_2) (see the infographic at the left).

“The product is so pure that it fulfills the high standards for ‘battery-grade’ material without any need for further processing. As a result, it can be used immediately for battery production,“ says Stenner. Can large-scale production now begin? Patrik Stenner smiles. “The results in the laboratory look very promising, and we’re already testing a prototype. But this is a research proj- →

ect, and there's still a whole series of questions that have to be answered before we can implement the process on an industrial scale," he says.

However, it's already becoming obvious that this process will be more manageable, more efficient, and more sustainable than the previous ones. The conductivity of the ceramic membrane is excellent on a laboratory scale, with a recovery rate of more than 99 percent. Initial comparisons suggest that the new process should be more economical and cost-efficient than the processes previously used. In this development process, the Evonik experts are benefiting from their experience with membranes and also their particle know-how. Because they are specialists regarding materials and their characteristics and applications—silicon dioxide and other special oxides, for example—at the nanometer scale, they know exactly how they can create a ceramic membrane that allows only lithium ions to pass through. They are now about to conduct the first tests with "genuine" wastewater flows. After that the next step, setting up a pilot facility, has to succeed.

A facility is running on an experimental scale at the Evonik laboratory in Hanau. The facility's results are promising

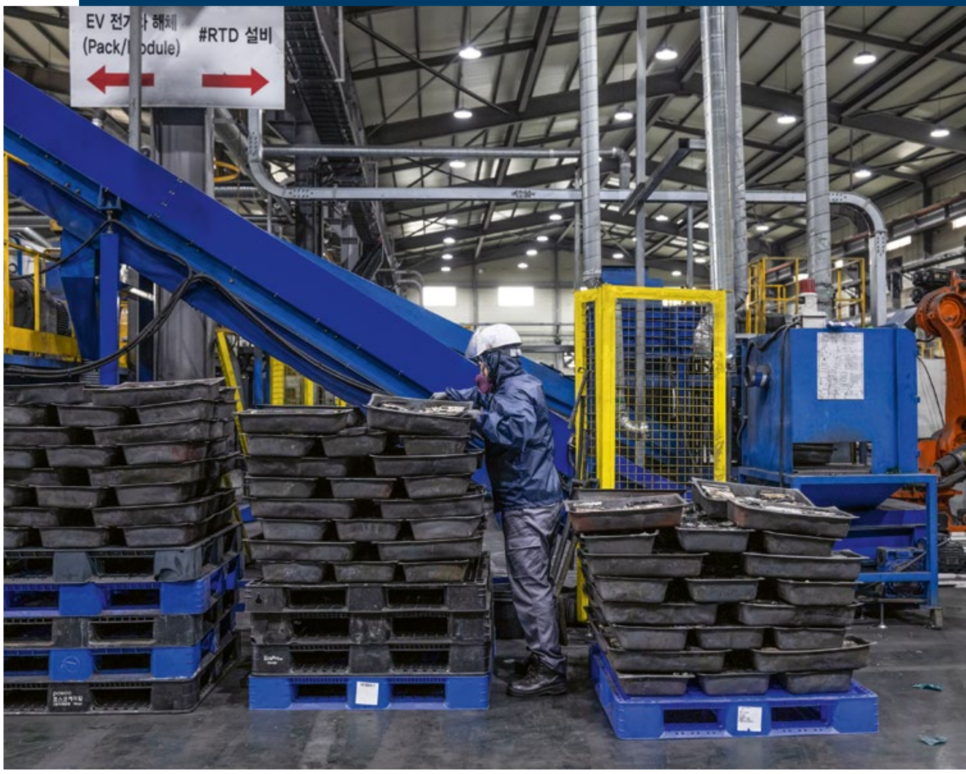
LITHIUM FROM NATURAL SOURCES

In Germany, a country with an automaking tradition, there is a huge demand for lithium. Tesla just recently commissioned an automobile production plant at a site near Berlin, and the company's CEO Elon Musk also plans to build a battery factory adjacent to it. Automakers such as Volkswagen, Mercedes-Benz, BMW, Audi, and Porsche also have plans of their own. Most of them want to cooperate with battery producers to build battery factories near their production locations. As a result, they are creating a tremendous demand for lithium in the heart of Europe.

One potential source of lithium might be available in Saxony, which has a long-established mining industry in the Ore Mountains near the border between Germany and the Czech Republic. Lithium has been discovered in the Zinnwald mine, which was largely closed down 75 years ago. The lithium can be found underground in a vein that extends all the way to the Czech Republic. It is estimated that more than 35 million tons of ore lie under the earth in this region. The mineral known as zinnwaldite contains 1.6 percent lithium on average. On just the German side of the Ore Mountains ridge, the deposit contains approximately 125,000 tons of lithium. That corresponds to about 650,000 tons of lithium carbonate, which would be enough to equip about 20 million electric cars such as the ID.3 from Volkswagen, according to Armin Müller from the operating company Deutsche Lithium. The new Tesla factory is located only 250 kilometers from the mining region. That's a clear locational advantage over Chile and Australia.

The Evonik process can also be used with natural deposits of lithium brine—and that would open up another stream of raw materials in Germany. The Australian company Vulcan Energy has joined forces with the local energy utility in the Upper Rhine Graben region in the western part of Germany. Tesla is owned by Elon Musk, the world's wealthiest man, and Vulcan Energy belongs to Gina Rinehart, a multibillionaire who is one of the world's richest women.

Her company's ambition is to extract lithium without generating any CO_2 emissions. The plan is to extract lithium from thermal deep water that is brought up from underground volcanic rock to the earth's surface. The deep water, which has a temperature of 120°C, is pumped to the surface. The heat is utilized, the lithium is extracted, and the now cooler water is then pumped back into the depths of the earth in another area. The



Old and defective lithium-ion batteries are shredded in this factory in South Korea. The resulting powder, which is known as “black mass” (see below) is the source from which raw materials such as nickel, cobalt, and lithium can be recovered

RAG-Stiftung, Evonik’s biggest shareholder, plans to establish a similar process using pit water from decommissioned mines in the Ruhr region.

DEVELOPMENT UNTIL 2025

The Evonik experts Gorman and Stenner think the application fields of primary lithium extraction are exciting. “However, for us that would actually be the second step,” says Gorman. “We are initially focusing on secondary lithium extraction—in other words, on recycling.” Both of them are confident that they will have developed the ceramic membrane process to market maturity within the next three to five years.

Gorman emphasizes that Evonik would not do the recycling itself. This task would be performed by the operators of recycling facilities, who could increase their yield of raw materials relevant for battery production with the ceramic membrane “made by Evonik.” Specialized companies of this kind are currently popping up in large numbers. Most of them are set up jointly by battery manufacturers, recycling companies, and automakers.

The Evonik experts believe that China, a global pioneer in the field of electric mobility, will be a significant market. According to a study conducted by the PWC consulting firm, a million new electric cars rolled out onto China’s roads in the first quarter of 2022—two thirds of the world’s registered battery-driven cars. In China, 15 percent of all new vehicles are electric. By comparison, that figure is 13 percent in the most important European markets, seven percent in South Korea, five percent in the USA, and only one percent in Japan.

GLOSSARY

Cell The smallest electrochemical current-producing unit of a battery. The cell consists of two electrodes, an electrolyte, a separator, and a housing. When the battery discharges, the stored chemical energy is transformed into electrical energy by means of the electrochemical redox reaction.
Battery An interconnected group of several cells. In primary batteries the reactions during the discharge process are partially or completely irreversible. In other words, the battery cannot be recharged.
Rechargeable battery A secondary battery in which the discharge reactions are largely reversible. As a result, it is possible to transform chemical energy into electrical energy and vice versa multiple times.
Lithium battery A primary battery in which lithium (Li) is used as the active material in the negative electrode.
Lithium-ion battery A general term for a rechargeable battery based on lithium compounds. The reactive materials in the negative and in the positive electrode and in the electrolyte contain lithium ions. Lithium-ion rechargeable batteries have a higher specific energy than other types of rechargeable batteries. Because deep discharging or overcharging causes them to lose capacity, they need electronic protection circuits.
Lithium-polymer battery A special type of lithium-ion rechargeable battery in which the electrolyte is a solid or gelatinous polymer-based foil. This enables a more open design, for example one that is especially flat. This type of battery is mainly used in electric vehicles.

Patrik Stenner with a sample of the precursor material from which the ceramic membrane is made. His goal is to also implement the process on an industrial scale

"We want our process to be more effective and more energy-saving than previous methods"

PATRIK STENNER, PROCESS ENGINEER AT EVONIK'S HANAU LOCATION

For a long time, German automakers found it difficult to gain a foothold with electric cars in the Chinese market. But now they have doubled their market share from two to four percent within one year, thanks to new models and expanded on-site production. Greater vertical integration would help German companies to expand this channel, according to the automotive expert Jörn Neuhausen from PWC. "In the future, investments in local battery production, the construction of gigafactories in Europe and the USA, and partnerships with raw material producers could play a bigger role for automakers in helping to reduce their dependence on volatile supply chains," he says.

THE DANGER OF A "BATTERY GAP"

The key success factor for the surge in electric mobility is the availability of batteries and the raw materials they contain. The Roland Berger consulting firm assumes that the global demand for lithium-ion batteries will increase to 2,800 gigawatt-hours (GWh) by 2030, and that about 30 percent of that demand will be for the production of electric cars. At the moment, the demand amounts to approximately 390 GWh. Wolfgang Bernhart, a senior partner at Roland Berger, believes that there is a high risk of "encountering a battery gap."

According to an analysis conducted by the Center for Automotive Research, which is based in Duisburg and Beijing, in the next six years there will be a global shortfall of battery cells for almost 15 million new cars. It will be caused mainly by shortages of basic materials such as lithium, cobalt, and nickel. "Access to raw materials originating in the circular economy is existentially important for the automobile industry, because otherwise the automakers won't be able to reach their own targets or the legally prescribed climate goals in the medium term," says Elisabeth Gorman.

The technology she and her colleagues are developing at Evonik and its partners could improve the sustainability of electric mobility and do even more. It could also help to ensure that less of the natural environment is sacrificed to the demand for lithium in the wide expanses of the Atacama Desert in Chile as well as in the Australian outback.

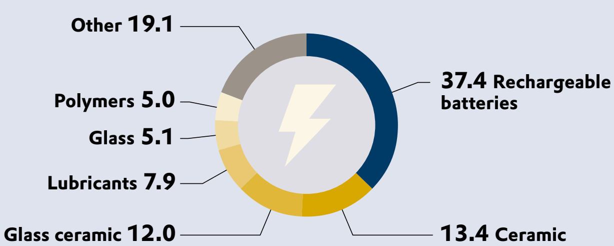
Christoph Bauer is a journalist who works at Evonik's Communications department

LITHIUM IN FIGURES

This lightweight metal, along with elements such as cobalt, nickel, and copper, is one of the most important raw materials for the energy transformation. Here's an overview of its economic significance

