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INSPIRED BY NATURE: BIOSURFACTANTS*

THE INNOVATION MAGAZINE

EVONIK INDUSTRIES

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Evonik is the first company to produce biosurfactants in industrial quantities
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Cover and back cover: Vetta/Getty Images | Photography page 3: C3, Evonik (2)

EDITORIAL

Entrepreneurial thinking

People who think outside of the box can be rather annoying because they like to contradict. And this is exactly why we need them for the innovation process—because they question existing processes and spot opportunities that others cannot yet see and which have a potential for innovation. Einstein put it this way: “We cannot solve our problems with the same thinking we used when we created them.”

In order to be able to do that you have to change your perspective—we should think about what the market needs and what we can accomplish with our expertise instead of focusing on what we can invent with our technologies. That’s because in the end the customer and consumer decide if an idea is good or not—not the person who had the idea.

Entrepreneurial skills are necessary for changing one’s perspective. An entrepreneur sees opportunities for new business and is determined to put them into practice even against opposition. He includes customers early on and builds up a network. He is passionate in pursuing his ideas and ensures that they will not get held up in daily routine.

Companies should foster this attitude in their employees. We therefore invited the finalists of the current Ideation Jam at Evonik to a boot camp. The around 30 participants spent three days becoming familiar with the methods of a corporate entrepreneur and further developing their ideas for new projects. I was stunned by the commitment and the enthusiasm they demonstrated when entering new territory. This is exactly what the innovation process is all about—you have to be open to alternatives in order to find new directions. Entrepreneurship is not a profession but a way of thinking: No initial situation or condition has to be accepted as unchangeable.

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CLEAN AND TINY HELPERS

Evonik has developed biosurfactants that, in addition to delivering the full cleaning power of a surfactant, are also exceptionally well tolerated by the skin and the environment. They are produced by yeasts and bacteria.

Inspired by nature: The *Starmerella bombicola* yeast, which Evonik uses to produce biosurfactants, is found in the honey made by bumblebees.

Photography: shutterstock

Dr. Hans Henning Wenk

What Evonik has ushered in this year is nothing short of a generational shift in personal care and cleaning products: a biosurfactant developed by researchers in the Nutrition & Care Segment is ready for the market and will be the first to fully meet all requirements for this kind of product—without compromise. It cleans well, is unaffected by water hardness, is gentle to the skin, can be produced entirely from renewable resources—with no need for tropical oils—and is biodegradable and safe for aquatic organisms.

Surfactants are the substances that—due to their special molecular structure—give laundry detergents, shower gels, shampoos, and dish soaps their cleaning power. Along with water, they constitute the most important components of these products, and are the bedrock of daily cleaning and hygiene.

Used as a cleanser for centuries, soap is probably the oldest surfactant known. Although made from natural resources, its high pH makes it less than gentle on the skin. Its cleaning power is not terribly impressive either, and, when used in hard water, it causes calcium and magnesium salts to precipitate, resulting in soap scum.

The first generation of synthetic surfactants was far superior to soap in terms of cleaning power and stability in hard water, but the poor biodegradability of these substances resulted in mountains of foam forming in rivers and lakes. This problem was solved with the next generation of biodegradable surfactants—these, however, still were not particularly gentle on the skin and were manufactured from petrochemical raw materials.

Even though biodegradable surfactants that are tolerated by the skin and made from renewable resources have been available for some time, they still have considerable room for improvement: The right balance between cleaning power and skin tolerance is still a compromise, and tropical oils remain an indispensable raw material.

A way out of the niche

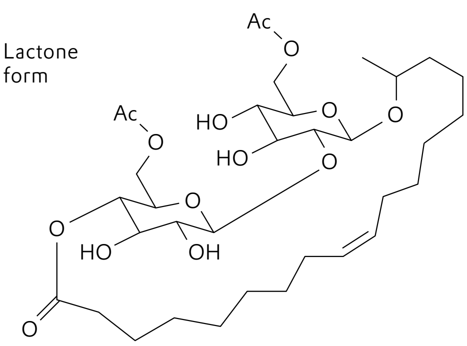
This is where biosurfactants come into play. Produced naturally by microorganisms, these surfactants combine performance, skin gentleness, and biodegradability to an unprecedented degree, and in addition they are based entirely on renewable resources—with no need for tropical oils.

Sophorolipids have already been known to researchers for decades. This special type of biosurfactant from the family of glycolipids is produced by yeasts and occurs naturally in materials such as the honey made by bumblebees. In the late 1980s, scientists recognized the potential of these molecules as detergents, but were not successful in ➔

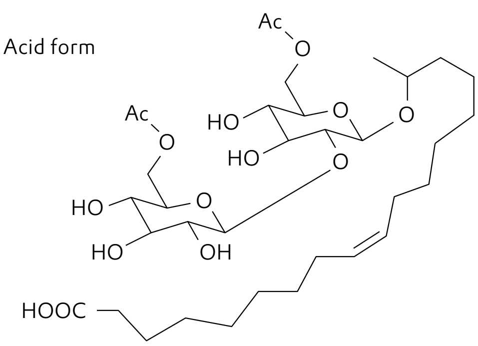
Figure 1: Superior nature

Yeast enzymes easily do something that presents a real challenge for chemists: synthesizing sophorolipids from sugar and canola oil.

Lactone form



Acid form



➔ developing a commercially interesting process for manufacturing them. Although the first biosurfactants have been on the market for several years, these are highly specialized, costly, and available only in small quantities. Consequently, they have not found broad application in detergents and personal care products so far.

With support from Creavis and Process Technology, the Biobased Materials research team (now part of Nutrition & Care) took on sophorolipids in 2010 with the aim of succeeding where others had failed. After all, as biosurfactants, sophorolipids promised a unique combination of properties that no group of detergents had yet been able to deliver.

Not only do sophorolipids have a complex chemical structure (**Fig. 1**)—synthesizing glycolipids in general is a challenging task, as the hydrophilic sugar component is very difficult to join to the lipophilic half of the molecule. Although this problem still gives chemists a headache, it was solved long ago by the *Starmerella bombicola* yeast. Enzymes within these microorganisms turn sugar and canola oil into sophorolipids in a series of enzyme-catalyzed steps. Theoretically, all that is left to do is to isolate the product, but that has turned out to be a tricky task on an industrial scale.

A calculated risk

The first challenge arose even before the biotech process: Not enough material was available for analyzing whether sophorolipids met all of the test requirements for detergents. But in order to know for sure whether it would be worth the effort to develop the bioprocess, Evonik first had to develop the process—a chicken-and-egg dilemma. The company decided to take a calculated risk; even wild-type *Starmerella bombicola*, after all, had all of the properties needed for industrial production. In genetic terms, at any rate, the company did not expect any surprises.

It would take a long time, however, until enough samples of suitable quality were available. Because of their unique structure, surfactants bind with a large number of both hydrophilic and hydrophobic substances, making it extraordinarily difficult to separate out yeast cells and the byproducts of the bioprocess. The company also had to develop an additional modification step in order to optimize the surface activity of the material for the target application. And finally, the product needed to be as concentrated as possible in order to reduce transport costs and offer the customer as much flexibility as possible for developing formulations. Only once they had cleared these hurdles were the application technology laboratories able to take a close look at sophorolipids and establish their market advantages.

The technical application properties are not the only critical features for achieving a successful market position, however: The sophorolipid profile also opens up new opportunities for formulators wishing to distinguish their products from the competition in the rapidly growing green market. The fermentative production process is not the only factor in this equation—its extraordinary environmental compatibility plays a role as well, as does the fact that it is made from 100 percent renewable resources found in Europe.

That Evonik was able to develop this complex biotech process (**Fig. 2**) to the point of marketability in just five years was primarily because all of the technical expertise needed—from analysis to process development and final processing—was available in-house in the form of an interdisciplinary team collaborating seamlessly across multiple departments and segments. The team also had a head start thanks to early cooperation with an industrial partner who had already been experimenting with sophorolipids for some time.

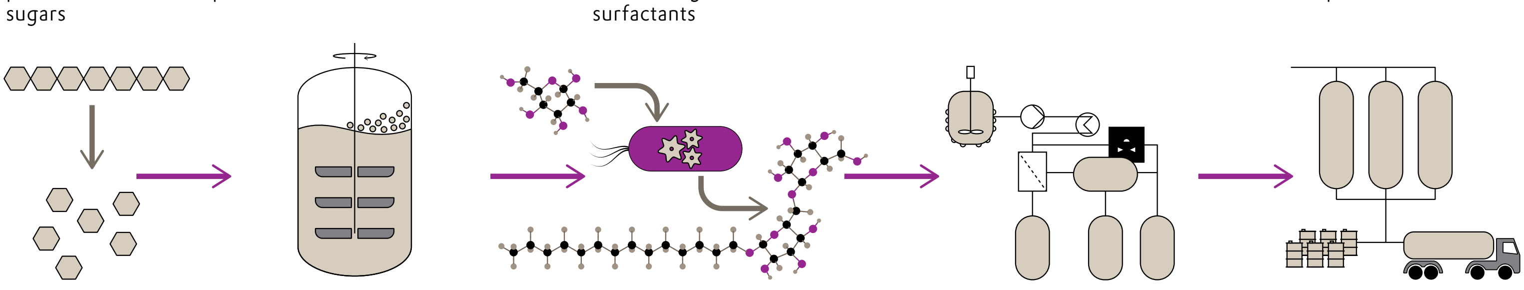
The successful scale-up at Evonik Fermas allowed the company to take the next step:

Figure 2. The biotechnological process

Starch from plants is processed to form simple sugars

The microorganisms convert sugar into biosurfactants

Storage, filling, and transportation



Special microorganisms are cultivated in fermenters and fed with sugar

Separation of cells and byproducts

The first household cleansers containing sophorolipids are now on supermarket shelves.

At a glance: Biosurfactants...

1

...are **gentle on the skin** and thus ideal for use in cleaning products as well as in personal care products.

2

...have a **powerful cleansing effect** and excellent foam-forming properties.

3

...**work better in combination with enzymes** than traditional surfactants do.

4

...are **unaffected** by hard water.

5

...are produced entirely from **renewable**, non-tropical raw materials.

6

...are 100 percent **biodegradable**.

7

...are an order of magnitude **more compatible with aquatic organisms** than conventional surfactants.

industrial-scale production. The Household Care Business Line in the Nutrition & Care Segment has managed to enter the market for the first time: Ecover, a Belgian detergent and cleanser manufacturer, has launched its first products containing sophorolipids from Fermas, and these are now on supermarket shelves.

Development does not stop with successful market entry, however. Researchers, for instance, are searching databases to determine whether other microorganisms could produce sophorolipids perhaps even more efficiently; at the same time, the Creavis biolaboratory in Shanghai is working to optimize the *Starmerella bombicola* fermentation process (see page 28).

Rhamnolipids for long-lasting foam

Because the demands on biosurfactants vary from one application to the next, Evonik is looking to molecules other than sophorolipids that it can develop for use in cleansers and personal care products using biotech production processes. Researchers also identified a second class of interesting products known as rhamnolipids—another glycolipid (Fig. 3) that, in addition to its mildness and environmental compatibility, is known largely for its powerful foam-forming effects. Consumers perceive foam as a sign of cleaning power in detergents and cleansers—a factor even more important than its impact on the actual cleansing effects of the product. Long-lasting suds signal thorough cleaning, especially in emerging markets, where a good deal of laundry is still washed by hand, even as standards of hygiene are increasing. The same applies to shampoos and shower gels, where a creamy lather is seen as a sign of gentle care. Unlike sophorolipids, rhamnolipids required the skills of microbiologists during the initial process development stage. In nature, the molecule is produced by *Pseudomonas aeruginosa*, a bacterium that is found in abundance in the soil and in water, but that is potentially pathogenic to humans. Occupational safety alone was reason enough for Creavis researchers to transfer the metabolic pathway to a harmless bacterium, which now serves as the production organism. The bacterium was also modified in such a way that, unlike the wild-type species, it does not depend on oil as a food source, but instead obtains all of its carbon from sugar.

The process engineering involved turned out to be even more sophisticated than was the case for sophorolipids. Not only does the medium need to be vigorously stirred in the bioreactor—it also has to be thoroughly aerated in order to accommodate respiration in the aerobic microorganisms. Given the powerful foam-forming properties of rhamnolipids, keeping the foam inside the bioreactor was no easy job.

After numerous failed attempts, however, strict process control yielded the solution. As with sophorolipids, close collaboration between Creavis, Process Technology, and R&D groups in Nutrition & Care enabled Evonik to meet the challenge of designing an efficient product preparation process.

In order to develop a product that adequately meets market needs, intense collaboration with selected customers was established early in the work with rhamnolipids. After all, Evonik's goal is to use biosurfactants as a vehicle for expanding its leading market position in gentle, next-generation surfactants.

Although there are still a few hurdles to surmount before commercial production can begin, the company is just about to take an important step on the road to the commercialization of rhamnolipids: Before the year is out, Evonik Fermas will be starting up a pilot plant for testing important process parameters under industrial conditions and for producing initial batches of products that customers can use for pilot studies.

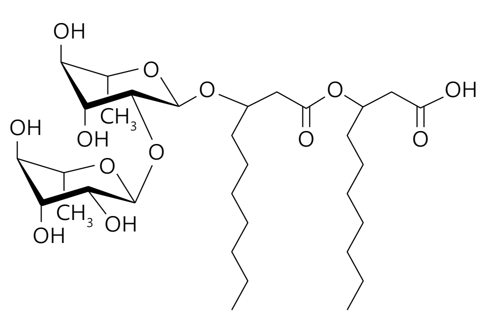
The expert

Dr. Hans Henning Wenk heads the R&D Biobased Materials Department within the Nutrition & Care Segment, where new raw materials are developed for cosmetics and other applications.

henning.wenk@evonik.com

Figure 3. Creamy foam

Desired in application but feared in production: The rhamnolipids that Evonik is currently developing generate especially large amounts of foam.



Infographic: C3 Visual Lab | Photography: shutterstock, Dirk Bannert, Stefan Wildhirt

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DATA MINING

The foam makers

Showering, washing, cleaning—without surfactants all these activities would be a drag. That's because surfactants are amphiphilic: they "like" both oil and water. That's why they're able to remove dirt and grime, provide bubbles and foam for bathtime fun, and degrease and lubricate. We take a look at the market for surfactants, the way they work and their applications.

Composition of surfactants

Surfactants consist of a polar (hydrophilic) part and a nonpolar (hydrophobic) alkyl group. Nonionic and inorganic surfactants have a combined market share of around 90%.

Nonionic surfactants

Hydrophilic Hydrophobic

Resistance to acids, alkalies and hard water. Primarily used in washing powder and detergents, and as emulsifiers.

Anionic surfactants

High washing power. Primarily used in household detergents, washing and dishwasher powders, and washing-up liquid.

Cationic surfactants

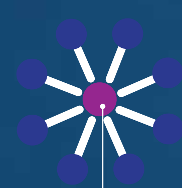
High affinity to fibers. Primarily used in fabric softeners and conditioners.