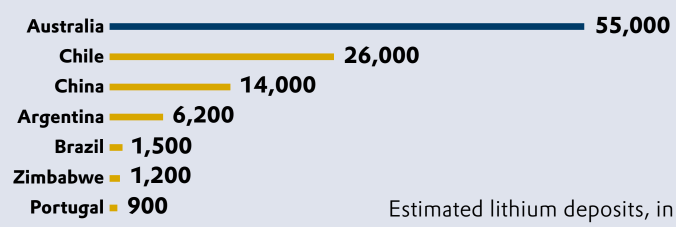
INFOGRAPHIC **MAXIMILIAN NERTINGER**

Indispensable for energy storage
Use of lithium in 2015, in percent

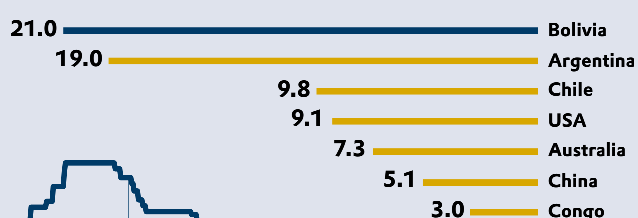


The largest suppliers
Lithium extraction in 2021* in metric tons

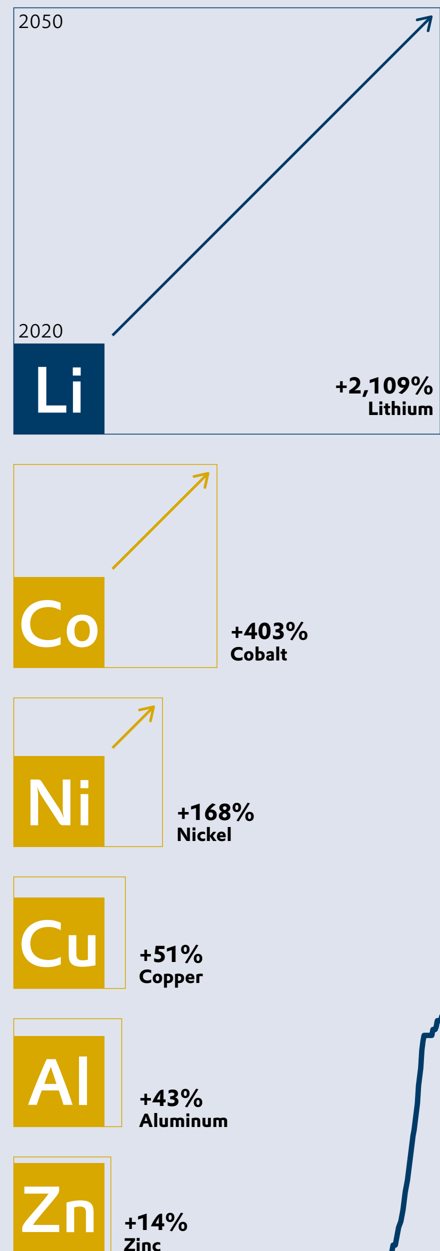
*Forecast



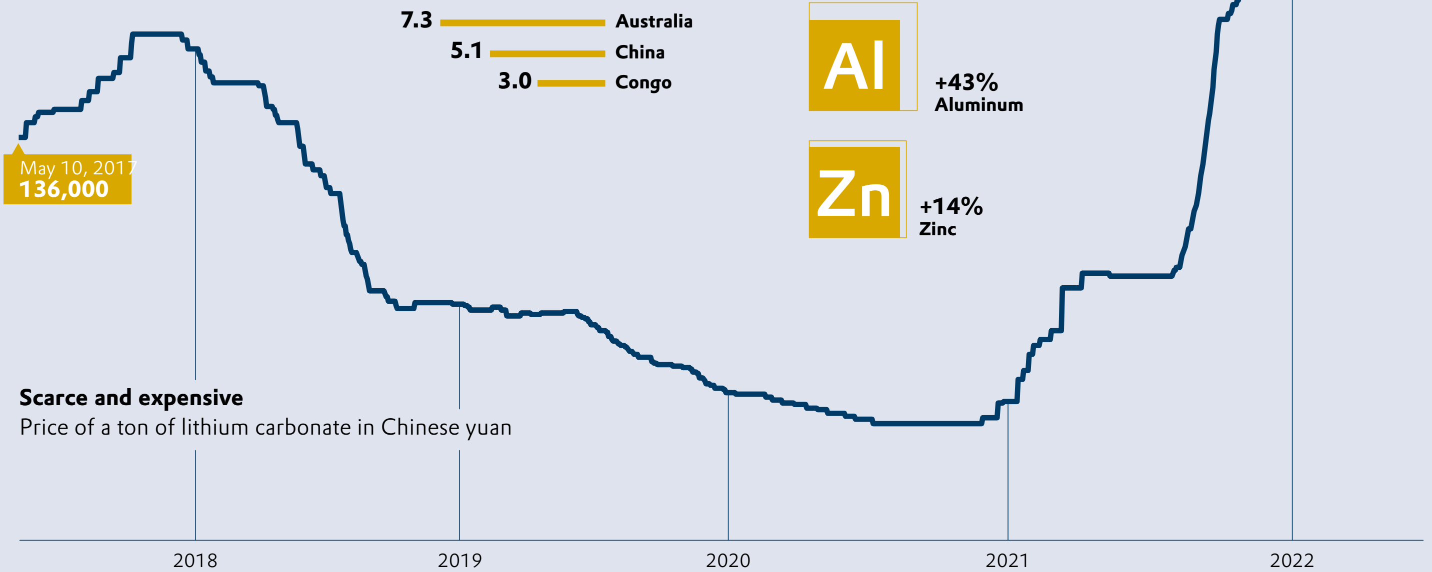
Estimated lithium deposits, in millions of tons



The demand is growing
Increase in demand for selected metals to be used in technologies for the utilization of renewable energies in Europe in 2050 compared to 2020*, in percent



Scarce and expensive
Price of a ton of lithium carbonate in Chinese yuan



Sources: U.S. Geological Survey, German Mineral Resources Agency, KU Leuven, Trading Economics

"In this context, we cannot simply rely on markets"

COVID-19 and the war in Ukraine have stretched global supply chains to their limits. This applies especially to raw materials that are needed for the energy transition. René Kleijn, professor for industrial ecology at Leiden University explains how industries and countries can get more resilient to price shocks and lack of supply

INTERVIEW **CHRISTIAN BAULIG & JÖRG WAGNER**

Fighting for a more sustainable management of natural resources: René Kleijn in front of the Institute of Environmental Sciences at Leiden University

Professor Kleijn, last year you described in one of your papers how a suddenly erupting war can lead to severe supply disruptions for materials that are critical in the energy transition. That's exactly what has happened one year later in Ukraine. Do you have a prophetic gift?
RENÉ KLEIJN Of course I would rather have been wrong than be in the situation we are in right now. The global transition in terms of renewable energy has accelerated in the last few years. That's good because we have to comply to the global climate goals. But if we are really going to make this transition, it will require a huge amount of material—and nobody really knows where those materials will come from. I've been working on this topic for quite a while so I'm happy to be one of the individuals who has predicted the problems that might occur a bit beforehand.

In many industrial countries the energy transition started 20 years ago. Why didn't we prepare for situations like these?
There's been a lot of confidence that markets would solve these types of issues of supply and demand. Many politicians follow the idea that if demand is there, supply will somehow materialize. This obviously is not true in every case. Since the beginning of the COVID-19 pandemic we've been confronted with the fact that we are very reliant on global supply chains—take face masks or components for ventilators. When the supply from China was disrupted because of lockdowns and harbors not operating, the whole global distribution basically broke down.

The logistical effects of the pandemic have decreased. Why are we still suffering from shortages of critical raw materials?
We are in a situation where mining companies have to make investments far in advance in order to get mines up and running. It's a long process that can take 10 to 20 years, from finding a resource somewhere, obtaining the permits, doing the exploration and getting the funding in place to open a new mine. Take, as an example, copper that is needed in generators for wind turbines, in solar cells and in the electricity grid. Mining experts told me that to meet the upcoming demand in the next 30 years they would have to invest into two large mines every year starting today! This gives you an impression of the type of effort that is needed to produce the materials needed for the energy transition. In this context, we cannot simply rely on markets

And that's not even taking into account political problems like Russia—a country we have recently tried to avoid global trade with.
Exactly. In some cases we rely on imports from authoritarian states and, as we see with Russian gas, it's quite difficult to enforce sanctions if you depend on these imports. And there's no way that we could ever introduce the same type of measures for China.

Does this mean we have to turn back globalization in favor of a more regional approach?
Not necessarily. But we do have to look at the resilience of supply chains in order to absorb shocks →

Child labor: In countries such as the Congo, copper and other raw materials that are important for the energy transition are extracted under dubious conditions

in the system. The more resilient you are, the more shocks you can absorb, whether they are demand shocks like the quick uptake of electric vehicles, for example, or supply shocks where you suddenly don't have materials from Russia and Ukraine available anymore because of a conflict.

How can we create resilience?
One thing is to diversify our supply. A lot of regions like the US or Europe are looking at safe and reliable partners like Canada or Australia from which we can get lot of our raw materials in a way that we find acceptable. But we also have to consider more mining within Europe…

…which is not an easy task.
Indeed, we're not used to large scale mining in our backyards anymore. However, we need to use way less mining for renewables than we have used and still are using for coal mining.

This argument won't convince the people who are directly affected in their communities.
That's true. We should be aware of that and understand it. However, we have this problem with many aspects of the energy transition, whether it's mines or wind turbines or power lines. We also have good ways to deal with these concerns in terms of public involvement during these processes. That's why Europe sometimes cannot act quickly.

You are suggesting financial compensation?
There has been a huge resistance against compensating people for impacts that they have encountered. Let me give an example from my country: We have closed a huge gas field in the North of the Netherlands because the extraction of the gas caused small earthquakes—without catastrophic consequences. The operator and the government made a huge sum of money from extracting the gas. If you had one percent of that revenue flow into the local communities, it might have solved all the issues. The gas field could probably still be open and play an interesting role in the current energy situation.

What's in it for people in other parts of the world where we source many critical raw materials like cobalt?
There are a lot of places in Africa where local communities are very disappointed with the way the Chinese operate in their countries—paying to the elite, extracting the resources, and maybe building a railway or a road here and there. I think we can act differently. We can bring long term commitment. We can

A booming sector: The solar industry requires large amounts of rare raw materials such as tellurium, indium, and gallium. China is one of the most important customers bring a social and responsible type of mining there. We can help the people to earn some money from extracting resources, and at the same time also develop local communities. I know this sounds a bit idealistic and would be difficult to make happen in countries where a lot of corruption exists. But I do think this could be a unique selling point for European sourcing activities.

Will this strategy lead to higher prices for strategically important materials in the future?
Kleijn Yes, I think we have to pay for more security of supply. Furthermore, the European Commission is aiming for responsibly sourced materials. And that means that there is also a price premium for materials being responsibly produced and mined, in Europe where we have environmental legislation and take care of local inhabitants, whilst materials from mined in an irresponsible manner and refined in China might not have that label.

The impact of war: After Moscow's invasion of Ukraine, deliveries of oil and natural gas from Russia were reduced or stopped altogether

If we're struggling so much to secure the supply of raw materials—shouldn't we ask ourselves if we really need all these materials?
Indeed, you could really question whether everybody should have a 60 kWh or even 100 kWh battery in his or her electric vehicle. That leads to a huge amount of material wasted because the car is just standing there for most of the time not being used. Do we really need that? Once you start integrating cars into the electricity network, it's maybe going to be a different story. But a reduction of energy use and material consumption is always the best and cheapest and most sustainable option. Sometimes, we tend to forget about that.

Many companies, like Evonik, are working on new generations of batteries that don't contain rare and expensive ingredients like lithium at all. Will scarcity of resources induce faster technological progress that helps us overcome some of the current problems?
I'm very optimistic about what technology can do. We already have lithium ion phosphate batteries that don't use any cobalt. They have a little bit less capacity than other batteries but at the same time they are also safer in terms of fire hazards. However, in the end, it's not only engineering, it's also economics, it's business models: The product that sells best and makes the most money is not necessarily the one that is engineered best. Therefore, it's important for governments to set out biases. If we really want to steer our engineering capabilities, our ingenuity, our creativity in the right direction we should have something like a carbon price, for example.

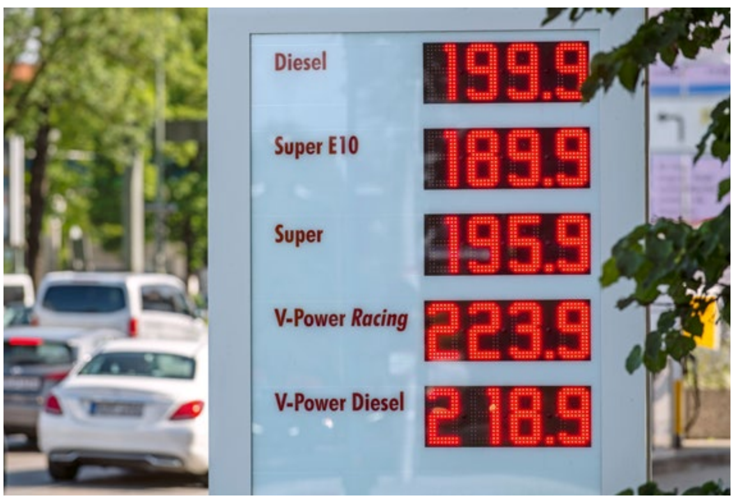
We've already introduced carbon pricing in recent years...
...which is a good start. Including the costs of environmental degradation into the cost of materials increases the price of materials and makes the circular economy a lot more attractive. People take care of materials much better than before.

However, some business models won't work anymore if prices for raw materials are increased very strongly by political regulation. Do we simply have to accept that?
Yes, raw materials will become more expensive. But I don't see how you could do it in any other way. The extraction of raw materials leads to a lot of environmental degradation that's in many cases not being paid for at the moment. There is no way we are going to meet our climate goals if we don't have carbon pricing.