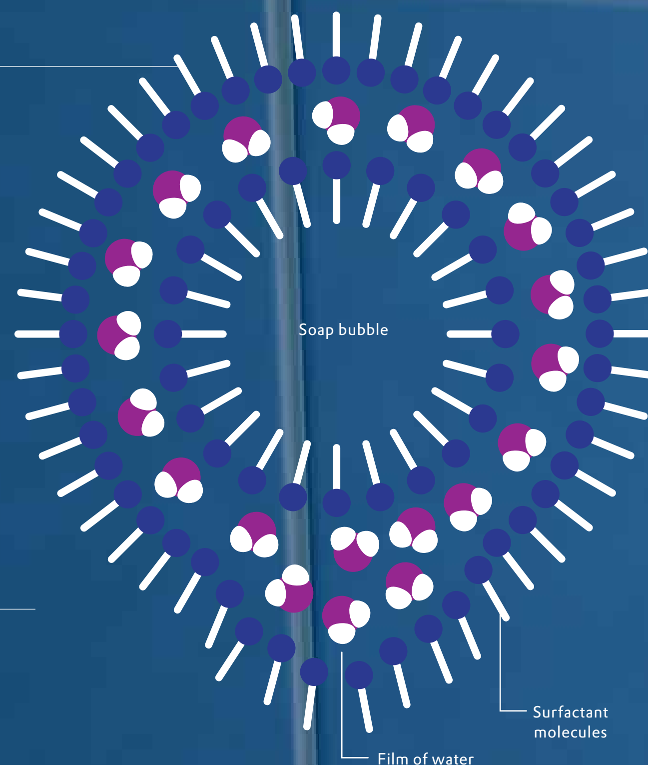
Amphoteric surfactants

Very mild. Preferred for use in cosmetics.

Why soap bubbles burst

In a soap bubble two surfactant layers enclose a film of water. Gravity makes the water flow downward; the two surfactant layers above touch and repel each other, thereby causing the bubble to burst.





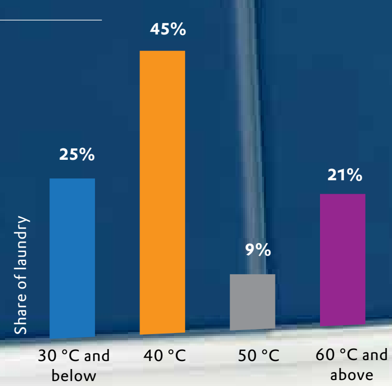
Surfactants form micelles

Nonpolar substances—oil, dirt, air—migrate to the nonpolar interior of the micelles. This is why surfactants clean and lather.

Europe's washing temperature

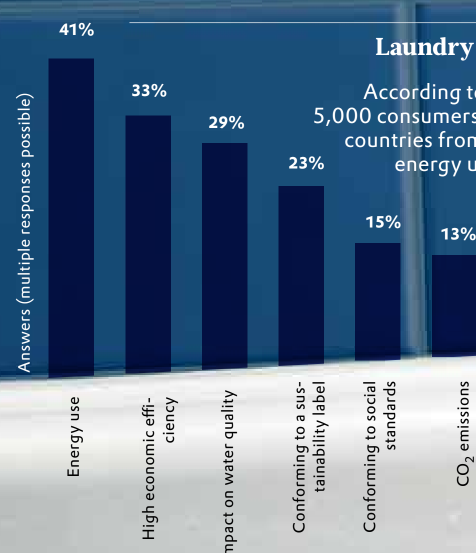
(wash-cycle temperature)

In 2014 a large share of Europe's laundry (79%) was washed at an energy-saving temperature of below 60 °C; the average wash temperature was 42.6 °C.



Laundry and sustainability

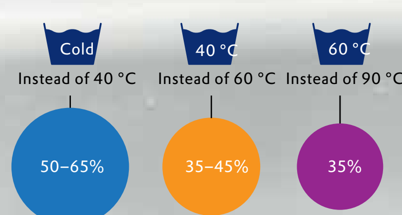
According to a survey of around 5,000 consumers from 23 European countries from the end of 2014, energy use is a key factor.



Less is more

(Energy saving in % according to temperature reduction)

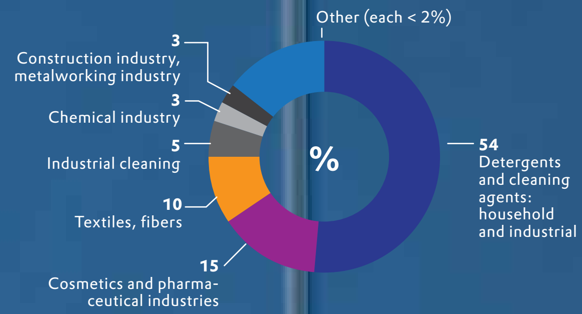
Washing laundry at a temperature of 40 °C instead of 60 °C can save up to 45% of the energy used.



Source: A.I.S.E.© 2014, A.I.S.E. Low Temperature Washing Initiative 2013, CESIO, TEGEWA e.V.

Use of surfactants in Western Europe

Apart from washing, surfactants are also used in many industrial processes, e.g., for wetting, dissolving, defoaming and lubricating.



How often Europe washes

Washing machine

Per week and per household

84% full

Dishwasher

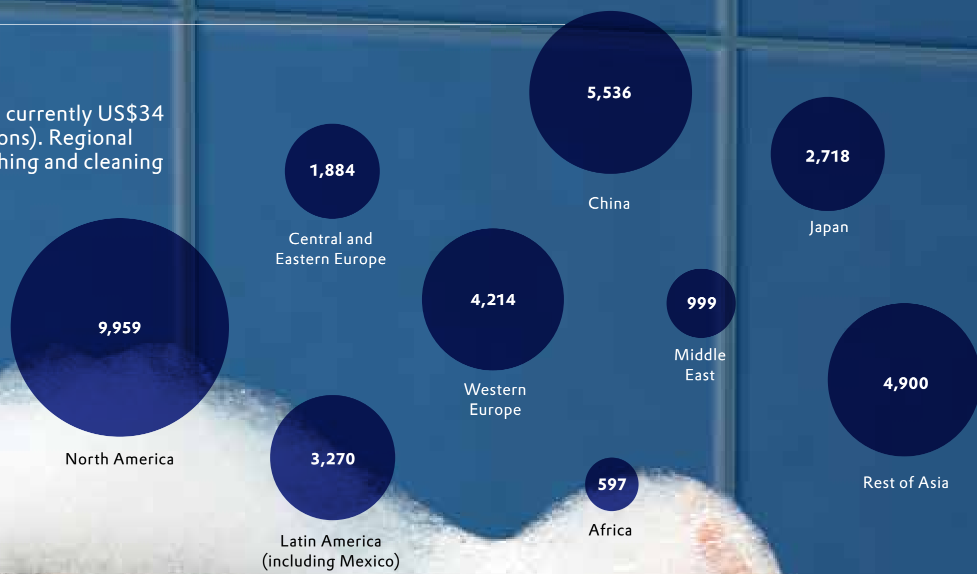
Per week and per household

94% full

A global market
(2015, in million US$)

The market volume for surfactants is currently US$34 billion (approx. 14.8 million metric tons). Regional differences are relatively small: Washing and cleaning are global needs.

Source:
IHS Chemical Estimates, IHS 2015



Photography: Radomir Tarasov/Alamy Stock Photo | Infographics: C3 Visual Lab

CONCENTRATED CARE

Detergent surfactants based on vegetable oils and fats have long been extremely successful products at Evonik. A team from the Personal Care Business Line has now succeeded in making the conventional production process more economical and sustainable. A further plus point: This also allows more highly concentrated products, with more surfactant in less water.

Evonik uses the new process to produce betaines, which are mainly used in shampoos and shower gels, as well as in dishwashing liquid.

Ralf Klein

Millions of tourists love the sight of palm trees on the beach. Coconut palms and oil palms are even more popular in industry, where the demand for coconut and palm oils has been growing rapidly for years. That growth is set to continue, particularly in the food industry. The pulp and pits of the fruits contain various oils that give many products in both the food and the cosmetics industries important and indispensable properties. Evonik, for example, has been producing amphoteric surfactants—or betaines as they are also known—primarily from coconut oil, for the last 50 years. In that time, cocamidopropyl betaine (CAPB) has become the most important secondary surfactant worldwide. Nowadays, neither shampoos and shower gels nor dishwashing detergents can do without CAPB.

The reason for this lies in the specific properties of betaines. These amphoteric compounds are insensitive to water hardness, and even relatively small amounts in the formula solubilize large amounts of grease and dirt. At the same time, they reduce the skin irritation often caused by primary surfactants. In many cases, secondary surfactants give the products the required viscosity and creaminess in the foam and improve handling and use of the products. Currently, over 700,000 metric tons of betaines are used worldwide each year—about 70 percent in the area of cosmetics/personal care, and around 20 percent in household products. The rest go into other technical applications, such as bituminous emulsions for road construction.

Growing demand for surfactants

Advanced surfactant formulas are increasingly replacing ordinary soaps, particularly in regions such as Asia and South America, where the demand for cosmetic products is rising along with the standard of living. In the years ahead, over 40 percent of the worldwide growth in the cosmetics market will take place in China and Brazil.

Evonik is one of the world's leading suppliers of betaines. Its portfolio comprises about 30 different betaines, which the Group produces at eight sites around the globe. This gives Evonik an exceptional position, not only for future global development, but also in regional growth markets—for example, through new production plants in Shanghai (China) and in Americana (Brazil), west of São Paulo.

Up to now, CAPB has been synthesized in a two-stage process. Refined and hydrogenated coconut oil is first converted to cocosamidoamine at high temperatures in the presence of dimethylaminopropylamine. The cocosamidoamine is then reacted to betaine with monochloroacetic acid. This second stage is exothermal and must be cooled continuously.

Despite all optimizations of the process, the second stage used to be the technical challenge, because a highly viscous gel phase can develop during the reaction, limiting the yield and cost effectiveness of CAPB production. For this reason, only products with a maximum of 30 percent active substance content had become established in the past.

Over the course of the various development stages, the addition of diluting agents proved beneficial and allowed the manufacture of products with as much as 37 percent active substance content. But the different diluting agents also have negative properties in cosmetic formulations, such as clouding, reduced thickening efficiency or additional costs. A team from the Personal Care Business Line has now found a way to control gel formation in the second stage. To do this, the developers carefully examined the gel phase: When does it occur? What parameters define it? How can it be selectively influenced?

Undesired gel phase successfully avoided

In the tests, the team used a 1 kg laboratory reactor with the same energy and temperature profiles as the existing commercial-scale plants. After two years of experiments, simulations, and calculations, the developers understood how the undesired gel phase can be avoided under certain conditions. The solution required the precise control of parameters such as pH value, temperature, and mixing ratios. From what was then the conventional process emerged a highly automated one in which a process control system regulated what happened in the reactor with pinpoint accuracy.

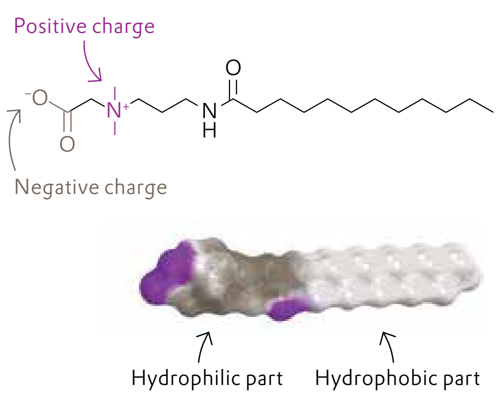
The first product made using the new process is TEGO® Betain P 50 C, which Evonik first introduced in 2015. The modified process allowed the production of more highly concentrated betaine—and with other raw materials. Instead of time-honored coconut oil, the amphoteric compound can be produced from refined palm kernel oil (PKO). In the past, palm kernel oils were considered waste products of palm oil production, and are now used primarily in technical industries. The C in the new TEGO® Betain P 50 C stands for sustainably certified PKO. With the growing importance of climate protection and sustainability, the palm-based tropical vegetable oil has become a controversial subject: How much does cultivation stress the environment and climate by destroying natural virgin forests?

For this reason, the Roundtable of Sustainable Palm Oil (RSPO), of which Evonik is a member, established a global certification system for palm oil and derivatives in 2004. The Roundtable offers all manufacturers and processors along the value-added chain, as well as the consumer, the opportunity of procuring oil exclusively from sustainably certified plantations and mills.

Besides the environmental advantages of TEGO® Betain P 50 C, there are even ➔

Multi-faceted grease and dirt remover

An indispensable ingredient in shampoos, shower gels, and dishwashing detergents: cocamidopropyl betaine (CAPB).



In the years ahead, over 40 percent of the worldwide growth in the cosmeticsmarket will take place in China and Brazil.

Photography: Jason Verschoor/Getty Images, Evonik, Rolf van Melis | Infographic: C3 Visual Lab


Around 20 percent of global betaine production goes into household products.

The Expert

Ralf Klein is responsible for the global business activities involving basic products in Evonik's Personal Care Business Line.

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→ more benefits for customers. Higher active ingredient content reduces the amount of water to be transported—with a correspondingly positive impact on the carbon footprint and lifecycle analysis. The products are safer to handle, since conventional betaines used to have to be preserved because of their vulnerability to germs. Highly concentrated betaines are self-preserving, because germs cannot survive in the lower water content (aW value). Additionally, formulations with TEGO® Betain P 50 C thicken significantly better than comparable formulas based on coconut oil betaines. The product thus fulfills key customer requirements for multi-functional products.

Most importantly, however, one metric ton of palm kernel oil is €200 to €300 less expensive on the world market than coconut oil. This price advantage cannot be fully realized yet, because the costs for certification have to be calculated against it. But because the supply as well as the demand for certified oil is rising constantly, the raw material costs will be about 15 percent lower in the medium term. Over the long term, the certification costs will drop so dramatically that the use of certified raw material will no longer pose a competitive disadvantage.

The optimized production process saves time—about five percent—and can be used in both new and existing plants. The necessary conversions are minimal in terms of time and costs. Tests with the new process were conducted in the plants in Shanghai (China) and Jakarta (Indonesia).

Thanks to the high concentration of the new betaine, less water needs to be transported. The result is an improved CO_2 balance.

Access to regional oils

In 2015, Evonik produced the first commercial quantities of TEGO® Betain P 50 C in Essen and Shanghai, and provided them to prominent international cosmetic companies for suitability tests and studies. The plants in Brazil, the United States, and Indonesia will commence production of TEGO® Betain P 50 C by the end of 2016. The plan is to replace about 25 percent of traditional betaines with the concentrate by 2018. The positive feedback from the market justifies these plans—the first contracts with cosmetic companies are in preparation.

TEGO® Betain P 50 C does not mark the end of the current developments on the market. The team continues to work on optimizing products with high added value—those that can have a higher concentration of active ingredients, for example. The new process also opens up access to regional oils and fats, such as those made from algae or forage crops, and can thereby foster greater sustainability and use of a broader range of raw materials.

TEGO® Betain P 50 C not only optimized one of the most widely used production processes in the Group but also demonstrated that new paths can be profitable, even in the stable and longstanding raw material business. The modified process makes entry into sustainable and future-oriented raw materials easier for customers. It makes their business activities in internationally traded commodities more stable and predictable.