Is it just the relatively low price of freshly mined material that makes recycling so difficult?
We live in a throwaway society where materials are just too cheap to actually matter. Within the EU Horizon 2020 funded SUSMAPRO project we work together with the university in the German city of Pforzheim and investigate the recycling of rare earth metals, which are crucial ingredients for the energy transition. They are in the magnets of wind turbines and the motors of electric vehicles. There will be a huge need for magnets. The technology to recycle them is currently being optimized within the project—that will not be the issue. Another part of the problem is: How do you get these magnets from the electric vehicles to the recycling plants? →

“I’m very optimistic about what technology can do”

René Kleijn (58) is an associate professor in Industrial Ecology at Leiden University in the Netherlands. He is the author of many scientific publications and helped develop the field Industrial Ecology into a mature scientific discipline in the early 2000s. His research revolves the systematic analysis of sustainability issues using tools like Life Cycle Assessment and Substance and Material Flow Analysis. Kleijn has applied these tools in many different domains including the chemical industry, the energy sector and the recycling industry. In recent years, the focus in his research has been on critical raw materials, resilient and responsible supply chains, circularity, and possible material constraints within the energy transition



Inflation: Because the supply of oil and other raw materials is faltering, consumer prices, including the price of gasoline, are exploding worldwide

Have you ever seen the motor of an electric car with its rotor? It consists of steel blades with holes. The magnets are often glued into the holes. So if you want to recycle these magnets, you have to dismantle all of the housing in order to get to the motor. Then you have to take out the motor, dismantle it to reach the rotor and somehow get these magnets out of the rotor that they are glued in. After that, you have a hundred euro or so of material. This is not going to fly economically.

You are asking for stricter regulation?
Yes. Either you have to enforce recycling of this stuff or you need a huge price premium on recycled materials. That’s the only way this will work out. Today, the price of the material alone is not enough to steer the system in the right direction. Materials are extremely cheap, and labor is extremely expensive in countries like the Netherlands or Germany. That’s in part because environmental and social costs are not included in the price of materials. They’re often mined in places where there is not enough environmental legislation and awareness of social issues. Calculations show that if you sourced materials responsibly, something like an iPad might actually cost around 10.000 Euros.

For some materials like cobalt or nickel, recycling already seems to work very well. In the EU these materials are recycled at an estimated rate of 95 percent, with copper up to 80 percent. On the other hand, lithium is virtually not recycled at all. Can you explain this?
Again, it’s about the prices of the materials. Nickel and cobalt are more valuable than lithium. However, the price for lithium has increased dramatically over the last couple of months. So maybe recycling is getting economically more attractive. Technically, recycling the main ingredients of batteries is not very difficult: You can basically discharge the battery, throw it into a shredder and then separate the materials from each other. That’s a cheap process that you can do at a large scale. And that’s the point: There’s only a business case for recycling if you can do it at a large scale.

The trend towards electric mobility has started just some years ago—with only a few million cars and batteries being already on the road. It’s still 15 or

Headwind: Protests are an increasing threat in places where raw materials are extracted. In the Netherlands, citizens successfully demonstrated against natural gas extraction

20 years from now that these batteries will be ready for recycling. Are we too impatient with regard to circularity in this field?
It's not going to be for the next 10 to 20 years that we can rely on the circular economy to provide a significant part of the inputs. So for the moment, we need to have a lot of input from primary sources—we are building up our stock of materials. But today we have to make sure that products are designed in such a way that one day we can actually get those materials back and recycle them.

If your scenario is a circular economy for critical raw materials—why would a mining company invest billions in setting up operations that are superfluous in 30 years?
That's a dilemma, indeed. Miners are generally hesitant, because 20 years ago they were promised a large market for materials that are needed for all these green technologies. They invested in mines, but as it turned out the market took up much slower than they anticipated. There was overproduction and the prices went down. So why should they invest now?

One idea could be to invest public money.
This could be a valid strategy. Take as an example rare earth materials, which actually aren't rare at all: Their price is extremely low if you compare it to the price of the final products in which they are being used. So the added value you can create with just investing in a few hundreds kilotons of material is huge. It's strange that the US or the EU—huge economic powers—have just not acted upon that. Unlike Japan that has invested in specific mines and refineries like the Australian Lynas.

Could this example serve as a role model for the EU?
In Japan, the industry is very much linked to the government and therefore the government really acts upon what the industry wants. In China, a lot of these companies are basically state owned.
In the US, we can see huge government involvement to secure the supply of raw materials for batteries by using legislative measures like the Defense Production Act. Here in Europe we don't have that tradition of interfering in these industries, except for maybe France. In Germany it's already a lot softer. If the large car manufacturers complain that they don't have enough raw materials, the German government will act with bilateral agreements with other countries. Countries like the Netherlands or Denmark are not into that at all.

Since 2020, we have the European Raw Materials Alliance, an organization to ensure reliable, secure and sustainable access to raw materials. Wouldn't this be an institution to bring forward more investment in this field?
The ERMA is an organization that is at least thinking about these issues. And there's a lot of funding going into research projects. But I don't see that power politics in Europe that you have in Japan, in the US or in China. Although that might change in the near future since a Raw Materials Act is coming up in the EU. I'm not sure what that will entail, but it's one step in that direction.

In wake of the war in Ukraine, we have experienced a rebound of fossil fuels like coal for example. Are you afraid that the trend towards renewables is losing pace?
Indeed, circumstances are changing. In many regions solar power is the cheapest energy that you can have—even without intervention from governments. So it should prevail in a free market. But now, again, prices are rising because of raw material prices going up. I think we can solve a lot of issues. But governments have to set the right boundaries within the market economy so engineers can go in the right direction. Engineering and economics will not do that by themselves.

TOUGH AS LEATHER

Artificial leather spares animals and can also benefit the environment. Thanks to modern chemistry, both benefits can be achieved without sacrificing quality. Evonik is developing solutions that make the production of leather substitutes even more sustainable

TEXT **TOM RADEMACHER**

Tesla swears by it, and so do Stella and PETA. What is it? Artificial leather. Tesla, the US electric automaker, sells all of its Model 3 cars with seat covers made of imitation leather. The fashion designer Stella McCartney has always refused to use genuine leather for her handbags and shoes. And the animal protection organization PETA publishes artificial leather style guides for a growing throng of fashionistas who want to save cows' lives. "A killer look without any killing" is its slogan.

"Vegan leather" is a current trend. The concept itself is a perfect fit for our age. More and more consumers are concerned about climate change, animal welfare, and the environment. Man-made leather offers many advantages in this area. It doesn't victimize living creatures or require arable land for growing animal feed. It's less of a burden on the climate and consumers' consciences.

There's no need to worry about compromises regarding quality and workmanship. Gone are the days when imitation leather felt like plastic and quickly became brittle and cracked. Today even experts find it hard to tell the difference between the imitation and the original. In some applications, artificial leather is even superior to real leather. This has become possible thanks to improved chemical ingredients and new production processes. Evonik is an expert in both. Today its products can be found in just about every layer of modern artificial leathers. The Essen-based specialty chemicals company now plans to set new benchmarks for the sustainability of the production processes as well.

FLEXIBLE AND RESILIENT

One of the incubators of innovative products for artificial leather is located in the town of Herne in the heart of the Ruhr region. This is where Evonik produces crosslinkers—substances that give the layers of modern polymers their longevity as well as several other special properties. From its base in Herne, Evonik has exported this technology and its products throughout the world. The production complex in western Germany is exactly duplicated by the one in Shanghai, China. Additional production plants are located in Antwerp (Belgium) and Mobile, Alabama (USA). Crosslinkers of the Evonik brand VESTANAT® make it possible to produce particularly durable coatings and polymer films. They link the long polymer molecules into a robust network that resists intense mechanical and chemical strains. This ensures the durability of vehicle structures, industrial flooring, and wind turbines, for example. In artificial leather, by contrast, crosslinkers extend the molecular chains to create a flexible yet resilient material.

Cutting into artificial leather reveals how this works. The material is multilayered, consisting of several plies, each of which performs its own task. A textile base →

The Evonik expert Denis Pukrop develops processes for producing artificial leather without solvents and with much less water

The right mix: At the application technology unit in Marl, Evonik produces and tests prepolymers that harden during 2K and 1K processes to form coatings for artificial leather

“In high-quality artificial leathers polyurethane dominates”

MICHAEL MEYER, HEAD OF THE FILK FREIBERG INSTITUTE

guarantees stability, a foam layer ensures a soft texture, and a topcoat provides surface structure and color. In most cases it is covered by a clear layer that protects the material from UV light and other stressors. “Actually, in most cases there are still a few more layers that work together to create the desired effects,“ says Dr. Michael Meyer, a biologist and process engineer who heads the FILK Freiberg Institute, a successor of the research institute for leather and artificial leather technology in Freiberg, Saxony. The institute’s origins can be traced back to a tannery school in the 19th century, when leather production and mining flourished in this region.

CHINA DOMINATES THE MARKET

During the GDR era, the institute also specialized in artificial leather. Nowadays Meyer and FILK work for both the leather and the artificial leather sectors—and everything in between. “It’s no longer possible to make an absolutely clear distinction between them,” says Meyer. He points out that paints and plastic coatings have long been used in the processing of leather made of animal skins as well. “The automobile industry and its demand for surface designs that can be reproduced any number of times gave this change its biggest boost,” he explains. Today the institute also focuses on biotechnology. That’s because researchers are increasingly experimenting with biological raw materials in order to produce artificial leather (see the info box).

But the overall situation is still well-defined. “The global market for artificial leather is very clearly dominated by traditional products based on PVC or polyurethane,” says Martin Lei, an Evonik manager who heads the marketing of crosslinkers in the Asia-Pacific region from his office in Shanghai. In the sector, there are practically no alternatives to China. Over 80 percent of the world’s supply of artificial leather comes from China. Most recently that amounted to about three million tons per year. China is followed, at some distance, by other Asian countries such as Vietnam and Thailand. “Even in the case of some artificial leathers that are marketed as ‘Made in Italy,’ for example, only the final finishing steps were actually carried out in Europe,” says Lei. “The basic material comes from Asia.”

The amounts of artificial leather made from PVC and from polyurethane (PU) worldwide are roughly equal. However, when it comes to quality PU is very clearly superior. “PVC is cheap to produce,“ says FILK director Meyer, “but in high-quality artificial leathers polyurethane dominates.” Polyurethane is more versatile, usually more pleasant to the touch, longer-lasting, and superior even to genuine leather in some respects. For example, PU artificial leather can be washed in a washing machine.

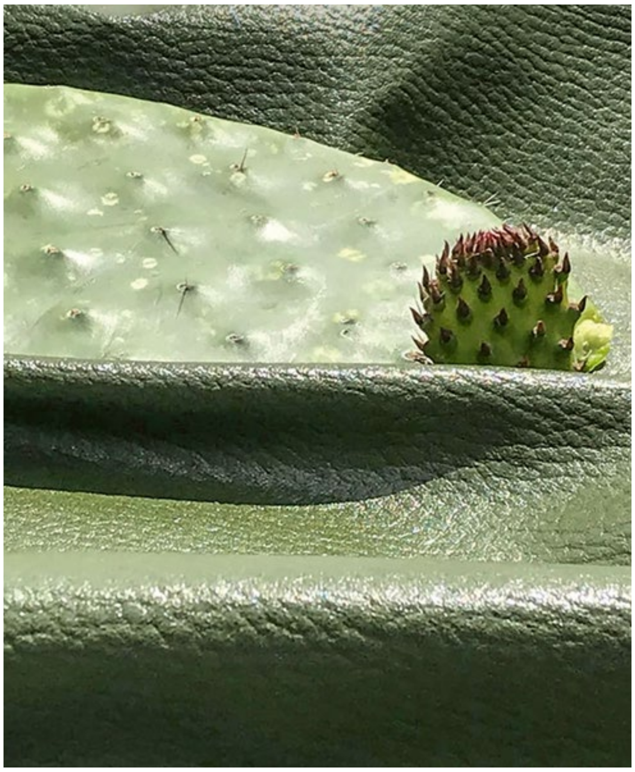
LESS PROBLEMATIC ALTERNATIVES

Its production is also becoming increasingly sustainable. Today artificial leathers based on PU can largely be produced without the use of harmful solvents. This was not always the case. For a long time the use of dimethylformamide, or DMF for short, was a particular defect of PU artificial leather production. DMF is used to transfer the plastic in dissolved form onto the textile web. During the deposition and drying processes, the solvent evaporates and the PU layer remains. Large amounts of water must be used to wash out the DMF residues. Because DMF is harmful to workers and the environment, manufacturers are trying to eliminate it. Last year the EU once again tightened the directives for the sale of products that contain even minimal amounts of DMF. The Chinese government is also pressuring industries to reduce the amount of DMF and other solvents they use. And more than 170 fashion companies have joined forces to completely ban chemicals such as DMF from their supply chains.

The industry has been offering less problematic alternatives for a long time. For example, the foam layer, the topcoat, and the protective coating of polyurethane →

Artificial leather is produced in large coating and embossing facilities. Here it’s being produced for use in the automobile industry

Evonik employee Silvia Herda uses a titrator to determine how completely the monomers in the prepolymers have been synthesized



Imitation leather can also be produced from cacti

LEATHER MADE OF MUSHROOMS, CORK, AND CACTI

Substitutes derived from raw materials also require chemistry

Artificial leather is also part of the trend toward "organic" materials. Scientists are researching many innovative leather substitutes with a biological basis. For example, Evonik is working on a mixed material that not only resembles leather but also can be processed in completely new ways. In 2019, the company therefore invested in the US startup Modern Meadow, which produces collagen with the help of yeast cells. This structural protein is a major component of skin and connective tissue. The startup company, which is based in Nutley, New Jersey, aims to use collagen together with biologically based polymers to produce a material that is similar to leather. Michael Meyer, the expert at the FILK Freiberg Institute in Saxony, calls biomaterials of this kind "trend substitutes." Today there are artificial leathers based on apple peel, pineapple leaves, mushrooms, cork, and cacti. However, even these biologically based materials can become usable alternatives only with the help of chemical products and coating technology. By now some of them have matured to the point of being very acceptable alternatives. "All the same, they are not purely natural products," says Meyer, the leather expert.

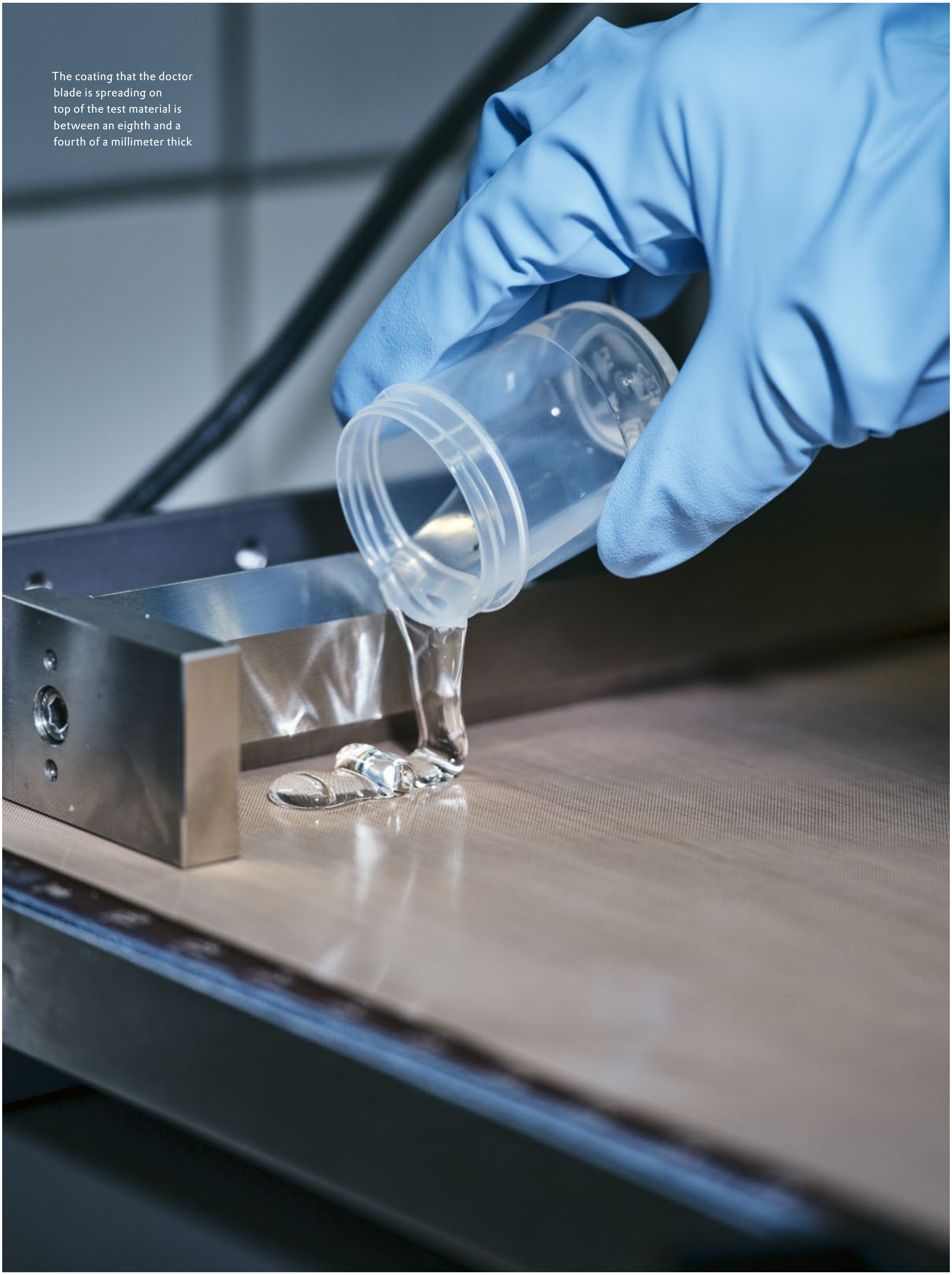
can be applied as a watery dispersion—a mixture consisting almost exclusively of water and PU microparticles. As a result, only water rather than organic solvent evaporates in the drying oven. According to market forecasts, the use of the dispersion process will increase about sixfold between 2021 and 2027 in China's PU artificial leather production industry alone. Evonik is promoting this trend by offering products for this process.

However, in the past it has been difficult to produce a foam layer based on aqueous PU dispersions at the desired level of quality. There was a lack of foam stabilizers specially optimized for this application. Developers from the Evonik Comfort & Insulation business line precisely focused their research on this area in order to fill this technological gap with their foam additives of the ORTEGOL® P brand. These foam additives also improve the energy, raw material, and emissions balance of artificial leather production and are 100% based on plant-based raw materials.

UV PROTECTION AND TOPCOAT IN ONE

Meanwhile, Evonik is working on other alternative technologies at the Marl Chemical Park. "It also works without any water at all," says Denis Pukrop from the Crosslinkers business line. He has helped to develop a process in which the PU topcoat of modern artificial leathers can be applied from reactive systems in a simple, efficient, and environmentally friendly process. This process, which is known as 2K, is already common practice in some industries. For example, it's used by metalworking companies for processes such as coating sheet metal to make it weather-resistant.

"2K" stands for "two-component." The components of a chemical reaction for long polymer molecules are mixed in a liquid state and applied in order to start the →



The coating that the doctor blade is spreading on top of the test material is between an eighth and a fourth of a millimeter thick

After the coating has been spread, it is dried on the heating plate (on the left in the photo) for five minutes. In the production process, machines carry out these steps in continuous production

Textured, soft, and remarkably realistic: modern artificial leather can often be hard to distinguish from animal leather

polymerization on the base material. “People are familiar with this process in the two-component glues they can buy in DIY stores,“ says Pukrop. “As soon as the two components are stirred together, polymerization begins and the mixture hardens.” For polyurethane, the process uses polyols—alcohols with three or more hydroxyl groups—which harden to form a network of long-chain polyurethane molecules when they are mixed with the right crosslinkers.

In the 2K process, a polymer layer forms on the carrier material within minutes without the need to subsequently remove any water or solvents. “In order to accelerate the process, you need a much shorter time in the oven and a correspondingly low energy input,” says Pukrop. A key product for this process is VESTANAT® IPDI—cycloaliphatic isophorone diisocyanate, in chemical terms—which improves the drying and hardening of such coatings. That’s why it also plays an important role in dispersion processes. Incidentally, it also makes the coating light-fast and weather-resistant. “As a result, it’s possible to directly incorporate the UV protection into the topcoat and dispense with an additional protective coating,” Pukrop explains. There’s also another advantage: Evonik uses renewable raw materials to manufacture this product—as well as all of its other isophorone products from Herne. In the life cycle assessment of the example cited above, 75 percent of the product consists of renewable carbon.

FURTHER SIMPLIFICATION IS POSSIBLE

The 2K process that Evonik has optimized especially for artificial leather production offers advantages in terms of efficiency and sustainability. However, it does have a catch. Its use is well established in the coatings industry in particular, but for the manufacturers of artificial leather it’s a new challenge, and because of the components’ reactivity and other factors it’s not very easy to manage. Because the reaction begins automatically, good timing is important. Once the two components have been mixed together, the bonding process can no longer be halted. “A product change results in residues, and that results in waste and costs,” Pukrop explains.

As a result, the expert has improved a further process for the production of artificial leather. It’s called a 1K process because it uses only one component. In this process, the same components as those used for the 2K process have already been mixed together previously. They can be transported together and handled without any problems. The trick here is the fact that the polymer reaction has been chemically blocked. The blockage is resolved only after the mixture has been briefly heated to a temperature between 130 and 150°C, allowing the polymerization to begin. Evonik is already offering blocked crosslinkers of this kind for other industries, such as manufacturers of powdered coatings. This recently patented process has been optimized for artificial leather production in order to make especially flexible and stretchable coatings possible. “For the manufacturers, this means they don’t have to learn so much new information about how to manage the process, and they also need to make fewer changes in their production processes,” explains Guido Streukens, who heads the application technology unit for VESTANAT® in Marl. The blocking material simply releases small amounts of alcohol to resolve the blockage.

Today the sector is only beginning to replace solvent-based processes with water-based ones on a large scale. And the 2K process is only being used in a few special applications. However, the advantages of modern 1K technology are adding up: no use of solvents, drastically reduced consumption of water and energy compared to the dispersion processes, and even less production complexity and waste than for the 2K process. Thanks to excellent reasons like these, Tesla, Stella, and PETA may soon be joined by many other fans of vegan leather.

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

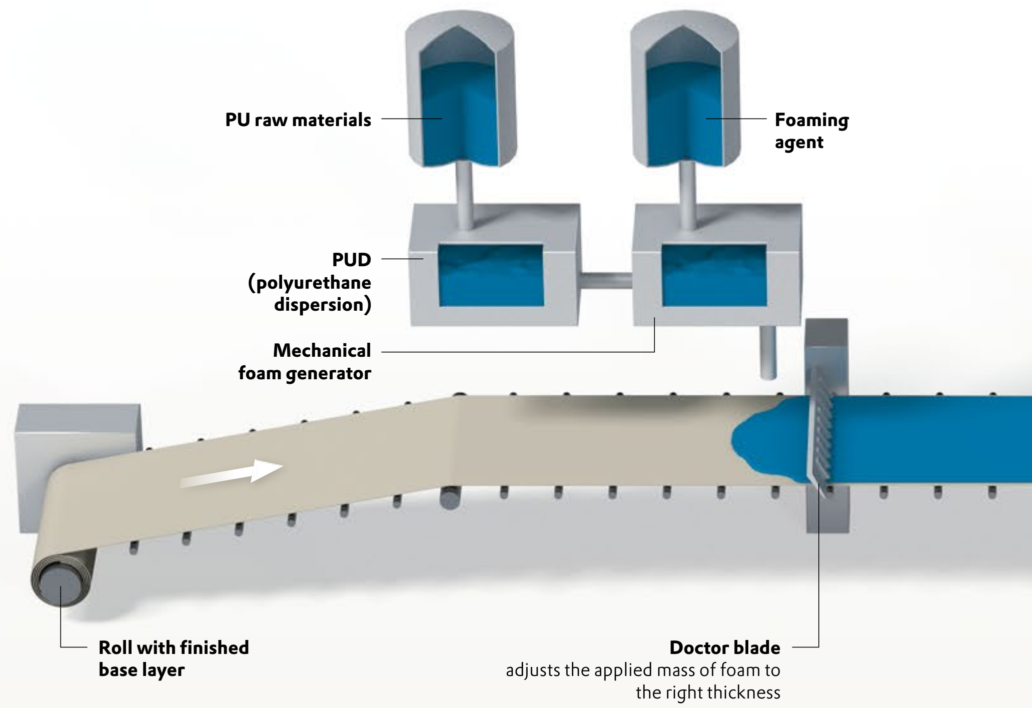
Layered for perfection

Today's artificial leather consists of a variety of layers. Especially when it comes to high-quality polyurethane-based artificial leather, specialty chemicals from Evonik make the manufacturing process more sustainable

INFOGRAPHIC **MAXIMILIAN NERTINGER**

PERFECT FOAM

Evonik supplies important components for the polymer as well as additives that ensure, for example, that the pores in the foam produced are of the right size.