For Evonik, the globally available new raw material palm kernel oil simplifies volume planning and increases product and supply security. The technical edge that was achieved in betaine production consolidates the Group's leading role in the highly innovative and profitable cosmetics market.

TEMPORARY AIDS TO HEALING

In the Medical Devices Project House Evonik researchers are working on materials for higher-performance implants. Bioresorbable, load bearing, and tear-resistant, they will help bones heal and reduce complications arising from stents.

Dr. Andreas Karau

Most bone fractures are no big concern, at least not when the subject is young. For standard fractures, it is enough to immobilize the affected body part for a few weeks with a plaster cast. The body self-repairs and new bone material grows in the damaged area, thereby healing the fracture.

More serious fractures often require surgery. Nails, screws or plates made of metal are used to reconstruct the bones. These materials keep the bone fragments in place and give the bone sufficient support to withstand a limited amount of stress. The drawback is that these fasteners and plates either remain in the body or have to be surgically removed. Ideally, these load bearing implantable devices would be made of materials that can degrade in the body after they have served their purpose.

Over 20 researchers from Creavis, the strategic innovation unit of Evonik, are hard at work in the Medical Devices Project House located in Birmingham (Alabama, USA) to devise solutions to address such challenges. As their starting point, they use biodegradable polymers based on polylactic acid (RESOMER®, RESOMER® Select) from Evonik's Health Care Business Line. Medical device manufacturers are already producing biodegradable screws, pins, and small plates from these materials. However, they cannot be used for load bearing applications as they are not strong enough to withstand high forces. To improve the mechanical properties of the products, and at the same time, their biocompatibility, the scientists rely on composite materials that, in addition to biodegradable polymers, contain inorganic substances such as derivatives of calcium phosphate. These make the material harder and can also be used to promote the formation of bone material once the polymer gradually degrades.

Evonik foresees a high demand for such materials, which bridge the gap between polymer and metal. For instance, Osteoporosis: Worldwide, more than 8.9 million bone fractures are attributed to osteoporosis each year.

Osteoporosis risk

1 in every 3

women and every 5 men over the age of 50 will develop osteoporosis at some point.

Osteoporosis results in

8.9 million

bone fractures each year worldwide. Often, vertebrae or extremities are affected.

Source: International Osteoporosis Foundation, 2016

Suitable biodegradable materials can also improve the treatment options for cardiovascular applications. Worldwide, more than two million stents are used every year and most are made of metal. These remain in the vessel permanently and in five percent of the cases, contribute to the formation of blood clots (also known as thrombosis). Metal stents covered with a biodegradable polymer are more recent developments. They contain an anti-inflammatory substance which reduces the risk of future vessel occlusion. The latest generation stents are completely biodegradable. The first RESOMER®-based stents have just recently entered the market. They have to be elastic enough to prevent rupture during implantation but still need to hold the vessel open for several months. In the Project House, Evonik is working on further optimizing the material properties for these systems with additives.

Most projects in Birmingham support the vision of regenerative medicine: Medical devices made from biodegradable materials should provide support for living cells, tissues or organs for a certain period of time and then be replaced by the body's own tissue. In the long term, the researchers also want to populate a polymer matrix with living cells and so create real biological implants. These could be used to restore cartilage or replace damaged myocardial cells with healthy ones.

If there's no need to remove screws, there's no risk of complications due to a second operation.

The expert

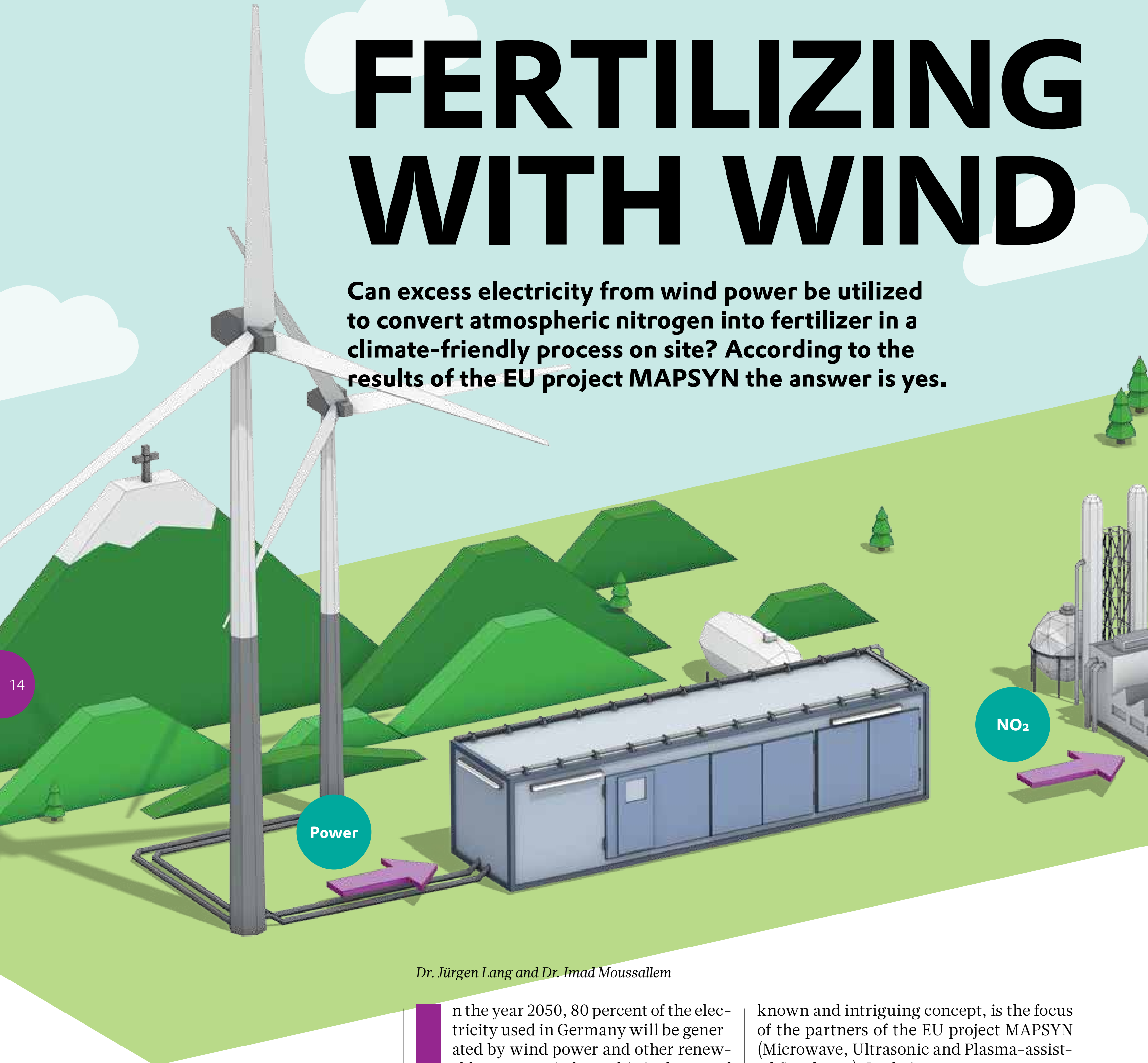
Dr. Andreas Karau is head of the Medical Devices Project House of Creavis in Birmingham.

andreas.karau@evonik.com

Photography: Uwe Feuerbach, shutterstock (2)

FERTILIZING WITH WIND

Can excess electricity from wind power be utilized to convert atmospheric nitrogen into fertilizer in a climate-friendly process on site? According to the results of the EU project MAPSYN the answer is yes.



The idea of MAPSYN: Using electricity from wind power in a compact system, atmospheric nitrogen is converted by cold plasma into NO_2, which in turn is easily converted into fertilizer.

Dr. Jürgen Lang and Dr. Imad Moussallem

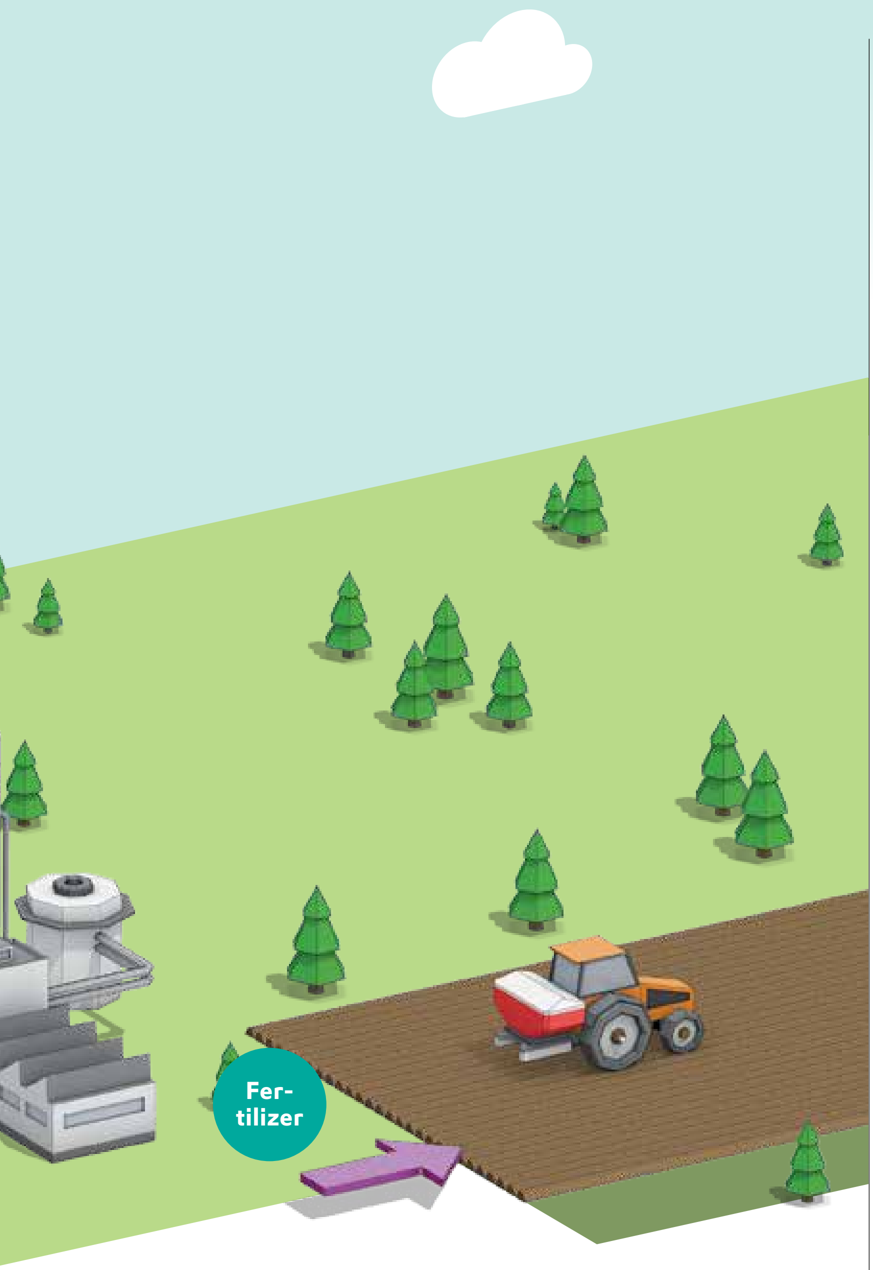
In the year 2050, 80 percent of the electricity used in Germany will be generated by wind power and other renewable sources. At least this is the stated intention of the German Federal Government. The only problem is that the weather-sensitive power supply has to be harmonized with the equally variable demand for electricity.

How to meet this challenge is currently an open question. One possibility, for example, is to significantly expand the transmission grid to spatially offset the difference between supply and demand. Another idea is to store the electricity in large-scale batteries set up locally, near wind parks or household solar energy systems.

Practical use of renewable and temporarily surplus power on site, a relatively unknown and intriguing concept, is the focus of the partners of the EU project MAPSYN (Microwave, Ultrasonic and Plasma-assisted Syntheses). In their system, one or more wind turbines generate electricity without carbon dioxide emissions. The electricity powers a small, compact plant nearby that produces nitrogen dioxide (NO_2) from the surrounding air. The NO_2, in turn, can be easily converted to nitrogen fertilizer, which is then used to enrich the soil in the fields of the region.

A process with history

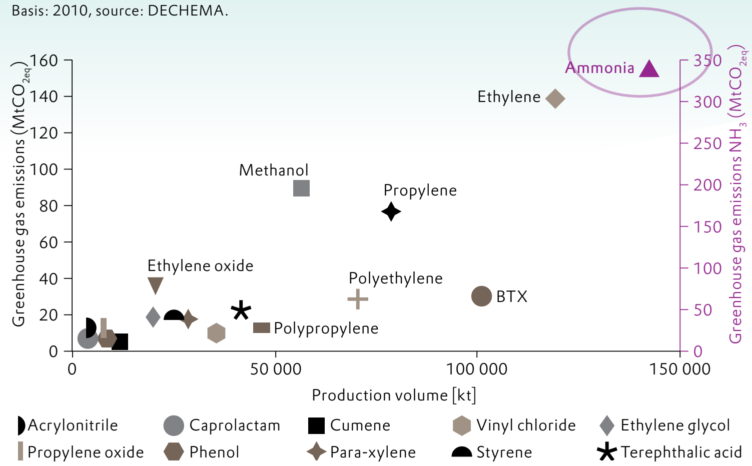
To obtain nitrogen in the form of NO_2 from the air, the scientists in the project rely on a process that basically has been known for a long time but was forgotten. Its origins can be traced back to 1903, when physicist



Effect of key chemicals on the climate

Of the 18 quantitatively most important chemicals worldwide, by far the most climate-relevant gases are released in the production of ammonia.

Basis: 2010, source: DECHEMA.



Kristian Birkeland conducted the first laboratory experiments with an electric arc. An electric arc occurs when high electrical voltage is applied to two metal points or electrodes. The electricity then passes through the air and ionizes it, wresting electrons from its molecules. This creates a plasma—the fourth physical state of matter, in addition to solid, liquid, and gaseous.

In a plasma, the non-reactive nitrogen molecules in the air are also activated, so that they react with the atmospheric oxygen. Based on the results of his laboratory experiments, Birkeland worked with electrical engineer Sam Eyde to develop a commercial-scale process, the Birkeland-Eyde process. It is no coincidence that both scientists come from Norway: The country's hydropower was a low-cost energy source for generating electrical arcs. As early as May 1905 the first small factory—it nevertheless employed 100 people—for the production of NO_2 for fertilizer was built in Notodden in southern Norway. A twelve-person commission from the French bank Paribas visited the factory in August of the same year. The bank's managers were fascinated by the technology and placed their trust in Birkeland and Eyde. They invested a considerable sum of money in the construction of another factory, which was much larger than the first and commenced operation in 1908.

Economically, however, success was short-lived. In 1913, BASF opened the first fertilizer factory in Ludwigshafen to make atmospheric nitrogen usable in the form of ammonia. It was based on the Haber-Bosch process, which replaced the Birkeland-Eyde process because of its lower energy consumption. In 1926, the Haber-Bosch process required only 4,000 kilowatt hours to chemically bind one metric ton of nitrogen from the atmosphere. This stood in contrast to the 61,000 kilowatt hours required by the electric-arc process. Moreover, the energy for the catalytic high-pressure process according to Haber and Bosch did not have to come from electricity. Instead, it was provided by the more cost-effective combustion of natural gas.