1. THE FOAM LAYER

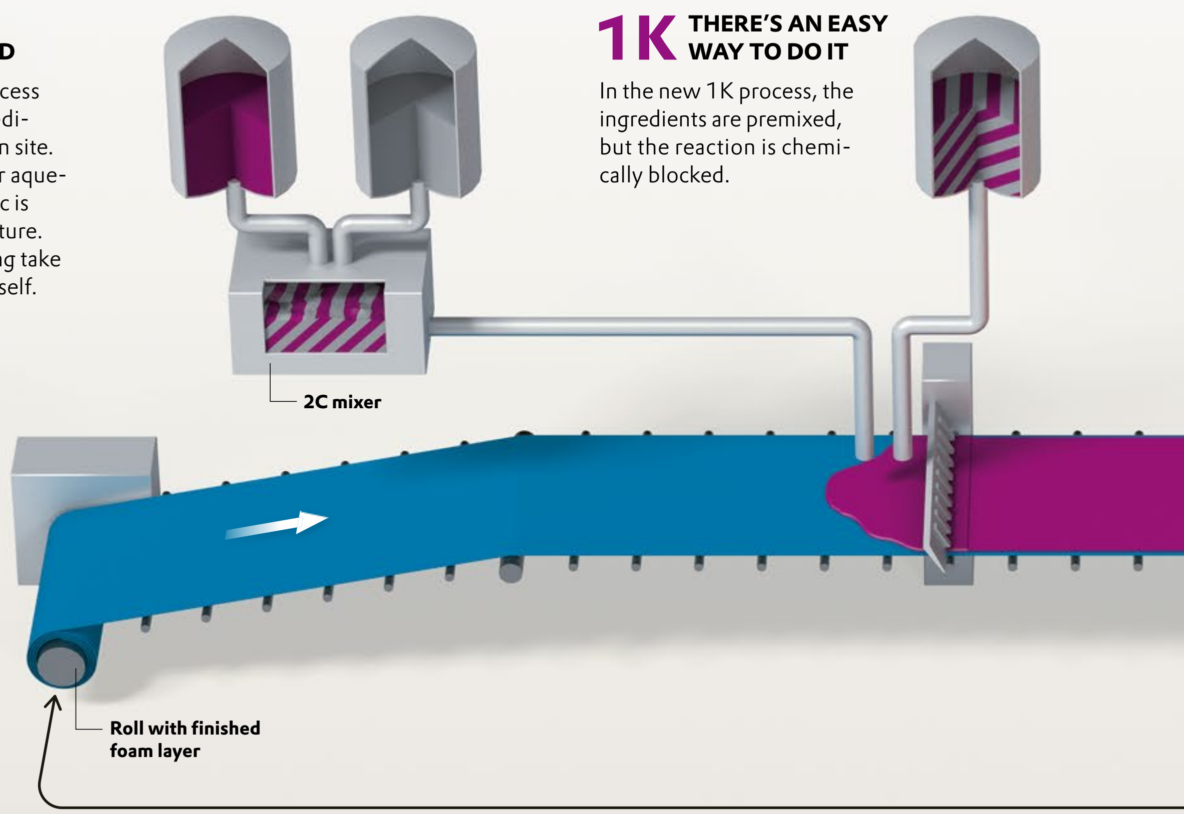
To create the grippy feel of leather, smooth foam is applied to a roll of base fabric. Today, this can also be done with water instead of aggressive solvents.

2K DIRECTLY POLYMERIZED

In the 2-component process (2K), liquid plastic ingredients are mixed directly on site. Instead of as a solution or aqueous dispersion, the plastic is applied as a reaction mixture. Polymerization and curing take place on the base layer itself.

1K THERE'S AN EASY WAY TO DO IT

In the new 1K process, the ingredients are premixed, but the reaction is chemically blocked.

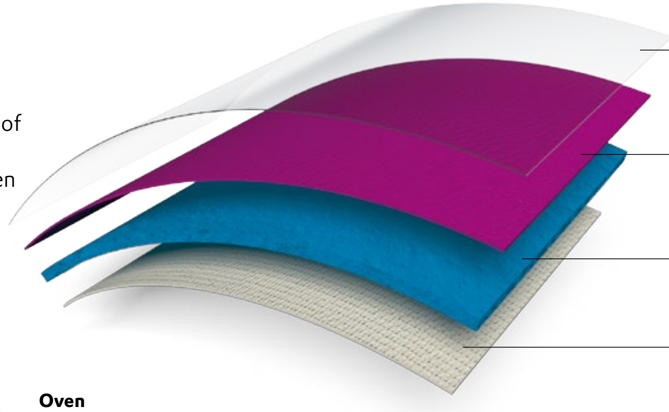


2. THE COLOR LAYER

The material gets its coloring and leather-like surface when the color layer is applied to the foam. The 2K and 1K systems developed by Evonik allow this to be done entirely without water or other solvents.

FOUR LAYERS

Today's artificial leather mainly consists of layers of plastic that are gradually applied to a mostly woven base material.

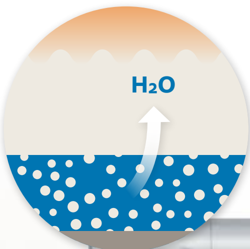


Topcoat
- A transparent PU coating protects against environmental influences
- Additives give it a perfect finish

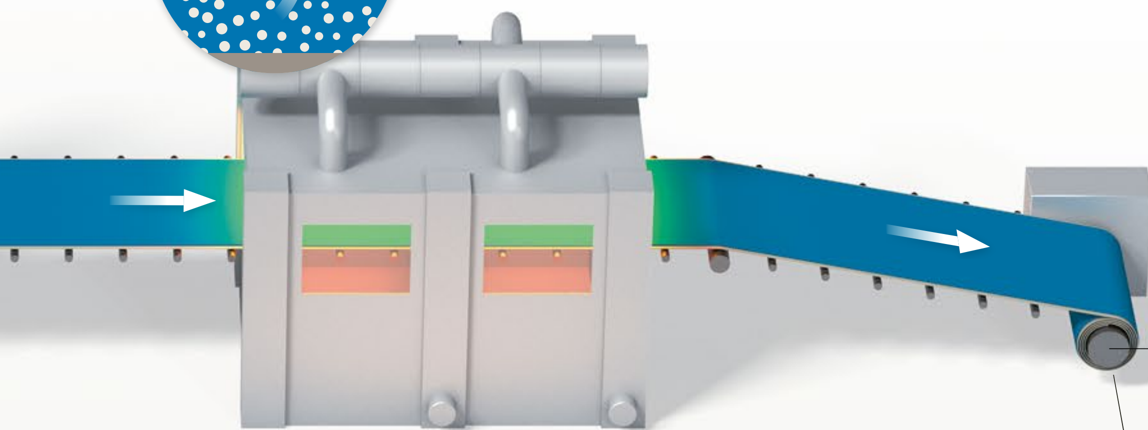
Color layer
- Surface structure and color are applied as a PU coating
- Crosslinkers and additives make them particularly robust

Foam layer
- Auxiliaries, additives, and catalysts ensure the PU foam is smooth and has a grippy feel

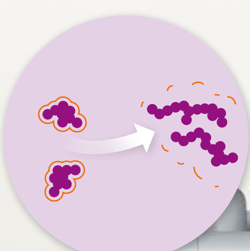
Fabric base layer
- A woven textile gives the material its tensile strength.



Oven
The material is dried at a temperature between 60°C and 120°C.
This can take over an hour in the water-based process.

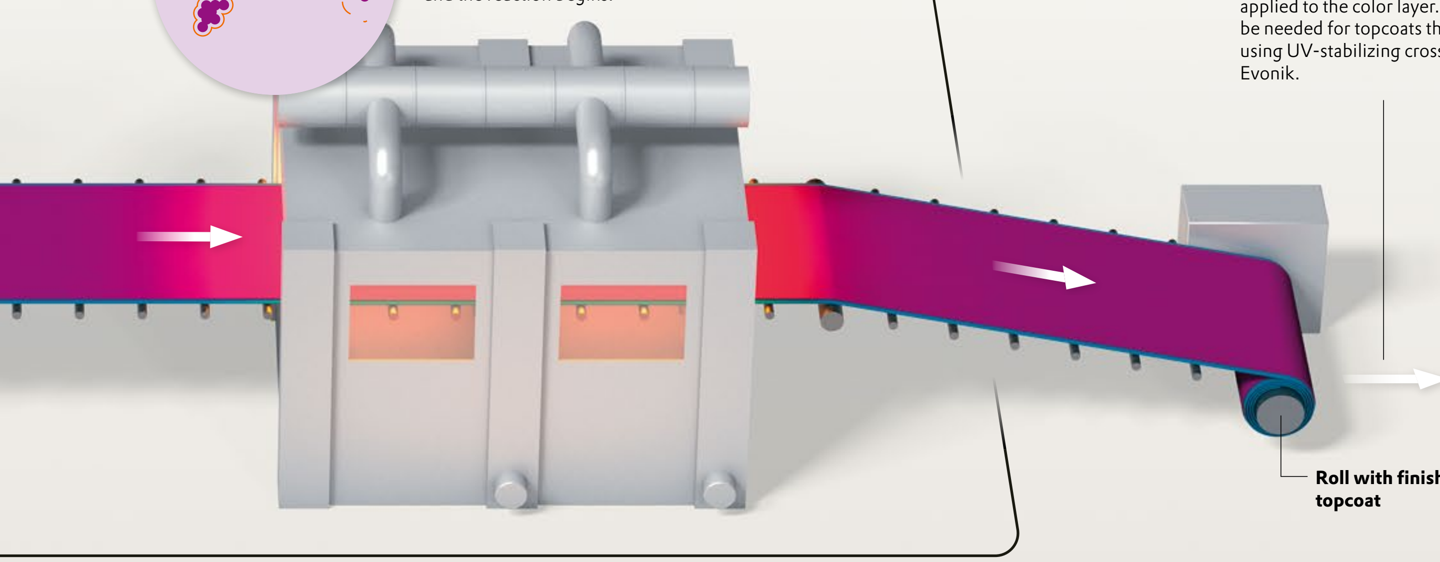


Roll with finished foam layer

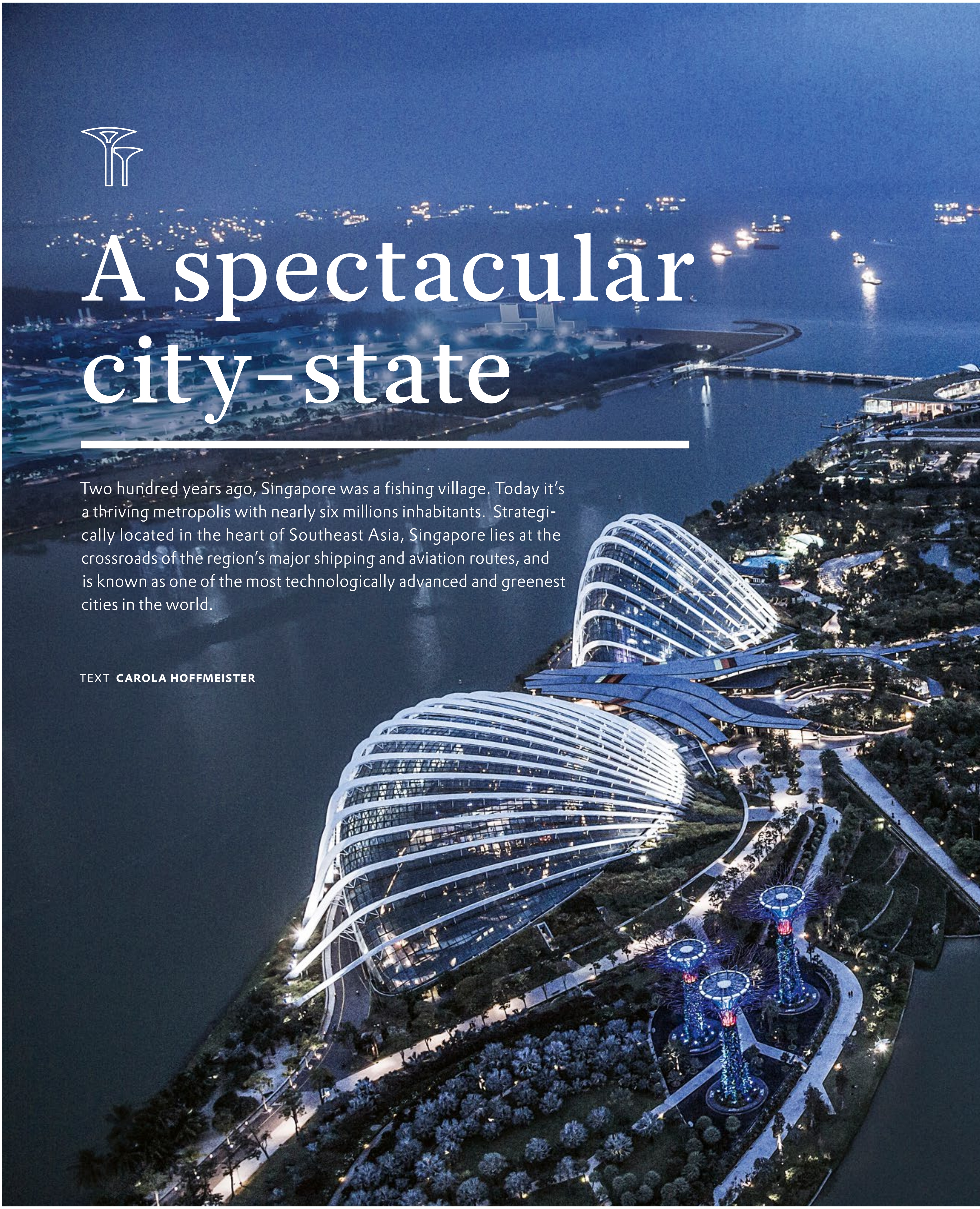


Oven
In the 2K process, a few minutes in the oven speed up the reaction.
In the 1K process, brief heating in the oven dissolves the chemical blockage and the reaction begins.