An emissions-free alternative

But today, this is exactly the main disadvantage of the Haber-Bosch process: For each kilogram of ammonia produced, between 1.15 and 1.3 kilograms of CO_2 are normally released. With annual worldwide production of about 140 million metric tons of ammonia, that means significant emissions, which have an impact on the climate.

Two additional factors diminish environmental performance. The first is that for fertilizer production, part of the ammonia is oxidized, which in turn is associated with significant N_2O emissions. The second is ➔

140

million metric tons of ammonia are produced annually.

Process engineers during construction of the MAPSYN pilot plant.

Infographic: C3 Visual Lab
Photography: Evonik

➔ that ammonia is produced in a few enormous plants that serve the worldwide market. Consequently, considerable emissions are generated again when the fertilizer is shipped to customers.

Against the backdrop of the energy revolution and current climate protection goals, scientists at the University of Eindhoven in the Netherlands and at Evonik have reevaluated the Birkeland-Eyde process for the MAPSYN project. In this work, they have also explored whether the historical process can be improved based on advances in plasma technology that have occurred in the meantime. They have already demonstrated in the laboratory, in fact, that energy consumption can be reduced by half.

The key task for the researchers is activating the nitrogen in cold—in other words, non-thermal—plasma. What sets it apart is that in cold plasma the electrons move considerably faster than the heavy ionized and neutral particles. The electrons have a significantly higher temperature—typically at least 10,000 degrees Celsius—than the heavy particles, which can be only as warm as 20 degrees Celsius. Cold plasmas can be generated through short, precisely controllable high-voltage pulses using special switching devices and generators.

Laboratory trials show that energy requirements for conversion of nitrogen are reduced by half compared with the traditional process.

Plasma process in a small space

As part of their work, the MAPSYN scientists at Evonik in Hanau have built and commissioned a pilot plant—not on the grounds of the site but in the EcoTrainer **(Fig. 3)**. The EcoTrainer is a 12 x 3 x 3-meter container that contains the entire infrastructure required for small-scale production, including water and power lines, exhaust air system, process control system, fire-protection systems. The EcoTrainer has already proven itself in other EU projects (see *elements* 53).

The plasma reactor in the pilot plant was developed by the Fraunhofer Institute for Chemical Technology in Mainz. The Dutch Institute for Fundamental Energy constructed ballast units and the generator. One of the things the plant is expected to show is that energy efficiency can be improved on the pilot scale as it was in the laboratory.

At the same time, the MAPSYN scientists—here, primarily researchers from the University of Hull in Great Britain and the University of Eindhoven—are synthesizing and testing new catalysts for the plasma process. Evonik and its project partners view this work as an opportunity to further improve energy efficiency and the yield of NO_2 production.

Such catalysts could make plasma technology attractive for other commercial-scale processes that, up to now, have to run under high pressure and high temperatures. Currently, the chemical industry still considers plasma processes to be rather exotic, even though they have been used successfully in acetylene synthesis in Marl for over 75 years. Evonik uses them also in the production of silicon tetrachloride and disilane hexachloride.

The Experts

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Mobile and modular

The cold plasma process is being tested by Evonik in Hanau. The pilot plant is installed in EcoTrainer, a retrofitted mobile container with standard dimensions.

CompanyNews

Evonik is acquiring the Specialty & Coating Additives business (Performance Materials Division) of the US company Air Products and Chemicals, Inc. for US$3.8 billion (approx. €3.5 billion).

The two companies are highly complementary, for example in the area of specialty additives for coatings.

REINFORCEMENT FOR SPECIALTY ADDITIVES

Evonik is strengthening its leading position on the high-margin specialty additives market through the acquisition of Air Products' Specialty & Coating Additives business. The transaction is to be completed by the end of 2016.

Air Products' Specialty & Coating Additives business will be rapidly integrated into the growth segments Nutrition & Care and Resource Efficiency. The combined specialty & coating additives business has a turnover of around €3.5 billion and an attractive EBITDA margin of more than 20 percent. With their products and their strong positions in the key global markets, Evonik and the newly acquired business are highly complementary.

The two businesses serve three particularly attractive, rapidly growing core markets: coating and adhesive additives, high-value PU foam additives, and specialty surfactants for industrial and institutional cleaning. They target the same end customers, but with different and complementary products. For instance, Evonik is a leader in PU foam stabilizers, while the Specialty & Coating Additives business of Air Products is well positioned in PU foam catalysts. Demand for these products is rising strongly, and the market for these additives will grow far more quickly than overall demand for chemical products.

Like Evonik, Air Products' Specialty & Coating Additives business follows a solution-oriented business model driven by intensive interaction with customers in research and development and outstanding technical service. The acquisition will allow Evonik to significantly strengthen its innovation leadership.

The planned acquisition remains subject to formal approvals from the relevant antitrust authorities.

Photography: Evonik

Expansion at Membranes ➜ Methionine for shrimps ➜ Actives from plants ➜

Expansion for polyamide 12 powder

Evonik plans to build a new production line for special polyamide 12 powder (PA12) in Marl (Germany). The new plant, which is scheduled to become operational in late 2017, will increase the Group's existing annual capacity for polyamide 12 powders by 50 percent.

Evonik sells its PA12 powders under the brand name VESTOSINT®. The powders are used, for example, for household appliances such as dishwasher baskets, but also in automotive and medical technology production and as matting and structural agents in coatings. Evonik also anticipates significant increases in demand in tool-free production—especially in the 3D printing industry. Due to their mechanical properties and chemical resistance as well as the high melting point of finished products, PA12 powders are particularly suitable for use in powder-based 3D printing processes. Fiber composite materials represent another growth field. Polyamide 12 powders are an ideal matrix for thermoplastic composites made of fiberglass, carbon fibers, and aramid or steel fibers.

Air duct part for an engine compartment, manufactured by 3D printing.

Specialty silicones from China

Evonik has started the construction of a production facility for organically modified specialty silicones in Shanghai (China). The project is part of a global investment initiative; the first expanded production plant became operational in Essen in late 2014. The completion of the new facility is planned for mid-2017.

With it, Evonik is strengthening its position as a market and technology leader. Specialty silicones are needed in numerous industries. As additives for plastics, specialty silicones are used for furniture, car seats, and mattresses. They also play an important role within the formulation of insulation materials for producing insulation for energy-efficient refrigerators. They serve as defoaming agents in industries such as construction, textiles, and plastics. Specialty silicones are also used in coatings and inks. Markets for specialty silicones have grown substantially over the past years.

Expansion of the membrane business

Evonik will further expand its Austrian site in Lenzing/Schörfling to double the existing production capacities for the hollow-fiber membrane modules of its SEPURAN® brand. The membrane offers a highly selective and efficient method for the separation of gases from gas mixtures such as methane, nitrogen, and hydrogen. The production of additional membrane modules is projected to begin in late 2017. Evonik's investment will create over 30 new jobs in Schörfling.

The gas separation modules that Evonik produces in Schörfling are primarily intended for the biogas market and for hydrogen and helium extraction. The new hollow-fiber spinning plant will be dedicated to the production of membrane modules, in particular for nitrogen extraction. The hollow fibers consist of polyimide, a high-performance polymer, that is produced in the nearby Lenzing plant and is spun and then further processed in Schörfling. The infrastructure in Lenzing will be expanded as well.

Polyimide hollow fibers on their way through the spinning bath.

Professorship for Dr. Stefan Pelzer

Dr. Stefan Pelzer from the Innovation Management unit of the Animal Nutrition Business Line received the title of adjunct professor from the University of Tübingen. In 2001, Pelzer decided to transfer from the University of Tübingen to industry but he remained in close contact with the university researchers. He has been holding regular seminars on the subject of the basics and application examples of industrial biotechnology and has been publishing scientific papers with research colleagues since 2008. This work has now been awarded with the title of adjunct professor. An independent committee of university professors regarded his achievements positively, resulting in the senate giving its consent to grant him professorship.

Dr. Stefan Pelzer teaches industrial biotechnology in Tübingen.

Award for polyamide 12

The Evonik Resource Efficiency Segment received the European Plastics Innovation Award in the "Material Innovation" category for its use of polyamide 12 (PA 12) VESTAMID® NRG in high-pressure gas pipelines. PlasticsEurope, the Association of Plastics Manufacturers in Europe, and the Society of Plastics Engineers (SPE) had organized the joint award for the first time in eight different categories. It recognizes companies that have attracted public attention with developments in plastics technology.

VESTAMID® NRG offers an outstanding property profile for high-pressure pipelines and can be exposed to pressures of up to 18 bar. Evonik has also developed solutions for the installation that enable significant savings of labor and installation costs, compared to steel. Gas utilities can build up their subterranean pipeline networks in a cost-effective way without any concern about losses in throughput performance.

Gas pipes for gas distribution with pressures up to 18 bar can be installed from a roll.

More capacity for catalysts

Evonik has commissioned an additional production area and erected a new building to house research, development, and scale-up operations for fixed-bed catalysts at its Marl site. The new building will be used for operations revolving around the continued improvement of fixed-bed catalysts, which are mostly used in the large-scale continual processes involved in the manufacture of base chemicals.

The new scale-up plant is used for the development of catalyst formulas at the laboratory scale. Pilot units are then used for transferring the formulas to industrial scale and optimizing them for production.

Methionine source for shrimps

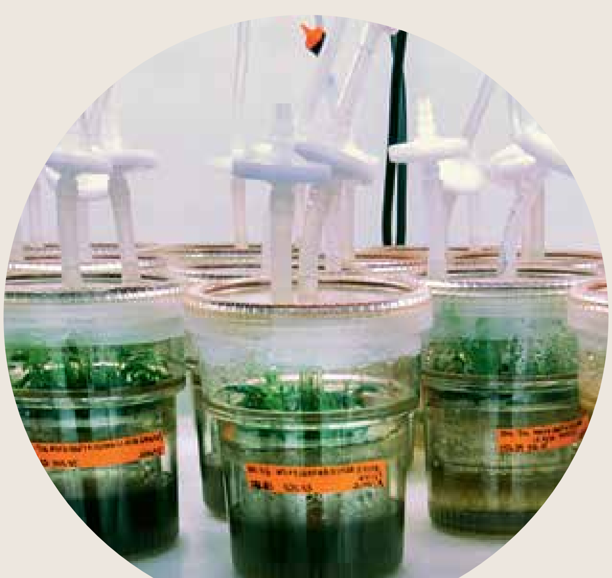
In Antwerp, Evonik will shortly be starting up the world's first plant for producing a new methionine source specifically for shrimps and other crustaceans. Scheduled for market launch in mid-2016, AQUAVI® Met-Met will be used as a feed additive in aquaculture.

The product has been specially developed for shrimps and crustaceans, which have totally different feeding habits and digestive systems than, for example, fish. The dipeptide, consisting of two DL-methionine molecules, is not easily water-soluble and is therefore not as quickly washed out of the feed. It becomes available for protein synthesis in the digestive tract of shrimps at the right time and in the right quantity.

Feed trials in many countries have shown that AQUAVI® Met-Met is the most efficient methionine source available for shrimps, and thus increases the efficiency and sustainability of shrimp farming.

PLANT-BASED ACTIVE INGREDIENTS

Evonik has taken over the startup Alkion Biopharma SAS, whose headquarters are in Evry (France). Alkion specializes in the development of biotechnological active ingredients for the cosmetics industry and was founded as a spinoff of Imperial College London in 2011. Evonik is purchasing this company to strengthen its portfolio of specialty active ingredients. The company is now offering its customers highly effective customized plant-based active ingredients that live up to their product claims. Alkion Biopharma SAS is one of the leading manufacturers of biotechnologically developed cosmetic active ingredients. The company has developed methods for cultivating plant biomass under laboratory conditions and obtaining biomass extracts with an exceptionally high yield of complex ingredients. The entire process takes place without altering the plant genome.



Alkion cultivates plants under laboratory conditions and obtains cosmetic active ingredients from biomass.

Professorship for Dr. Georg Oenbrink

Dr. Georg Oenbrink, head of Innovation Networks & Communications in Corporate Innovation, has been appointed Honorary Professor of the University of Applied Science in Aachen, Germany. For the past eight years, Oenbrink has been lecturing at the University of Applied Science on industrial aspects of plastics technology and on the management of innovation and technology. The University of Applied Science has now recognized this voluntary engagement with the award of an honorary professorship. The collaboration was established in 2008 at the request of Prof. Dr. Thomas Mang, head of the Applied Polymer Sciences degree program.

For eight years Dr. Oenbrink has been lecturing at the University of Applied Science in Aachen.

Acquisition of MedPalett

Evonik has acquired the company MedPalett AS, located in Sandnes (Norway), which specializes in food ingredients containing anthocyanins. The acquisition will help Evonik expand the portfolio of its Health Care Business Line in the area of advanced food ingredients.

Anthocyanins are known for their natural antioxidant properties. Numerous international studies suggest that they have health-promoting properties, including the prevention of cardiovascular disease.

MedPalett, which previously belonged to the Norwegian Biolink Group, developed a berry extract from wild Scandinavian bilberries and black currants from New Zealand that has a high anthocyanin content. The company manufactures the ingredient itself. It has been available as a dietary supplement under the brand name Medox® in Scandinavia since 2000. Evonik has distributed the berry extract since 2015 under the name Healthberry™ 865.

Scandinavian bilberries contain a particularly high amount of anthocyanins.

Dual process technology study program

TH Georg Agricola in Bochum (Germany) and Evonik offer a new, joint dual study program. It combines Evonik's chemistry apprenticeship with a bachelor study program in process technology at TH and therefore is ideally suited to prepare the students to become engineers.

The first six apprentices started their dual study program in the 2015/16 winter semester. Every year up to ten further students will enter the program and benefit from this perfect mix of practice and theory. Within the new dual study program, the apprenticeship at Evonik's Chemical Park in Marl lasts for 3.5 years. The cooperative study program at the university lasts for nine semesters and runs alongside the apprenticeship. The courses at the university can be attended full-time or part-time—meaning the courses and lectures are also held in the evening and at the weekends.

Further information:
www.evonik.de/ausbildung

Photography: Evonik (4), Carsten Behler, fotolia, Uwe Feuerbach

COMPETITION FOR RHODIUM

Each year, the chemical industry produces more than ten million metric tons of aldehydes from alkenes. It mainly uses rhodium catalysts for this process. Because of rhodium's rarity and fluctuating price, Evonik, together with partners, has developed alternative catalysts in a publicly funded project.

Prof. Robert Franke and Dr. Dieter Hess

Conversion of alkenes with syngas—a mixture of carbon monoxide and hydrogen—is one of the most important commercial methods for creating carbon-carbon bonds **(Fig.1)**. This process, known as hydroformylation, produces aldehydes, which are then used by industry to manufacture products such as drugs, surfactants, laundry detergents, and plasticizers. Consequently, hydroformylation converts inexpensive raw materials into valuable intermediates.