Further processing
A protective coating is currently still applied to the color layer. It would not be needed for topcoats that are made using UV-stabilizing crosslinkers from Evonik.



Roll with finished topcoat



A spectacular city-state

Two hundred years ago, Singapore was a fishing village. Today it's a thriving metropolis with nearly six millions inhabitants. Strategically located in the heart of Southeast Asia, Singapore lies at the crossroads of the region's major shipping and aviation routes, and is known as one of the most technologically advanced and greenest cities in the world.

TEXT **CAROLA HOFFMEISTER**

The two greenhouses of the Gardens by the Bay lie like two gigantic, prehistoric shells on land reclaimed from the sea,located southeast of the city center. The adjacent harbor is buzzing with activity even at night. It's the world's second-biggest harbor, after the Chinese metropolis of Shanghai. In Singapore, the status of the global economy can be observed up close. During periods of economic recession hundreds of cargo ships lie idle in the anchorage, but lately the harbor has barely been able to cope with heightened global demand. There are transshipment terminals on several islands. Jurong Island is one of them. Located about 30 kilometers from the central waterfront promenade, it is the heart of Singapore's energy and chemicals industry and also hosts two major Evonik production plants.

Honed across generations, Singaporeans have perfected their art of traditional street food in hawker centers — a collection of fast food stands under one roof that have been on UNESCO's list of the intangible cultural heritage of humanity since 2019. Almost every hawker center includes a stall selling Hainan chicken rice—a dish that was brought to Singapore by immigrants from southern China. The food offered by some hawker stalls is so good that it has been singled out by the Guide Michelin. Products from local Evonik plants are helping to make the production of chicken meat especially sustainable. In Singapore the company produces MetAMINO®, an amino acid that reduces the crude protein content of chicken feed and thus makes it easier for the birds to digest. The plant in Singapore is the biggest of the three Evonik plants worldwide that supply this product.

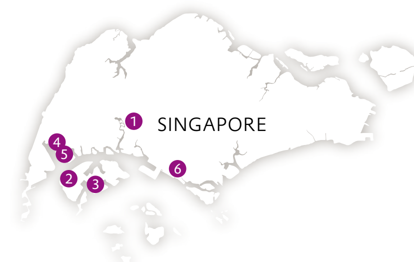

阿仔海南鷄飯
AH-TAI HAINANESE CHICKEN RICE
STALL NO. 7

The Raffles Hotel, which was built in the colonial style in 1887, is named after the founder of Singapore, Sir Thomas Stamford Raffles. It’s known as Singapore’s top address. The famous cocktail called the Singapore Sling was created in the hotel’s historic Long Bar. The opulent suites have been occupied by guests such as Elizabeth II, Charlie Chaplin, and Michael Jackson. Keeping the facade of this national monument brilliantly white requires regular maintenance. The splendor of the Raffles Hotel was recently restored by a renovation process that lasted two and a half years. The paintwork of buildings in tropical regions is especially durable if paints and coatings contain additives from the Evonik brand TEGO®.

Unlike many other megacities, Singapore is a paradise for cyclists. Away from noisy vehicle traffic, they zoom along well-developed bike paths from one park to the next while enjoying views of the city's harbors and skylines. This is made possible by the Park Connector Network (PCN), a 300-kilometer-long network of paths for hiking, jogging, and cycling that connects Singapore's recreation areas with one another. Cyclists heading for an outing in this green paradise need to have the right equipment. 3D-printed products made of high-performance materials from Evonik's ready-to-print INFINAM® line can offer the robust quality that is required for cycling and other outdoor sports — especially in hot weather.

More than 300 parks and gardens bloom and flourish in Singapore—a splendid environment that has earned this metropolis the title of "Asia's greenest city." In the hope of soon becoming the greenest city in the world, Singapore's government supports projects such as the Gardens by the Bay recreation area with its spectacular glass buildings. The Flower Dome, which covers 1.28 hectares, is home to more than 32,000 plants from temperate regions. In the smaller Cloud Forest Dome, orchids bloom on a misty mountain near a waterfall. Decorative cement walls in the Chinese Garden withstand the warm and humid climate thanks to anti-corrosive products such as Protectosil® from Evonik.

FOCUS
In 2018 Evonik expanded its research and development activities in Singapore by building a research center that focuses on resource efficiency. Innovations in the areas of functional surfaces and additive manufacturing are actively developed here. In addition, Evonik operates a large-scale plant for the production of methionine on Jurong Island. With the help of this amino acid, customers can make the feeding of farm animals healthy, efficient, and environmentally friendly.



Evonik locations
1 Nordic European Centre
2 Jurong Island
3 Jurong Island
4 Tuas
5 Tuas
6 Biopolis

The

6

locations have

700

employees

Looking up: Andrew Kincannon, head of Evonik's hydroprocessing catalyst technology center, on his way to check on the production process in Little Rock, Arkansas.

FOUNTAIN OF YOUTH FOR CATALYSTS

A new technology could help transform the energy industry and contribute to a circular economy. Invented by Porocel—now part of Evonik—this technology reduces waste and greenhouse gas emissions by rejuvenating catalysts for a broad range of oil refining applications. Biofuels might be next.

TEXT **NORBERT KULS**

Little Rock has been a catalyst for historical transformation before. In the late 1950s, the capital of Arkansas became the site of a pivotal moment in the American Civil Rights movement. The Little Rock Central High School was one of the first schools to be integrated after the Supreme Court ruled the racial segregation of schools unconstitutional. Nine African American students faced a mob of white supremacists and the Arkansas National Guard, which blocked the school gates. President Eisenhower eventually called in Federal troops for the students' protection. Today, the school is a National Historic Site with a museum dedicated to that struggle. The Little Rock Nine are honored with a bronze sculpture and a plaque facing Little Rock's Capitol building—one of the town's most prominent landmarks. →

The rejuvenator: Jim Seamans, Head of RD&I for the Americas region in Evonik's Catalysts Business Line, is the co-inventor of a new technology that can make a wide range of spent catalysts as good as new.

Spent catalysts are blackened from coke and sulfur. Fresh and rejuvenated catalysts come in a range of different colors.

“It feels good to make a difference with our rejuvenation technology”

ANDREW KINCANNON, HEAD OF THE TECHNOLOGY CENTER IN LITTLE ROCK

In a one-story former warehouse with white siding and a purple Evonik logo, a 15-minute drive from downtown Little Rock, a group of chemical engineers pushes for another historical transformation that could address one of the major challenges of our time: climate change. They have developed a technology that could help transform the energy industry, lead to lower greenhouse gas emissions and pave the way for a circular economy.

The change agent for that latest transformation out of Little Rock are actual catalysts—chemical tools used in refineries to take sulfur or nitrogen out of crude oil products like naphtha, gasoline, or diesel fuel in a process called hydrotreating. Eventually, that technology might be broadly applied to bio-based feedstocks like vegetable oil. “It is all about the energy transition,” says Jim Seamans, Head of RD&I for the Americas region for Evonik’s Catalysts Business Line. Seamans refers to his impressions from the recent AFPM annual meeting, the largest industry conference for American fuel and petrochemical manufacturers. “In the past, conference par-

“Customers can get the same performance as a fresh catalyst for a lower price and with a lower carbon footprint”

GUILLAUME VINCENT, EVONIK’S BUSINESS SEGMENT MANAGER FOR HYDROPROCESSING CATALYSTS

Magic drum: In the impregnation, active metals like Molybdenum that take sulfur out of crude oil are dissolved in a special solution and redistributed on their catalyst “carrier”.

ticipants focused on safety and new ways of desulfurization. Now, in light of the public’s expectation that we will control climate change, the question is how we will change an industry based on fossil fuels to use less oil and more renewable feedstocks.”

Seamans is a key player in this transition. Together with his colleague Guillaume Vincent, Evonik’s Business Segment Manager for Hydroprocessing (HPC) Catalysts & Services based in Germany, he is the co-inventor of a unique technology that can “rejuvenate” a wide range of different catalysts after they are used up—“spent” in industry jargon. Those catalysts become as good as new and sometimes even better after rejuvenation.

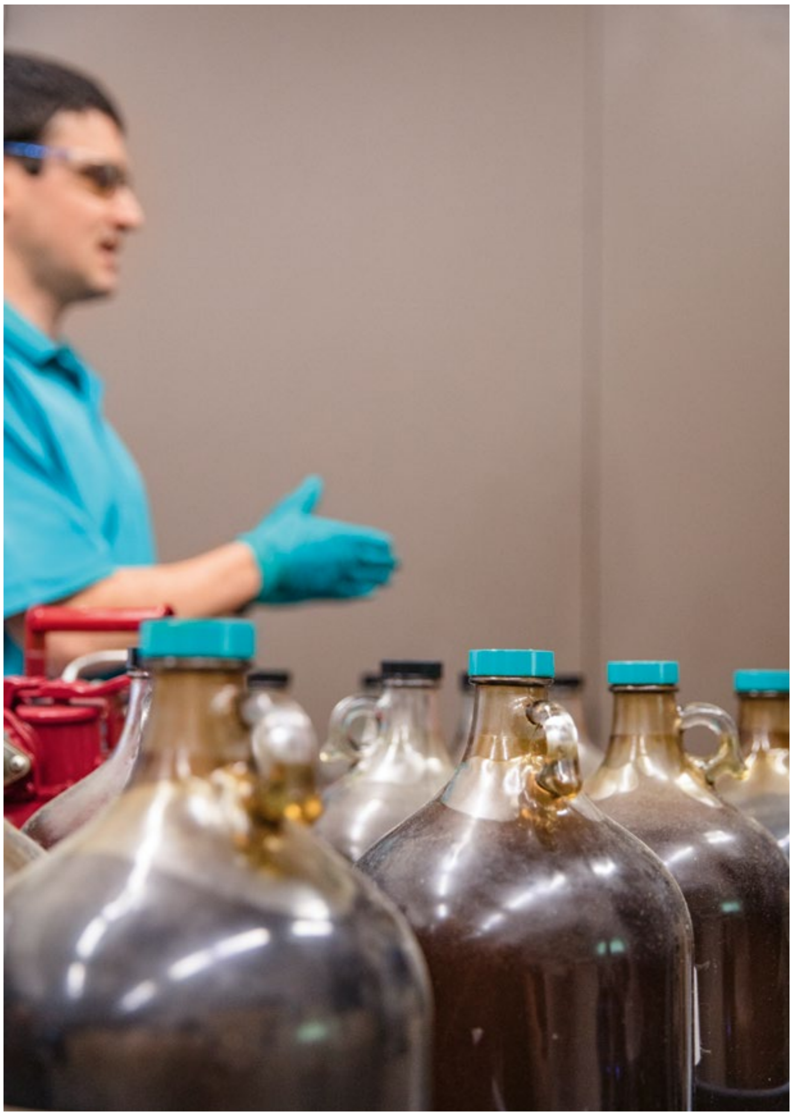
HOW TO REACTIVATE VALUABLE METALS

Seamans and Vincent developed the process at Porocel, a U.S. catalyst specialist acquired by Evonik in November 2020 for 210 million dollars to strengthen its catalyst business. The technology, aptly named Excel® Rejuvenation, helps avoid a recycling process to reclaim the valuable metals inside the catalysts. It also makes the manufacture of new, “fresh” catalysts unnecessary. This significantly reduces the depletion of natural resources, waste, and greenhouse gas emissions. The rejuvenation technology—a fountain of youth of sorts for spent catalysts—could see great demand as the sustainability transformation of the energy industry progresses.