The process was discovered in 1938 by Otto Roelen, an employee of Ruhrchemie in Germany. Originally, chemical companies used homogeneous cobalt catalysts in the process. This required a relatively high temperature (150 to 180 degrees Celsius) and high pressure (200 to 350 bar). The process consumed a lot of energy. Under these conditions, apart from the desired aldehyde, a relatively high percentage of secondary products were also produced.

In 1965, Geoffrey Wilkinson from the UK reported about the possibility of using a rhodium catalyst in the hydroformylation process. This had several advantages over the established cobalt-based catalysts: The processes could be conducted under milder conditions, which meant lower energy consumption, and were also more selective in producing the required aldehyde. But since cobalt is much cheaper than the precious platinum-group metal rhodium, corresponding catalysts are still competitive, especially for the production of longer chain aldehydes. With the help of these catalysts, the chemical industry produces more than 2.5 million metric tons of oxo-products each year. However, rhodium is generally used in the hydroformylation process because it saves energy and conserves resources.

Ten times more expensive than gold

Consequently, the industry is dependent on a precious metal that is subject to incalculable price fluctuations and that is mined in very few places, mainly in South Africa. Only a very small part of the roughly 20 tons of rhodium that comes on to the market each year is from other countries—Russia, Zimbabwe, and North America.

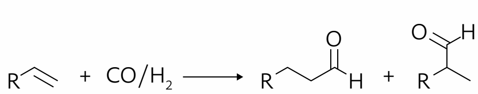
At the end of 2015, the precious metal, which is in demand especially by manufacturers of catalytic converters for automobiles, was trading at $650 per troy ounce (about 31 grams)—just half the price of gold. However, in 2008 the same amount cost $10,000—ten times the price of gold at that time. Similar prices are conceivable in the future, as the market is small but unfathomable

This is why in the long term it makes economic sense to find alternative transition metal catalysts. Also from a scientific aspect, it is exciting to examine the catalytic effect of metals such as iridium, ruthenium, and iron in hydroformylation. Experts have long believed that these metals are at least a thousand times less active than cobalt in terms of their catalytic effect. But the evidence for this is less than satisfactory. There are still many gaps in knowledge in the field of transition metal complexes for hydroformylation.

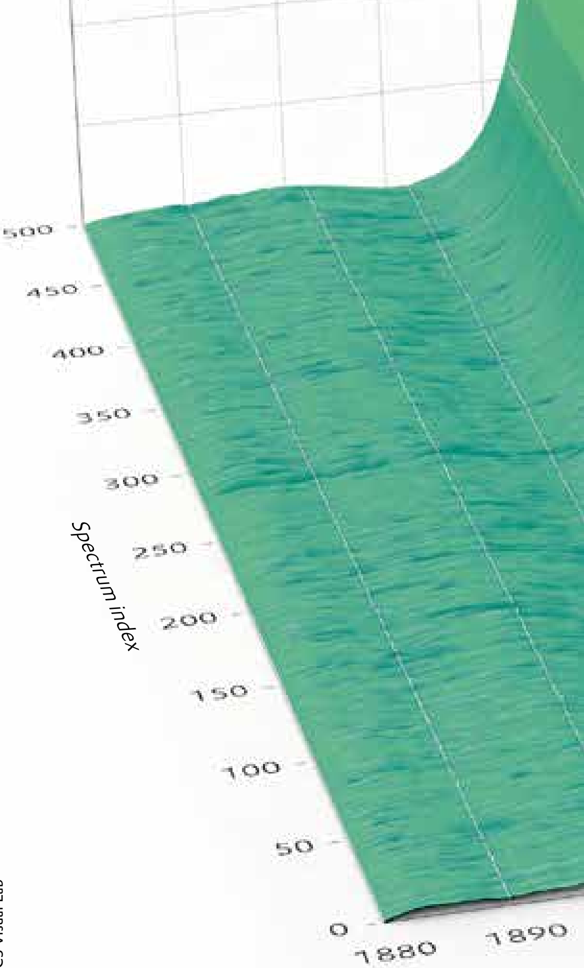
To change this, the Proforming (Process Innovations for HydroFormylation) project was launched in 2012. Funded until 2015 with more than €600,000 from the German Federal Ministry of Education and Research, Evonik researchers worked together with scientists from the team of Prof. Matthias Beller from the Leibniz Institute for Catalysis at the University of Rostock ➔

Figure 1. Essential process

The hydroformylation of olefines produces aldehydes, which are needed to manufacture drugs, surfactants, and plasticizers, for example.



Alkene Syngas Aldehyde

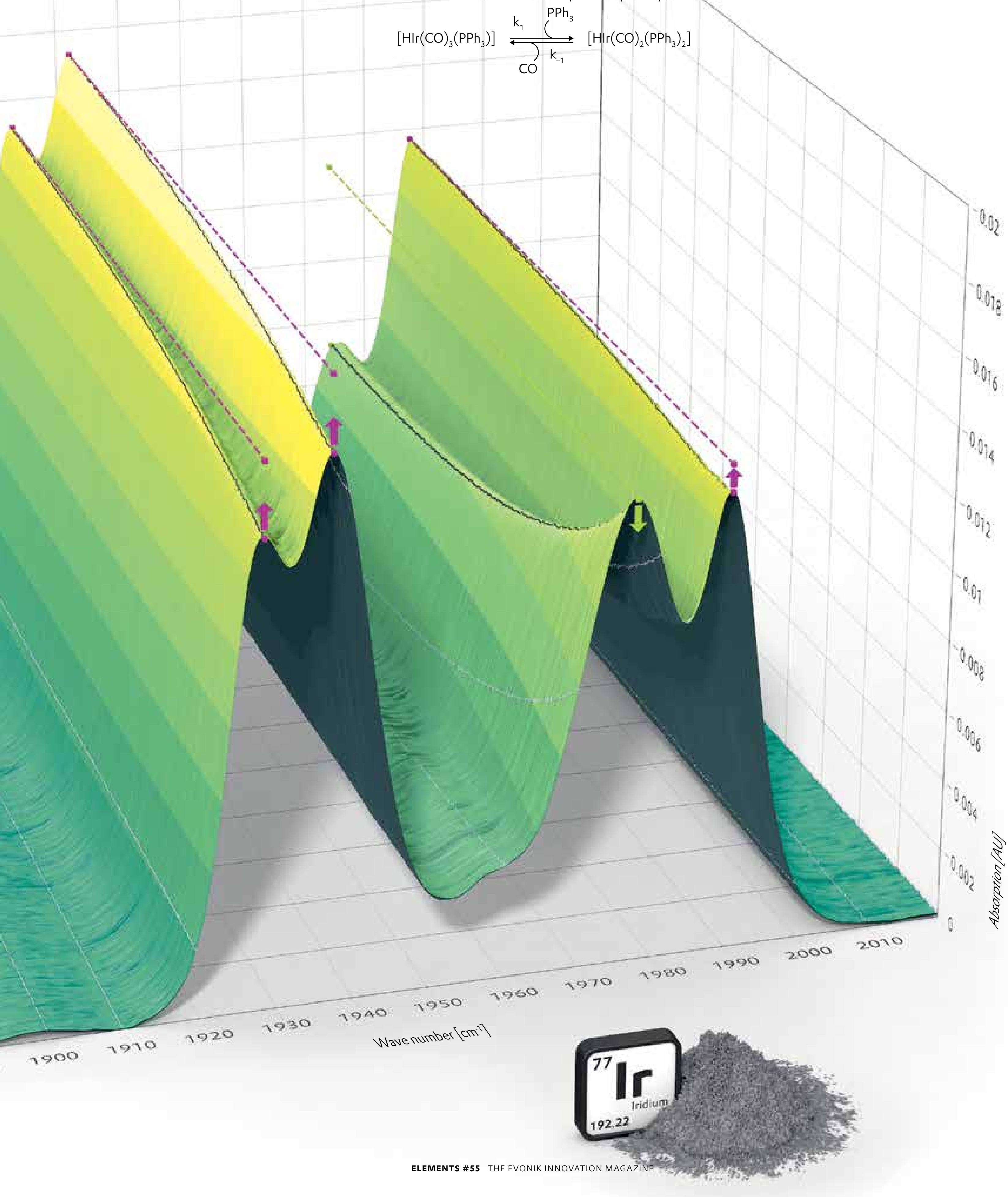


Infographic: C3 Visual Lab

Taking a close look at catalysts

Can iridium replace rhodium in hydroformylation? To answer that question, Evonik used FTIR operando spectroscopy. This combines reaction-kinetic and spectroscopic methods and gives insights into structure-effect relationships. On the basis of carbonyl stretching vibrations (1,900 to 2,000 cm-1), the spectrum shows how the balance between two iridium complexes changes if the surplus of PPh_3 ligand is increased from 2:1 to 10:1. These measurements provide valuable information on which structure of the iridium complex is especially active and selective.

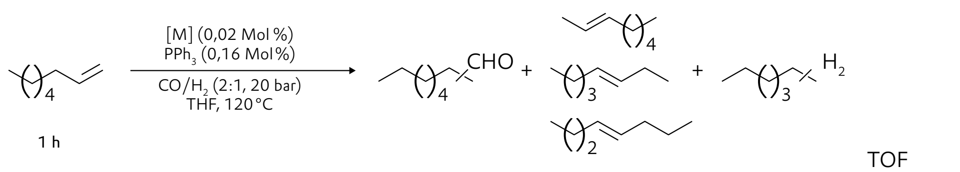
$$[HIr(CO)_3(PPh_3)] \underset{k_{-1},\ CO}{\overset{k_1,\ PPh_3}{\rightleftharpoons}} [HIr(CO)_2(PPh_3)_2]$$



In Evonik's autoclave facilities in Marl, catalysts are examined and assessed at pressures up to 300 bar and temperatures up to 2,000 °C.

Figure 2. Iridium versus rhodium

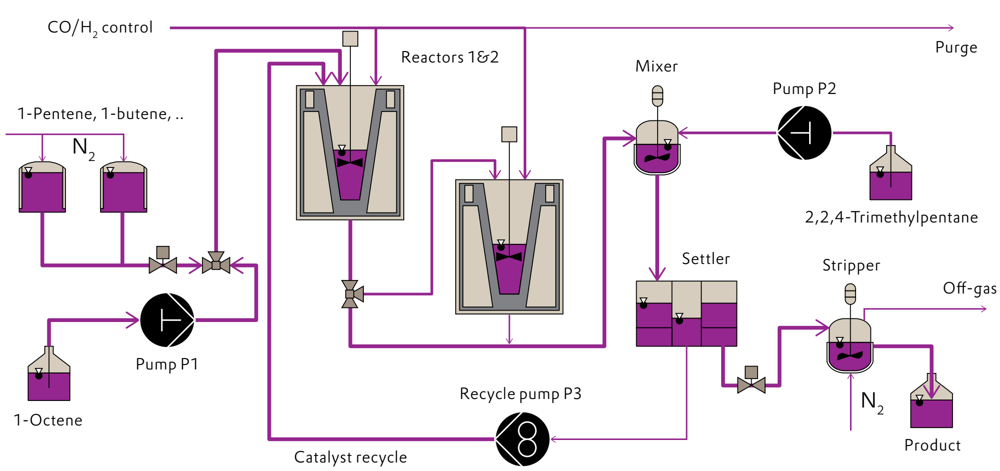
Iridium-catalyzed hydroformylation of 1-octene compared with rhodium-catalyzed hydroformylation: In contrast to rhodium catalysis, almost no alkene isomerization occurs with iridium.



				TOF
$[Ir(cod)(CO)_{12}]$:	65 % (*n*/*i* = 76:24)	2 %	19 %	163 h^{-1} (20 h)
$[Rh(cod)(CO)_{12}]$:	75 % (*n*/*i* = 60:40)	21 %	3 %	1.255 h^{-1} (3 h)

Figure 3. The mini-plant: Small but meaningful

Flow diagram for the mini-plant in which the researchers investigated continuous iridium-catalyzed hydroformylation of 1-octene. The setup is similar to that of a pilot plant.



➔ (LIKAT Rostock) and the team of Prof. Arno Behr at Dortmund University—with great success.

For example, the scientists found reaction conditions for hydroformylation in which iridium catalysts were just one order of magnitude less active than rhodium catalysts. They initially investigated the behavior of these iridium catalysts over a long period in a mini-plant. In this plant, hydroformylation runs continuously over long periods, similar to large-scale plants. The project partners also developed new catalysts based on ruthenium, which is currently traded at about $40 per ounce. Consequently, it is much cheaper than rhodium, for example.

The trick with carbon monoxide

In the past, the main problem with iridium-catalyzed hydroformylation was that the investigated iridium complexes also catalyze the hydrogenation of the alkenes well. This produces relatively large quantities of undesired alkanes.

Based on an idea from LIKAT director Matthias Beller, the scientists overcame this difficulty: At room temperature, they put the alkene in a solution containing a precursor of the iridium catalyst and the inexpensive ligand triphenylphosphine. When they had filled the autoclave—a special reaction vessel—with pure carbon monoxide, they increased the temperature and pressure and introduced the syngas.

When they carried out the hydroformylation in this manner, from 1-octene, for example, they obtained various nonanals (**Fig.2**) with a yield of 65 percent. This aldehyde mixture consisted of 76 percent linear n-nonanal and 24 percent branched isononanals.

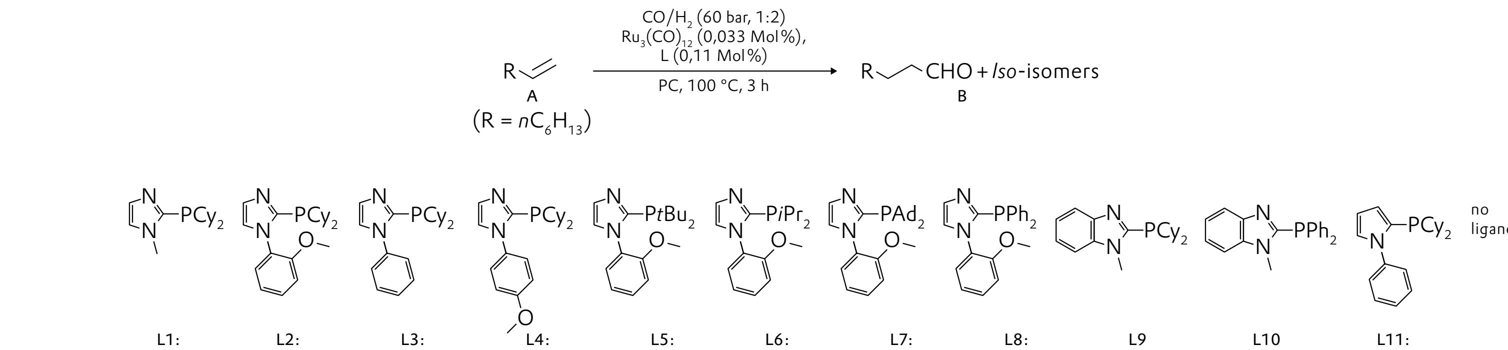
Arno Behr, a professor of technical chemistry at Dortmund University (Germany), and his team built a mini-plant (Fig. 3) for continuous iridium-catalyzed hydroformylation. Apart from their dimensions, the components of this mini-plant—reactor, mixer, stripper, liquefied gas tank—are the same as in a pilot plant. For example, the reactor holds about 0.8 liters, the mixer is 16 centimeters wide and long and is 13.5 centimeters high.

In the mini-plant the scientists converted 1-octene for up to 100 hours. Each hour, about half a liter of solution flowed through the mini-plant. The scientists thus proved that, in principle, continuous processing is possible. They also tested how efficiently the catalyst could be recycled by means of extraction. The result: Per hour, only 0.1 percent of the catalyst was lost for further use. This result is a solid basis for more developments to establish a commercial process.

The ruthenium catalyst developed in the Proforming project was also used in the mini-plant. The results are still being assessed. In the autoclave, this catalyst ex-

Figure 4. Successful ligand screening

In the systematic search for the optimal ligand for the ruthenium-based catalyst system, the imidazoyl-substituted monophosphine ligand L1 showed the highest activity and selectivity.



	L1:	L2:	L3:	L4:	L5:	L6:	L7:	L8:	L9	L10	L11:	
Yield B	79%	79%	75%	77%	0%	76%	0%	69%	37%	62%	0%	0%
Ratio *n/iso*	95:5	95:5	96:4	95:5	–	95:5	–	91:9	97:3	97:3	–	–

hibited hydroformylation activity and selectivity that has not been matched by ruthenium-based systems in the past.

Theoretical chemistry for practical applications

The new catalyst system consists of a three-core ruthenium carbonyl complex (Ru_3CO_{12}) and an imidazoyl-substituted monophosphine ligand. The scientists from Evonik and LIKAT found this ligand during their systematic search (**Fig.4**) by also using methods from computer-aided, theoretical chemistry. Hydroformylation of 1-octene using the new catalyst delivers nonanals with a yield of 79 percent. The nonanal mixture consists of 95 percent linear n-nonanal.

The committed collaboration, the complementary competences of the scientific partners, as well as the organizational support by Evonik´s Innovation Agency were the key factors for the success of the Proforming project. But there was one other success factor: the high level of expertise of the Evonik and LIKAT scientists in operando spectroscopy, with which catalysts can be observed directly doing their job under actual reaction conditions.

The reaction solution is pumped through steel capillaries that are screwed into the top of the autoclave into the measuring cell of an infrared (IR) spectrometer. This allows IR spectra to be recorded in second cycles. They continuously map the changing concentration of intermediate stages of the catalyzed reaction. The spectra also show the changes in the catalyst.

The scientists used sophisticated computer programs to interpret the spectra. On the one hand, these programs calculate the structures of possible catalyst complexes and the resulting bands in the IR spectrum. On the other hand, they analyze the measured spectra so that individual substances can be read from the complex overlapping patterns of the spectra—even when the respective substance is only present in very small concentrations.

Evonik now has new options to contend with the scarcity and price spikes of rhodium.

Eight publications in prestigious journals are further evidence that the Proforming project was extraordinarily fruitful from a scientific aspect. Evonik now has new possibilities, secured with three patents, to respond to the scarcity and price fluctuations of rhodium. However, one of the scientists' dreams could not be fulfilled: namely, establishing iron-based catalysts for hydroformylation. But sometimes dreams just need more time to become reality.

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The experts

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Dr. Dieter Hess is a senior scientist in the Performance Materials Segment, where, among other things, he is responsible for the autoclave facilities for oxo research.
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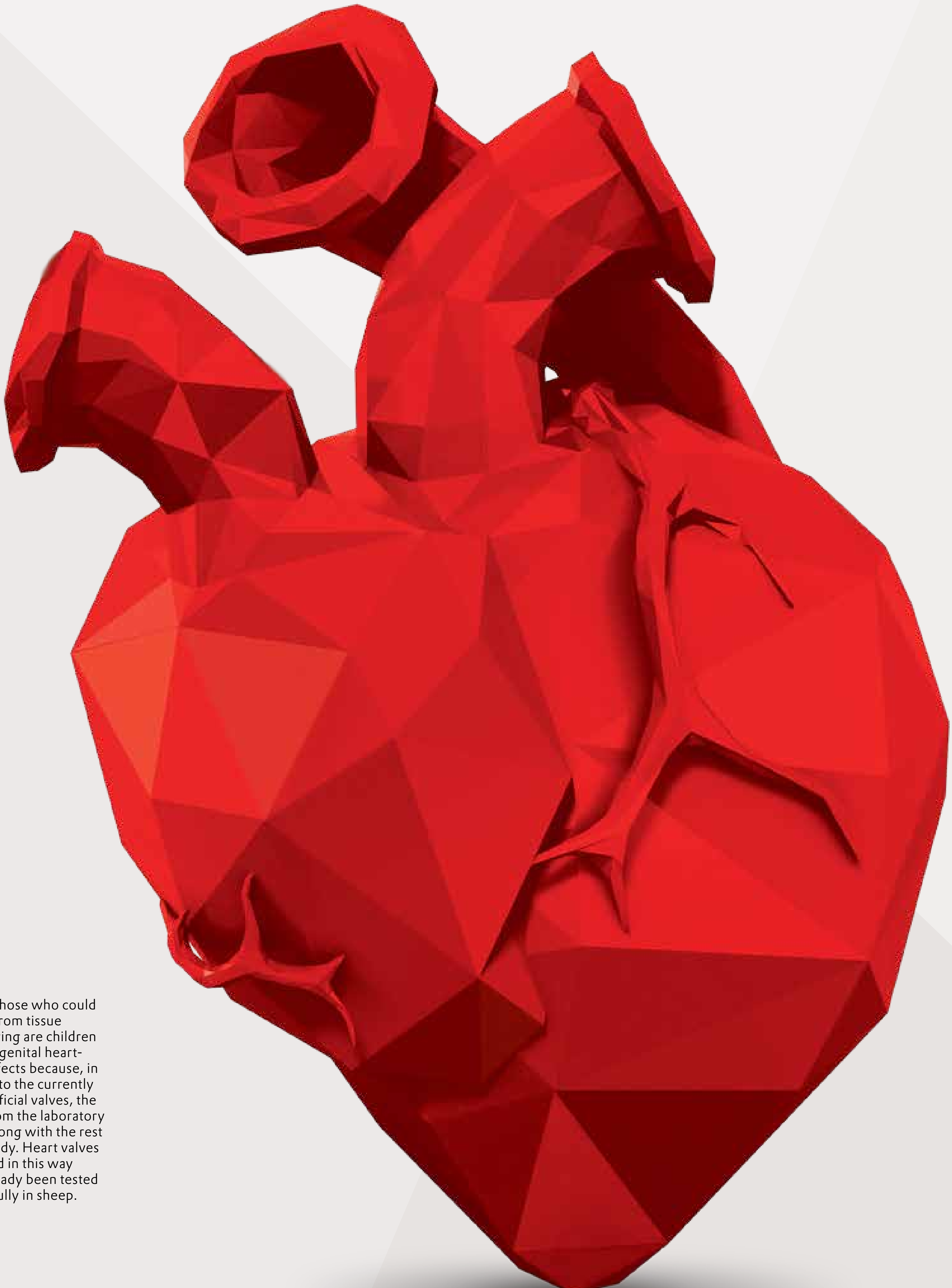


Among those who could benefit from tissue engineering are children with congenital heart-valve defects because, in contrast to the currently used artificial valves, the tissue from the laboratory grows along with the rest of the body. Heart valves produced in this way have already been tested successfully in sheep.

ORGANS FROM THE LABORATORY

Replacement at the press of a button

The number of people needing donor organs has been significantly rising worldwide for decades while the number of donors and performed surgeries has remained the same. In Germany alone more than 10,000 people are currently waiting for replacement organs.

Scientists around the world are therefore working on making the replacement of organs independent of human donors. They envision tailor-made engineered organs from the laboratory. From today's perspective, this can be accomplished by two different methods of tissue engineering: In the classical approach, living cells are placed on scaffolds of synthetic or biological tissue—the latter can also originate from donor animals such as pigs. In the second approach, the scientists want to simply print the required organs. Similar to 3D printing with polymers, they aim to print the living cells, as well as biocompatible materials such as hydrogels, layer upon layer and thus create the needed organ.

Furthermore, there are more areas of application for tissue engineering. Human cells from the laboratory can help to accelerate the development of new active ingredients in pharmaceutical research and thus reduce the number of animal tests. It is also conceivable to produce synthetic meat from muscle cells and thus reduce factory farming and the related CO_2 emissions.

However, there are quite a few obstacles to overcome before it will be possible to produce individual replacement organs at the press of a button or get a synthetic steak for which no slaughterhouse was needed: How can the living cells be provided with sufficient nutrients and oxygen while the organs are being built? Which materials are suited for making artificial scaffolds for organs?

In the search for answers, Evonik's Corporate Foresight Team has thoroughly examined forward-looking tissue engineering approaches. The focus here lies on the growth opportunities for the Group and the contribution specialty chemicals can make with respect to this technology—a technology that could put an end to long waiting lists and save the lives of thousands of people.

Photography: Daniel Cosma/Alamy Stock Photo

DR. DANIEL ROST

Applied passion

For Dr. Daniel Rost the attraction of chemistry lies in what it makes possible, whether in pure academic research or strategic raw-materials procurement in industry. For him it's always opening up new and exciting fields of activity at Evonik.

When Dr. Daniel Rost talks about catalysts, atom models, or carbon chains, his passion is obvious. His chemistry instructor was the one who awakened his enthusiasm for chemical processes in his mid-thirties. Today, he lives out his passion at Evonik. Rost came to the company in 2011 as a laboratory manager at Innovation Management in the Animal Nutrition Business Line.

Over the last four years, the primary focus of his work has been the petrochemical synthesis of methionine. The amino acid is used in the sustainable nutrition of pigs, poultry, and fish. A business area steeped in history, methionine was first used as many as 60 years ago as a food additive and later as a feed supplement. And this fascinates Rost: "How you can manage to continuously improve production steps over such a long period of time is quite remarkable," he says.

Such cost-effective operation was not something he learned at university. "There, we were more interested in generating elegant reactions with a few grams of substance," he said. On the industrial scale, operating efficiency and technical feasibility became extremely important. "Just starting out as a young chemist, I didn't understand that very well," he admitted. "I came to the company with over 200 name reactions up my sleeve and thought, 'Now I can save the world,'" he says.

Setting course for industry from early on

Rost began his academic training in his home city at the TU Berlin, where he completed his degree and doctorate in organic chemistry. In these years, he developed ruthenium-based metathesis catalysts, which are used in organic synthesis. "I also began to grapple with natural substance synthesis to broaden my knowledge." As far back as his time at university, Rost knew that he wanted to work in industry later on. He gathered his first industrial experience as an intern at Schering in Berlin and in the crop-protection division at BASF. He advises every student to do this.

To pass on his experience, he also circulates as a contact for junior chemists at orientation sessions. "Whether it's academics or industry, each path has its own justification, but also its advantages and disadvantages," says Rost, an ambassador of his field. "At university, for example, the focus tends to be basic research. Even though this work is important, I find it more exciting to achieve commercial value with my work as well," Rost explains.

Nonetheless, after earning his doctorate, he decided to stay in academia for one more year, working with Prof. David Evans at Harvard University in the United States. There, he did postdoctoral work on the synthesis of antibiotically active tetracyclines. "And I became familiar with completely new methods of working," adds Rost. "Also, I had always wanted to go to the States—after all, the American Sector in Berlin is where I grew up," he says.

Afterward, in 2011, conditions in the chemical industry were good, and Rost found a connection to Evonik through a personal contact from his time as an intern. As early as his job interview, he knew this was the right decision: "I really liked the atmosphere at Evonik."

He quickly oriented himself in his new environment. "In industry, you first have to learn to swim, to understand the company. But I was still involved in chemistry research, which I was already familiar with, and that gave me a feeling of security." For example, Rost brought his expertise in process optimization and worked on alternative synthesis routes. "Having been in the methionine business for 60 years, the company had already considered every possibility," he says. Also, the molecule is extremely small, so there are only a limited number of ways to assemble it. "And you always have to keep economic efficiency in mind. A new synthesis route can't be more expensive than the established route," explains Rost.

Among the new challenges in the company was project management: "That was not such a focus for us at the university. But one can adapt quickly." To this end, the team's work is essential—even if it is not always easy for a beginner. "Suddenly, I was no longer responsible for students but for people who, in some cases, had a lot more experience than I did and were a lot older than I was," says Rost.

Indispensable: Curiosity and communication skills

For a laboratory manager, curiosity and communication skills are also important when it comes to contact with other departments such as marketing. There, customers ask how stable methionine in fish food is in water or how homogeneously the amino acids can be distributed in the food. "Such questions are then sent back to R&D. So I also came in contact with colleagues from Animal Nutrition, which was a completely new field for me," says the chemist.

Rost's latest career choice is also a complete change of scene. Since early 2016 he has been head of Strategic Procurement and Production Coordination for Bioproducts. With this new post, he has gone from R&D to the beginning of the value-added chain. It's a jump into the deep end, but it's the right move for Rost as a chemist with an interest in business. "I can also imagine myself working in marketing or sales later on. That depends on a number of things in the company and, of course, my family," says Rost, who recently became a father for the first time.

Whatever the future brings, Rost is sure of one thing: Evonik still offers him many opportunities for advancement. Even the door to R&D, where his passion for chemistry began, will always remain open.

Photography: Evonik

“I find it exciting to achieve commercial value with my work as well.”

Dr. Daniel Rost

Feed amino acids by fermentation

For decades Evonik has been a leader in the production of amino acids for efficient animal nutrition. Except for DL-methionine these are obtained by fermentation.

Locally available carbohydrate sources at the respective production sites serve as raw materials. For Biolys® (a source of L-lysine) the raw material in the US and Brazil is dextrose from corn. Daniel Rost is responsible for its procurement.

FOLLOWING THE KNOWLEDGE

Evonik built a biolab in Shanghai in 2013. There, for the first time, the company's strategic innovation unit Creavis is studying yeast as production organisms.

Among Creavis' projects in Shanghai is the optimization of a bioprocess for the production of biosurfactants from yeasts.

Yeasts and bacteria are a little like humans and amoebas: They are at different stages of evolutionary development. Although yeasts and bacteria are both single-cell organisms, bacteria are prokaryotes—organisms that lack a cell nucleus—and yeasts are eukaryotes—organisms that have a cell nucleus. Their superior size and complexity compared to bacteria allow yeasts to make more complex molecules than bacteria can. This is why these organisms are so attractive to biotechnology. But designing them in such a way that they create particular desired target molecules requires special skill. Three years ago, Evonik decided to harness the potential of yeasts and develop its own expertise in the production of specialty chemicals using these organisms.

"China stood out as the obvious location for a yeast laboratory," says Dr. Markus Pötter, head of the Yeast unit (Greater China) of Creavis' Science & Technology unit. Evonik obtains large quantities of long-chained diacids from this emerging country, which is already using biotechnological production processes based on yeasts. Continuing to improve these processes and produce higher-quality molecules in the same way are the most important objectives of the biolaboratory. "We don't produce yeasts; we use yeasts to produce chemicals," stresses Pötter.