Seamans is part of a group of experienced Porocel veterans now working for Evonik. A chemical engineer with an MBA, he previously worked for the energy giant Shell and had already codeveloped rejuvenation technologies for its catalyst business.

The concept of rejuvenation is not new. Competitors like Albemarle, one of the world’s largest producers of hydroprocessing catalysts, have rejuvenated their products for years. But Evonik’s technology is unique in that it can be applied to a wide range of catalysts from different companies. “We had the idea to develop a fully independent rejuvenation technology,” says Vincent—triggered by customer needs across the globe. →

New strands of catalysts fall onto a conveyor belt to be dried.



Product Development Engineer Dan Miskin presenting crude oil jars in the testing center.

Porocel, founded in 1937 as a joint venture between Atlantic Richfield and Standard Oil of New Jersey, has manufacturing locations to rejuvenate catalysts in Singapore, Luxembourg, Canada, and in the United States, in Lafayette, Louisiana. "It helps to have a regional presence because we are taking the spent catalysts from the refiners in the region. And you can't easily move spent catalysts around the world," says Seamans.

A COLORFUL SOLUTION

The former warehouse on the outskirts of Little Rock next to another former Porocel plant is the brain of the business. It is a pilot plant and test center for catalyst rejuvenation. The excitement of being part of a bigger change is palpable. "It feels good to make a difference," says Andrew Kincannon, a chemical engineer who leads the technology center in Little Rock.

On a tour through the labs, Seamans and Kincannon point out measuring jars and sample containers filled with objects resembling small stones or beads from a craft store: Blue, white, green, black, and beige catalysts, some longer, some shorter. The colorful particles are a mix of "active" metals like Molybdenum or Tungsten and Nickel or Cobalt. The metals sit on a highly porous Alumina "carrier" that resembles a dry sponge to increase its surface (see infographic on p. 49). Eventually, the particles are stacked in layers inside a tube-like reactor on top of a whitish ceramic alumina foundation. This is known as a fixed bed reactor in the industry because the particles don't move. On top of that layered particle tower are other bead-like objects in a trilobe or hollow cylinder shape. Their role is to trap poisons during the refining process: Silicon found in coker naphtha or arsenic found in some crude oil.

Crude-derived products then flow through the tube reactor, and the catalysts remove sulfur and nitrogen. After a while, however, the catalyst loses its luster. Sulfur and carbon-rich petroleum coke collect on the metal sites and block the pores. The distribution, the "dispersion" of the active metals changes as well. "The metals start to bunch up," says Kincannon. "They agglomerate and the sulfur-containing compounds in the crude can't reach those active sites anymore."

WHERE THE "MAGIC" HAPPENS

A refiner then has two options. It can replace the spent catalyst with a fresh one. Or it can opt for rejuvenation and save up to 70 percent of the cost. For a refiner spending half a million dollars on a catalyst, that would translate into savings of 350,000 dollars. The Excel® rejuvenation is a two-step process. In a first step, called "regeneration," sulfur and carbon deposits are burned off gently. But that tried-and-true method only restores the catalyst to about 65 to 85 percent of its original capacity. "It doesn't get you back to full activity because it doesn't redistribute the bunched-up metals," explains Kincannon.

The second step, the actual rejuvenation, restores the catalyst's capacity to near fresh activity levels. Here's how it works: Evonik applies proprietary molecules to the regenerated catalysts. The goal is to redistribute the metals correctly. The "magic," as they say in Little Rock, happens inside a round steel container that looks like an oversized wine jug and is called impregnation drum. The metals are dissolved in an aqueous, acidic solution that has been sprayed on the alumina carrier and absorbed in its pores. Finally, the treated catalysts are placed in a thin layer on a stainless-steel belt and dried. "It is a little bit like a pizza oven," says Seamans. This process redistributes the metals close to their original state.

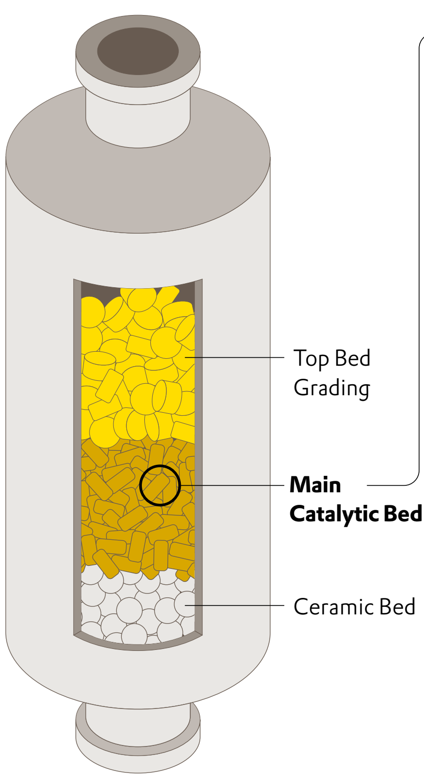
Sometimes, the activity of the rejuvenated catalyst even ends up higher than its original version. That happens when the metal distribution turns out better than the original manufacturer's. Rejuvenated catalyst particles also tend to be a little shorter. "You get a little bit more catalyst per volume when you load them into the reactor," explains Seamans.

In an actual refinery, the reactors with catalysts can be several stories high. In Evonik's Little Rock testing lab, everything happens on a much smaller scale. Kincannon and his team run eight, approximately eight-foot high reactor skids—a mini-refinery. Glass jars filled with dark brown crude rest on the floor, a plastic container with light-yellow →

(ALMOST) AS GOOD AS NEW

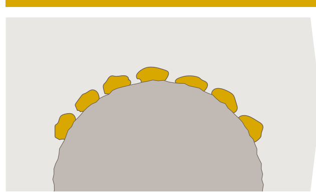
How the rejuvenation process helps catalysts to continue their careers.

REACTOR DESIGN

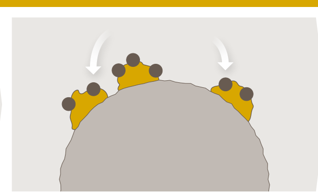


OPERATION AND REACTIVATION

REGENERATION



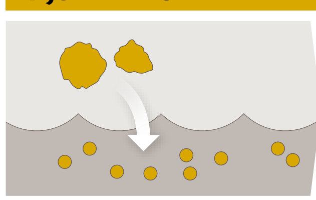
1. Fresh Catalyst
Metals such as Molybdenum or Tungsten form **active sites** on a porous **aluminum oxide** substrate. The more evenly the sites are dispersed, the better they perform.



2. Spent Catalyst
The active metals ensure that sulfur is removed from the oil that passes through the catalyst. This results in **coke deposits**. The active sites form **clusters** over time, decreasing their performance.

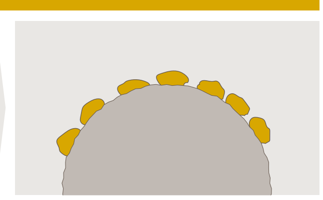
3. Regenerated Catalyst
In the regeneration process, sulfur and coke deposits are burned off gently. The metals, however, remain in **cluster form**. As a result, the regenerated catalyst achieves only 65 to 85 percent of its original activity.

REJUVENATION



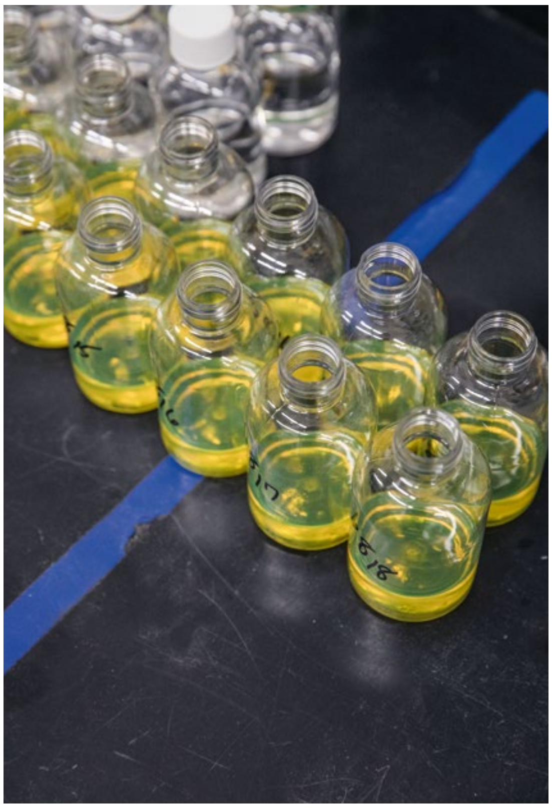
4. Impregnation
In the Excel process, an aqueous solution containing **chelating agents** is spread on the regenerated catalyst to dissolve metal agglomerates and to redisperse active sites.

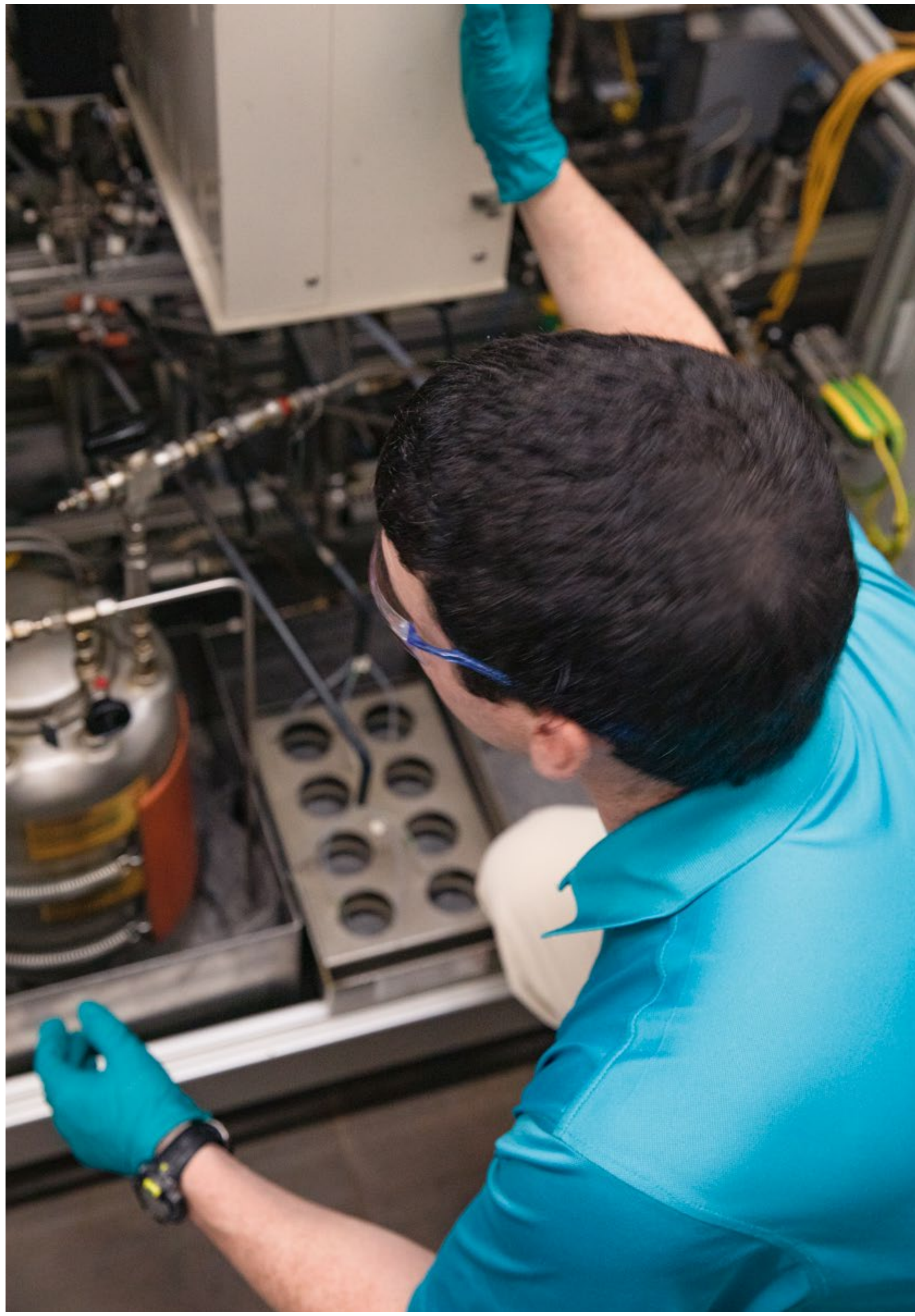
5. Drying
The catalysts are dried to remove some of the **aqueous solution**.