Yeast technology: a China strong point

An even more important factor in the decision to locate the laboratory in China than proximity to suppliers and customers was the expertise of Chinese researchers in the field of yeasts. Scientists at China's universities and research institutes have been working with yeasts for decades. There, the use of yeast technology to produce long-chained diacids, which are required for the production of specialty polymers, is a well-established industrial process. Their work has produced a number of well-documented strains that display properties such as good growth or desirable metabolic pathways. Most of these strains are lying unused in the strain collections of the institutes.

In the past, Chinese researchers developed the biomolecular methods and protocols for genetic engineering work on yeasts, because tools from the work on bacteria can seldom be used for yeast cells, which are structured quite differently. China's years of rigorous work on yeast technologies is reflected in the professional literature, as many key publications on the subject are by Chinese scientists.

In October 2013, Evonik opened the Creavis biolab in a modern research center in the Xinzhuang Industrial Park, where it occupies an area of about 300 square meters. Although the work conducted there requires only Chinese Safety Level 1, Evonik has established higher safety standards so that the laboratory can be used accordingly, if necessary.

A fully equipped biolaboratory

It is equipped with everything a biotechnologist needs, including an area for producing media, refrigerators and incubators for the strains, two sterile work areas, and eight one-liter fermenters. Here, researchers can test the fermentation processes simultaneously under various conditions. There are already plans to expand the fermentation capacity.

Markus Pötter has lived in China with his family and built Creavis' yeast research program there since 2013. Pötter remembers the biggest hurdles being the language and the formalities, which are often different from European customs. Even matters that are taken for granted, such as explaining to an installer the precise requirements for the equipment in the laboratory, proved unexpectedly difficult. Pötter received valuable support in the beginning from his colleague Dr. Li Li, who as a native speaker was able to overcome these obstacles.

And then there were the requirements of biotechnology, which were rather unusual compared to chemical syntheses: "It was nearly impossible to order two grams of antibiotic for a culture medium. I could have had 40 metric tons of hydrogen peroxide delivered to the door in two days," Pötter remembers.

The biolab team has grown steadily over the last two years. It now consists of one chemist, one lab technician, as well as four biotechnologists—all native Chinese, except for Pötter. Thus constituted, the team has the expertise, from genetics to product preparation, to optimize the yeast processes. Three additional researchers are scheduled to join the team this year. The team has also established partnerships with six Chinese research institutes to expand its knowledge.

For the universities, the most important thing is to be able to publish the results of their joint research. Evonik accepted this, as is customary in Germany—with the condition that it be able to patent develop- →

Infographic: C3 Visual Lab | Photography: Markus Pötter

Guest commentary

Biotech in China

Prof. Yan Feng has held a chair in the Department of Bioscience and Biotechnology at Shanghai Jiao Tong University since 2009. In addition, she is the Deputy Director of the Chinese State Key Laboratory of Microbial Metabolism.

Prof. Yan Feng

Modern biotechnology has enabled great advances in worldwide scientific innovation, and this has accelerated the process of building a green and sustainable society. In the past decade, economic and environmental factors have prompted the Chinese government to emphasize the development of biotechnology. A series of national and regional innovation centers has been established in China. Core scientific research groups have been set up in several universities and academic institutes, including but not limited to Shanghai Jiao Tong University, Shanghai East China University of Science and Technology, Beijing University of Chemical Technology, Tianjing University, Tsinghai University, Zhejiang University, and the Chinese Academy of Science.

With regard to biocatalysis, these interdisciplinary groups have devised and successfully executed elegant research procedures, ranging from the investigation of enzyme catalytic mechanisms, structural profiles, and rational/irrational design to the optimization of enzyme processes. Enzyme applications in the biotransformation process have attracted the attention of high-tech companies because of their high efficiency and environmental friendliness. The fast growth of the industrial enzyme market in China has intensified the need for academic-industrial collaboration. At the CAS-Huzhou Industrial Biotechnology Center, the IDEEP project has been initiated to market tailor-made enzymes that satisfy the specific requirements of the pharmaceutical industry. Today the strongly competitive companies in China's enzyme market include Vland Biotech, VTR Bio-Tech, Youtell Biochemical, and SunHY. Most of these companies have set up strategic partnerships with academic institutions →

Guest commentary

"We are confident that there will be great breakthroughs in biotechnology in China in the near future."

Prof. Yan Feng

➔ in order to push back the frontiers of knowledge and technology.

In the area of microorganism-based biotechnology, the traditional biofermentation industries have achieved great success in China. The current output of Chinese antibiotics, amino acids, and vitamins is one of the world's highest. For bulk chemicals such as citric acid, China is the world's top producer and exporter. Companies are increasingly realizing the importance of modern biotechnology for bolstering the competence of the bioindustry. Thanks to recombined DNA and metabolic engineering techniques, researchers can implement changes on the genetic levels and construct a well-organized metabolic network that increases productivity and lowers costs. Moreover, synthetic biology is based on the idea of *de novo* design and the combination of biological functions into intelligent bioreactors for the synthesis of new functional molecules. That enables the innovative production of high-value chemicals, medicines, and biomaterials. This cutting-edge technology has already been successfully utilized to yield new high-value products in chassis cells, such as drugs or drug precursors (pseudosugars, natamycin), natural products (tanshinone, ginsenosides), and biobased chemicals (succinic acid, adipic acid).

Taken together, the biotechnology research projects working with the scientific community in both academia and industry are necessary and will become a new trend in the next five-year plan, which will efficiently close gaps between laboratories and factories. The solid biomanufacturing foundations in China and successful modern biotechnology applications make us confident that biotechnology will make greater breakthroughs in the near future.

Dr. Li Li (left) and Dr. Markus Pötter in the biolab in Shanghai.

Benefits of yeasts as bioreactors

Compared with bacteria, yeasts offer advantages not only in handling but also in opportunities:

1
Yeasts grow at low pH values. This **reduces the risk of contamination**.

2
The cells are **more resilient**.

3
Unlike bacteria, yeasts **cannot be infected by phages**.

4
Because of their size, yeast cells **can be easily separated by centrifugation**.

➔ ments ahead of publication, if necessary. "This open approach may be the reason that, up to now, we've had no problems with intellectual property," says Pötter, dispelling a concern that often arises when dealing with China.

The team has now filed some of its initial patents and is in the process of preparing others. They come from two successful projects: the oxidation of alkanes to diacids, and the production of oils with specific chain lengths and saturation. The group of researchers is also working closely with colleagues from the Nutrition & Care Segment to optimize a bioprocess for the production of biosurfactants, or "sophorolipids," from yeasts (see also p. 4).

Flexibility with raw materials

In the long term, Pötter promises another benefit from using biotechnological processes with yeasts instead of chemical syntheses: greater flexibility in the selection of raw materials. For example, the same fermentation structure can be used with such differing carbon sources as petrochemical-based compounds, waste gas, and sugar. The only requirement is the presence of the yeast strain that has been optimized specifically for the relevant metabolic pathway.

The culture collections of the Chinese research institutes offer a large selection of microorganisms for this purpose. Then, should the price of a raw material increase, the process can be quickly converted for use with another. Pötter: "With yeasts, we can take production to the customer—and simply use whatever raw materials are available there." ●

Photography: Markus Pötter

WANTED: ENTREPRENEURS!

Evonik has sent employees to a boot camp to sharpen their entrepreneurial thinking and further develop their ideas for new projects. They are participating in a competition that will end with the selection of one entrepreneur within the company.

Who will benefit from the idea, and how? This is the question to be answered in the boot camp.

According to a report, bumblebees have no ability to fly: Their wings are far too small to move their plump bodies through the air. But bumblebees care little about this kind of speculation—they just fly. An entrepreneur behaves the same way. He ignores the fact that his idea may not fly and just keeps working on it. “An entrepreneur sees and exploits opportunities and takes responsibility. He is passionate and creative,” said Sebastian Cadell, an innovation consultant at the Danish company Nosco, at Evonik’s boot camp.

The boot camp is part of the Global Ideation Jam that Evonik started in January for all employees for the purpose of finding unusual ideas with the potential for innovation. A jury of experts selected the six most promising ideas from more than 80 ideas submitted through an online community. The teams behind the ideas, primarily young scientists, now have two months to prepare their ideas for the final round. A jury will then choose the best project proposal and one entrepreneur to develop it.

The first lesson of the boot camp is that creativity and technical knowledge are not enough to make an innovation out of an invention. A product can be excellent, fully developed, and promising—but without a market and customers, it is worthless.

Who benefits from it?

At the beginning of the boot camp, all of the teams defined the value of their ideas. The Value Proposition Canvas, a tool from strategic corporate planning, helped them with this task. The emphasis is on the concrete benefit to the customer: What value and benefit does the product create, what needs are satisfied with the product, and what problem does it solve? At the same time, the teams also had to identify potential customers: Who is the most important addressee for this product, and what services must be offered for marketing it? The teams used these questions to determine the value of their ideas with a predetermined matrix.

A good idea also needs a good team: Team building at the start of the three-day boot camp.

On the basis of these values, and with the help of the brainstorming tool Business Model Canvas, the teams then developed business models for their ideas. The tool helps to focus ideas, identify weak points, and prepare a basic framework for a business plan. In this way, the teams were forced to confront the foundational aspects—the most important resources for development, the cost structure for the entire process, the expected profit, and the sales and communication channels. They also had to identify their key partners inside and outside the company. This was a mammoth task, but one that advanced the ideas and showed where work was still needed. The grand finale in June will show who made the best use of the boot camp and developed their idea into a functioning business idea.

“With the Global Ideation Jam, we want to strengthen the entrepreneurial spirit at Evonik. Each one of you is part of the cultural transformation of a company that is open to innovative thinking and creative ideas,” said Dr. Ulrich Küsthardt, Chief Innovation Officer, at the opening of the boot camp. From online brainstorming and the offline collaboration of the team through boot camp to the final: the process is interactive and open across departmental boundaries. Participants can share their knowledge, provide food for thought, and establish contacts. “They are important multipliers of our innovation culture,” said Küsthardt.

Moving toward a business model: One of the six Idea Teams discusses potential markets and customers.

Photography: Mark Ansorg

RESEARCH THAT MOVES

For Evonik, initiating joint projects with strategic university partners is an important objective. in Essen recently Professors Takuzo Aida and Shigeo Kagami provided impressive proof that the University of Tokyo is a strong partner when they presented their entrepreneurial activities and showed how they taught hydrogels to walk.

ENTREPRENEURIAL SCIENCE

For several years, the University of Tokyo has focused on entrepreneurship to promote the conversion of research results into products. The University has developed a comprehensive set of tools for this purpose.

The numbers are not unusual for a university: 28,000 students, nearly 1,300 professors, 900 associate professors, and 300 lecturers. But the University of Tokyo is one of the most productive and successful research institutes in the world. Now it is working on a top position in the commercial use of innovations. .

"We're systematically promoting entrepreneurship at our university," says Prof. Shigeo Kagami, general manager of the Office of Innovation and Entrepreneurship at the Japanese University. The reason is that today innovation is no longer a clearly structured field with sharp dividing lines. Instead, it requires the kind of thought and action that is found in the triangle of university, university spin-offs, and industry.

Kagami's office sees itself as a mediator between companies and research institutes. "For an outsider, it's often not readily apparent which of the university's faculties are relevant for chemistry, for example," explains Kagami. "For this reason, we also provide content-related assistance to bring researchers with their focus on specific subject matter and language together with interested companies." In fiscal year 2014, the University of Tokyo was involved in approximately 1,600 collaborative research projects, most with private-sector participation. Within ten years, this figure has doubled—along with the project volumes.

In addition to mentoring and coaching for scientists, as well as maintaining a business incubator, through its venture capital arm dedicated to the university (University of Tokyo Edge Capital, UTEC: three funds of US$250 million in total), the university also operates as a risk money provider that invests in university-related start-ups. A good example is PeptiDream, whose technology is used to selectively construct peptide libraries with defined properties, and selected as Prime Minister Prize in February 2016. Another example is the Cyfuse Biomedical company, which develops 3D printing properties for cells and tissues.

In addition to UTEC, the University of Tokyo is also part of a public-private fund program made up of four leading Japanese national universities, whose objective is also the financial backing of innovations. As a result of this, the university founded another investment company as its 100 percent subsidiary (UTokyo Innovation Platform Co., Ltd.: total fund size is US$400 million).

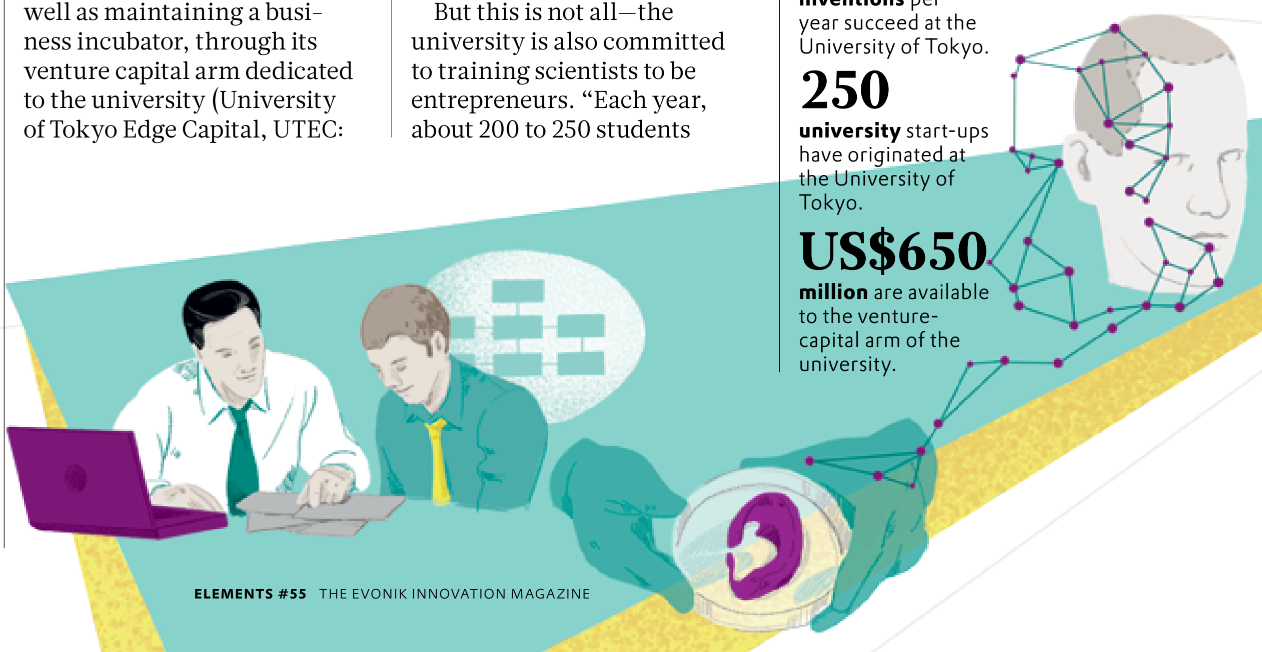
But this is not all—the university is also committed to training scientists to be entrepreneurs. "Each year, about 200 to 250 students pass through our six-month entrepreneurship program," says Kagami. The program also includes a business plan competition. Kagami's office also offers another entrepreneurship education program designed for young researchers, including postdocs and PhD students. In selecting participants, Kagami and his team take recommendations from professors when they see that a graduate has more potential for a career as an entrepreneur than as a researcher. ●