6. Rejuvenated catalyst
At the end of the process, the **active sites** are distributed almost exactly as before. The activity of the treated catalyst is restored to near fresh activity.

Engineer Dan Miskin is checking on a reactor skid—a mini-refinery—in the testing center (r.). Bottles with desulfurized fuel after crude oil got the catalyst treatment.

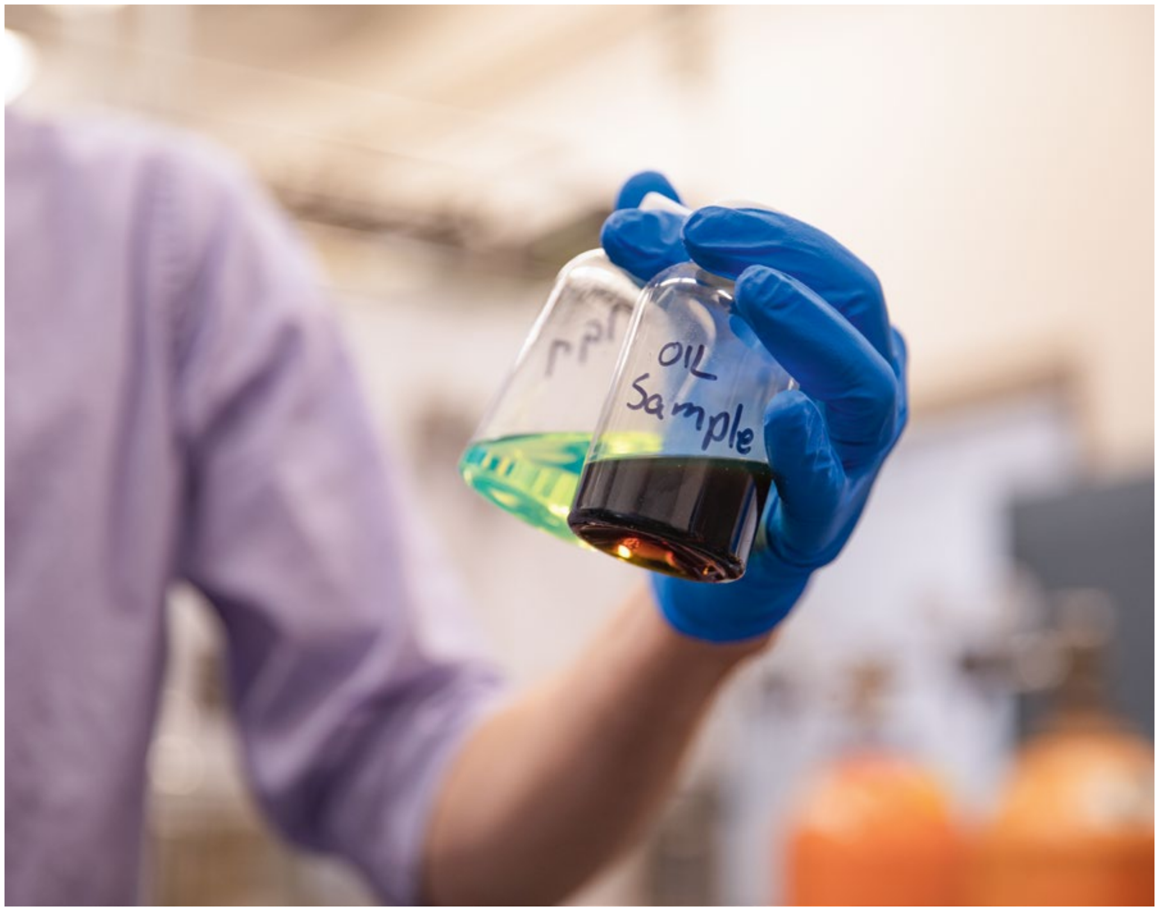




Diesel No. 2 and small bottles with clear liquid sit on a cabinet. Numbers are scribbled on the glass with a black marker. Similar bottles sit on the bottom of the mini reactors. They collect the desulfurized, clear fuel after it has moved through the stacked catalyst inside a slim 4-foot cylinder covered with aluminum foil and insulation.

The process is carefully controlled and monitored from a command center next door. It takes exact data, consistent testing, and patience to convince the notoriously conservative oil industry to adopt the technology broadly. The Excel® technology was introduced in the market only five years ago—a short time in the industry. "There is a very steep resistance to new technologies that are not proven," observes Seamans, who is based in The Woodlands, a suburb of the U.S. energy capital Houston. A refinery will not risk an expensive shutdown because a catalyst might not work. "We have over 100 successful refinery sales, but are still in the phase of convincing customers that our technology is viable and dependable," he says.

For Guillaume Vincent, it is a matter of perception and attitude. "It is like buying a new car versus a car with low mileage that drives just as well and costs less. Some customers just don't want a used car—even though they could



Crude awakening: Tech Center head Andrew Kincannon with samples of dark crude oil and refined, desulfurized fuel.

get the same performance as a fresh catalyst for a lower price and with a lower carbon footprint." But not everyone is skeptical. For one existing European customer, Excel® is already a big part of the strategy to reduce greenhouse gas emissions. Europeans generally seem to have embraced the idea earlier. "It is an easier sell," says Technical Manager Mike Martinez, also from Houston. Martinez collects data, does performance modeling, and presents at conferences. "We have started to build a track record," he says. "Every refinery in the world is on our radar."

AMBITIOUS PLANS FOR THE FUTURE

Potential clients are not just the big multinational refiners like TotalEnergies, BP, Phillips 66, or Repsol. Excel is also an option for smaller, independent refiners that usually operate in one country only. The third potential customer base are the government-run, public refiners in the Middle East, India, and other parts of Asia. This year, Seamans and his team also want to publicly share data that validates the performance of the Excel rejuvenation technology in different, more severe operating conditions in terms of temperature, pressure, or type of feedstock.

The future for Excel® not only includes fossil fuels. Andrew Kincannon points out a plastic container that looks like it holds yellowish diesel. But it is vegetable oil—the next frontier for Evonik's catalyst experts. Crude oil refiners seem to be moving aggressively from petroleum towards renewables. U.S. refiner Phillips 66 plans to convert a crude oil refinery in California into a renewable fuels plant using cooking oil and food wastes beginning in 2024. Competitors like Valero, TotalEnergies, Repsol, Chevron, or Marathon have also announced investments in biofuel refining.

"The opportunity from bio-based feedstocks is still fairly small because most fuels are still made with petroleum-based materials," says Americas RD&I Head Seamans. But the share of renewable fuels is increasing. Seamans estimates that by 2030 up to 20 percent of fuels could be bio-based. "It is definitely a growth market. But even with oil-based feedstocks, we have a lot of growth potential that we haven't been able to fully realize yet."

Norbert Kuls is Evonik's Communications Manager in North America and a former U.S. correspondent for German newspapers.

The sculptor Antonio Canova created this marble statue of Hebe, the Greek goddess of youth, in 1796. According to Greek myth, a diet of nectar and ambrosia gave the goddess immortality

FOREVER YOUNG

TEXT **BJÖRN THEIS**

In the future, will we be able to add a few months or even years to our lives by simply changing our diets? That may well be possible. The search for effective anti-aging dietary supplements has revealed some promising candidates

Scientists have long searched for foods that can enable us to lead longer and more active lives. Evonik too has established its dietary supplement MEDOX® in a market that aims to provide health and well-being—and it intends to explore this field in even greater depth in the future. The research focusing on the class of drugs known as senolytics is taking especially promising approaches. The substances in this group enable damaged cells in the body to destroy themselves. That prevents the body from accumulating substances that trigger aging processes.

THE VILLAGE OF CENTENARIANS

The longing for eternal life is as old as humankind. The epic of Gilgamesh, which dates back to the second millennium BC, is one of the oldest written records of the human art of poetry. In the epic, King Gilgamesh sets out to find a plant that wards off death. Roughly 1,200 years later, Homer sang of ambrosia, a food that granted immortality and was reserved for the gods of the ancient world. And in the third century BC the first emperor of China, Qin Shi Huang, dispatched his court magician, Xu Fu, to find an herb that prevents aging.

All of these efforts to gain eternal life have ended in failure, but they have yielded valuable insights. In 1878 the Englishman John Biddulph discovered the remote kingdom of the Hunza in the Himalayan mountains, many of whose inhabitants were 100 years old or even older. They owed their longevity not to divine ambrosia but to a mundane diet of dried fruits and nuts. After the Austrian physician Maximilian Bircher-Benner heard of this diet, he invented Bircher müsli. This was the first time that longevity was linked to a special diet. Additional proof of this connection was discovered about a century later. In the southern Chinese provinces of Guizhou, Sichuan, and Guangxi, scientists observed an unusually high proportion of people over 100 years old. Their investigations revealed that jiaogulan, a plant used by local people to make an herbal tea, was responsible for this longevity. Many positive effects are attributed to this "immortality herb," a member of the Cucurbitaceae (cucumber or gourd) family. It is reputed to reduce stress, decrease levels of blood sugar, and strengthen the heart and the immune system.

TARGETED CELLULAR DEATH

Thanks to discoveries like these, today scientists are convinced that diet has a key impact on aging processes. Researchers all over the world are looking for foods that can prolong our lives. For example, researchers at the University of Minnesota are investigating the effects of flavonoids, natural substances that are largely responsible for the colors of flowers and play an important role in the metabolism of many plants. In the course of their research, the scientists discovered fisetin, a yellowish substance that can be found in the Eurasian smoketree as well as in apples, grapes, cucumbers, and strawberries. Scientists suspect that fisetin is a potent senolytic that induces damaged cells to commit suicide—cells that would otherwise cause inflammation and trigger aging processes.

There are other promising candidate senolytics besides fisetin—for example quercetin, another flavonoid that can be extracted from apples, onions, and garlic. Also promising are the alkaloids piperlongumine, which is found in a pepper plant from Southeast Asia, and berberine, a constituent of barberries. None of these active ingredients will bring us immortality. However, it seems that they could enable us to live longer and healthier lives. That's a good reason for the Foresight team at Creavis to investigate these substances. For example, the incubation cluster "Prevention & Wellbeing" at Creavis aims to develop new health-promoting products.

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

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He
Helium

"Helium is our 'draft animal'"

LOG **KAROLINA FÖST**
PHOTOGRAPHY **JÖRG KLAUS**

Dr. Ruud Dirksen is a physicist who works at the DWD's Lindenberg Meteorological Observatory, which has been studying the vertical structure of the atmosphere since 1905. A native of the Netherlands, Dirksen heads the observatory's on-site radiosonde team

After hydrogen, helium is the lightest gas in the universe. We take advantage of this property at the DWD—Germany's National Meteorological Service. Helium is our "draft animal" that carries weather balloons with measuring instruments known as radiosondes into the sky.

Helium is a remarkable element. It is a noble gas that is extremely rare on earth. In outer space, however, it is the second most common element. Whereas the helium in the universe was created at the Big Bang, on earth it is a consequence of the aging of our planet. It is formed during the radioactive decay of elements such as uranium.

Radiosondes are launched twice a day at 14 measuring stations of the German Weather Service; here in Lindenberg near Berlin even four times. They climb at a speed of five meters per second and transmit information on air temperature, humidity, and pressure as well as wind strength and direction every one to two seconds. We can also determine how clouds form or Saharan dust disperses.

At launch, the weather balloon has a diameter of 1.5 meters. At an altitude of just over 35 kilometers, the balloon has expanded to about twelve meters due to the decreasing atmospheric pressure—and it bursts. The radiosonde floats back down to earth on a parachute.

Admittedly, when I started working at the DWD, I found it hard to imagine that such a small instrument could do so much. I previously worked on satellite projects in the Netherlands. I'm now fascinated by working with radiosondes. The data is very valuable. It saves lives because we can use the data to predict hurricanes and other severe weather. But the data also tells me whether I should rather cycle to work or drive.

Masthead

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“The scarcity of a thing…

…thus plays the largest role in increasing its price,” wrote the German philosopher of natural law, historian, and teacher of the law of nations Samuel von Pufendorf in 1672. At the beginning of the Age of Enlightenment, he already realized that the less of a coveted commodity is available, the more expensive it becomes.

Three and a half centuries later, we are experiencing at first hand how the sluggish supply of energy carriers and other raw materials leads to price surges. At the same time, the scarcity is creating incentives to develop technologies such as ways to recycle materials that are critical for the energy transition—like lithium, for example. In the long run, this would enable us to dispense with the expensive and environmentally harmful extraction of new raw materials.

2/2022 **Lithium recycling**