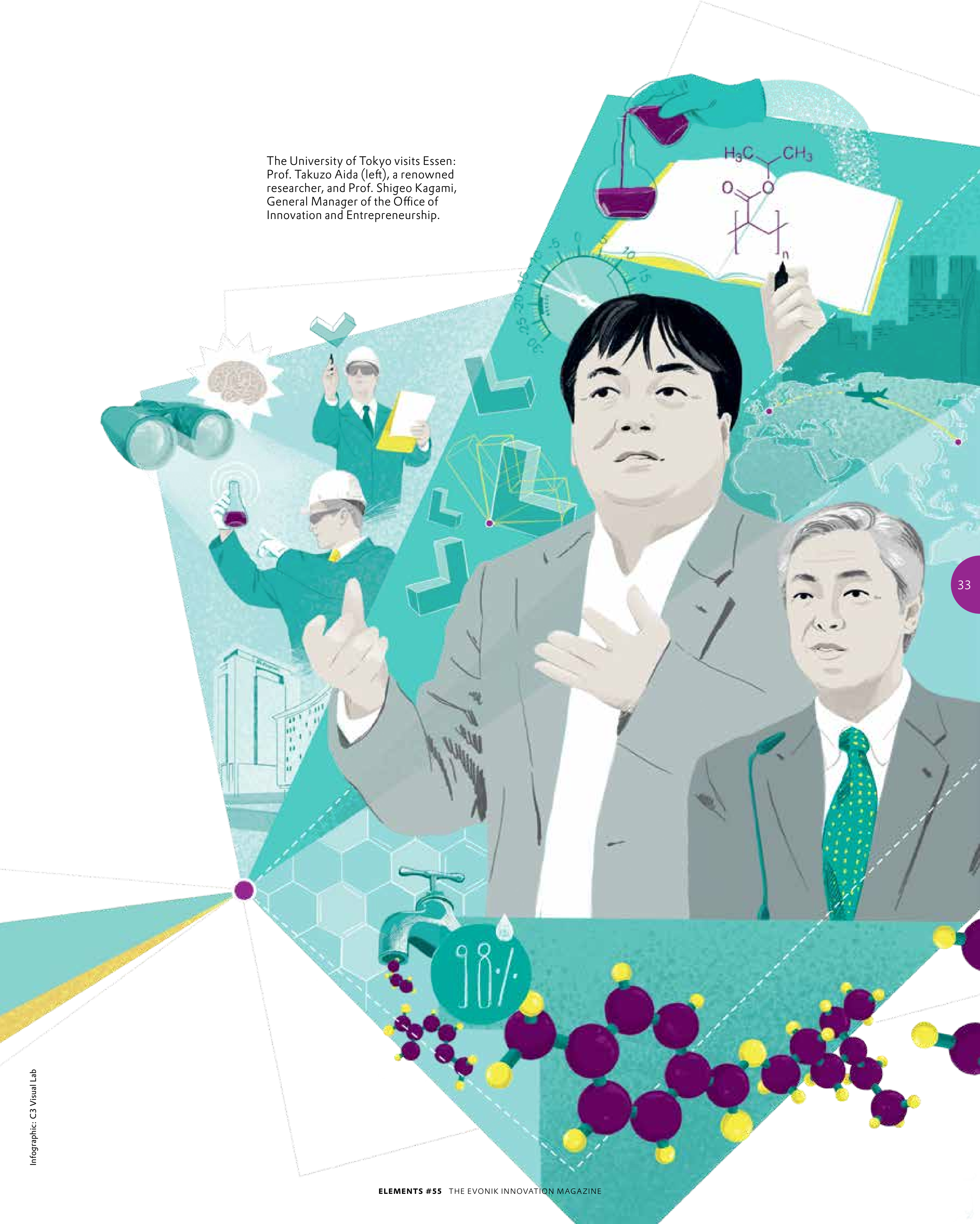
Entrepreneurship at the University of Tokyo

600
inventions per year succeed at the University of Tokyo.

250
university start-ups have originated at the University of Tokyo.

US$650
million are available to the venture-capital arm of the university.



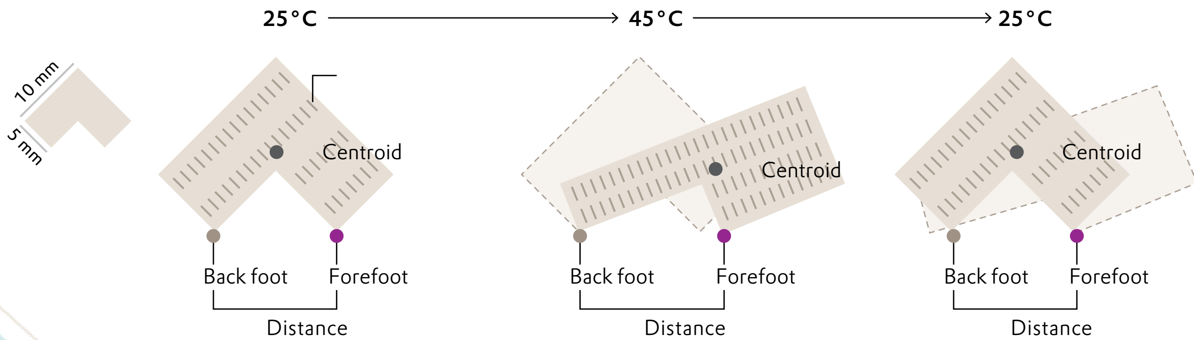


The University of Tokyo visits Essen: Prof. Takuzo Aida (left), a renowned researcher, and Prof. Shigeo Kagami, General Manager of the Office of Innovation and Entrepreneurship.

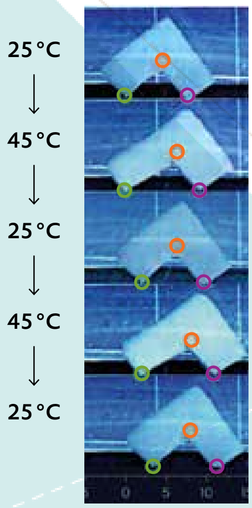
Infographic: C3 Visual Lab

Like an artificial muscle

Temperature-dependent contraction and expansion bring the hydrogel into motion, thanks to the L shape.



Original size of the hydrogel



Position [mm]

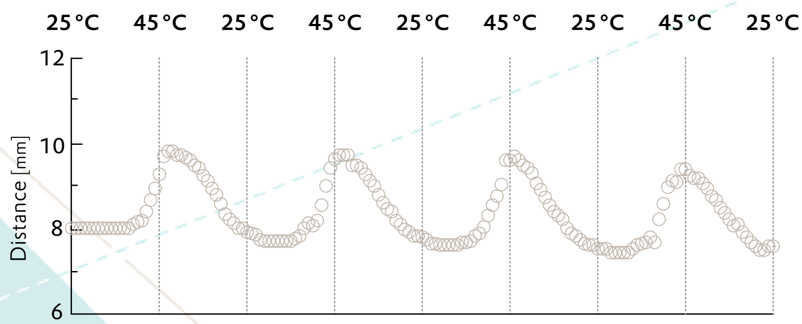
Photographically recorded

That the hydrogel L "walks" when subjected to cyclic temperature changes is due to the embedded nanosheets. Their spacing changes with temperature and spatial direction.

Adapted by permission from Macmillan Publishers Ltd: Takata, M. & Aida, T., Nature Mat. *74*, **1002** (2015), copyright 2015)

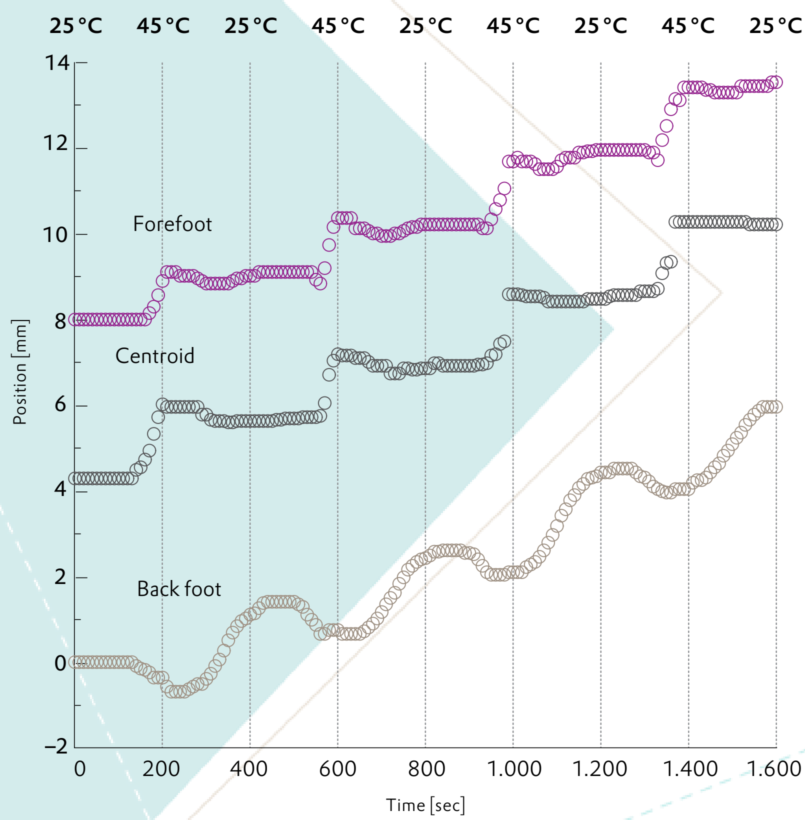
Steady movement

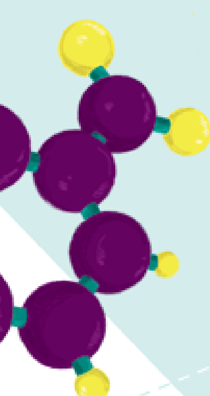
The distance between forefoot and back foot varies by about two millimeters between 25 and 45°C.



Mobile hydrogel

The hydrogel, which contains about 98 percent water, covers a distance of around 6 millimeters in just 27 minutes.





HOW HYDROGELS LEARNED TO WALK

The University of Tokyo also holds a leading position in international university rankings with its research in chemistry and material sciences. Prof. Takuzo Aida and his working group help contribute to this international renown. One of his specialties is soft materials that react to external stimuli. For example, he has taught hydrogels to walk.

Here is what a productive research life probably looks like: more than 280 scientific publications, including nearly 30 in Nature and Science, about 70 patents, and 20 research awards. Takuzo Aida (59), professor in the Faculty for Chemistry and Biotechnology of the University of Tokyo's School of Engineering, focuses his research on three topics: soft materials, macromolecules that are inspired by biology, as well as molecular and biomolecular machines. Aida is a good example of why Evonik agreed to a strategic partnership with the University of Tokyo about two years ago: The internationally acclaimed scientist is setting benchmarks in the research of new materials.

As part of the colloquium of the Society of German Chemists at Evonik in Essen, Aida provided insight into his research on soft materials that react to external stimuli. These can be very different types of stimuli, such as changes in light or temperature. The scientist and his team have worked particularly hard with hydrogels. "Our hydrogels consist of about 98 percent water, with a small mass fraction of mineral material and another order of magnitude lower percentage of organic components," explained Aida. In research, these kinds of hydrogels have become known as an interesting approach to reducing our dependence on petroleum-based polymer materials.

Aida and his colleagues first demonstrated the unusual properties hydrogels could have about six years ago when they developed a hydrogel that can be manufactured fast and easily. "Even a beginner can do it," stressed Aida. To produce this hydrogel, the scientists mixed sodium polyacrylate in water with commercially available mineral nanosheets. These 2D nanostructures initially stuck together. But because their positively charged peripheral areas interact with the anionic sodium polyacrylate, they spread themselves evenly in the aqueous solution. After the addition of a dendrimer-based binder, the nanosheets crosslink with each other and a 3D network is created—a transparent, dimensionally stable hydrogel with high mechanical stability," says Aida.

Over the past year, his working group together with other researchers demonstrated that hydrogels can even be used to create actuators that can be moved by changing the temperature. The hydrogel they used is based on a poly-isopropyl acrylate that is water soluble at room temperature but coagulates above 32 °C and is then insoluble. Dipole-dipole interactions are responsible for this behavior: At low temperatures, hydrogen bonds form. The bonds hold the polymer in solution but become increasingly weaker as the temperature rises.

This polymer-based hydrogel also contains titanate nanosheets, which the researchers align with a magnetic field during the production of the hydrogel and thus create a regular layered structure. The mechanical properties of the hydrogel are based largely on the anisotropy of the electrostatic repulsion between the nanosheets. Orthogonally to the nanosheets, the hydrogel is hard to compress. Parallel to the nanosheets, on the other hand, it is easy to compress.

The trick that makes an actuator out of this hydrogel is the temperature dependence. "The separation between the nanosheets changes so quickly when the temperature changes—the material contracts or expands again," explained the scientist. "With an L-shaped hydrogel in which the nanosheets are correctly positioned this sequence of contractions and expansions can be transformed into a linear movement."

In other words, the hydrogel L "walks" because of the cyclical temperature fluctuation. ●

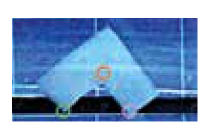
"We can pack the electrostatic repulsion between nanosheets in a hydrogel and put it to practical use."
Prof. Takuzo Aida

Infographic: Adapted by permission from Macmillan Publishers Ltd: Nature Materials 14, 1002–1007 (2015) doi:10.1038/nmat4363
Received 08 January 2015 Accepted 26 June 2015 Published online 10 August 2015, C3 Visual Lab

Strategic university partners

Evonik currently maintains seven strategic partnerships with universities: the University of Duisburg-Essen, the University of Tokyo, the University of Minnesota in the United States, the Shanghai Jiao Tong University in China, the research institute A*Star (Agency for Science, Technology and Research) in Singapore, the Technical University of Munich, and King Abdullah University of Science and Technology in Saudi Arabia.

More information on the hydrogel:
Thermoresponsive Actuation Enabled by Permittivity Switching in an Electrostatically Anisotropic Hydrogel. Nature Mat. **2015**, *14*, 1002–1007.



Video:
Hydrogel artificial muscle walks
https://youtu.be/XzfAvKWRKjY

BREAK OUT OF YOUR COMFORT ZONE!

Prof. Dr. Sabine Kuester teaches and researches at the interface between innovation and marketing. In the new "Horizonte [Horizons]" lecture series of Evonik Nutrition & Care, the Director of Mannheim University's Institute for Market-Oriented Management described how innovation is systematically becoming bolder and more successful.

There are two sides to innovation: a technology side and a market side. Clearly, the most sophisticated and powerful technology is worth little to an inventor when there are no customer needs for it to satisfy. Prof. Kuester's lecture focused on how research can orient itself more systematically to market conditions—that is, customer needs. "Ultimately," as event coordinator Dr. Walter Pfefferle, head of new business development at Nutrition & Care, put it, "for the purpose of directing funds to the right projects."

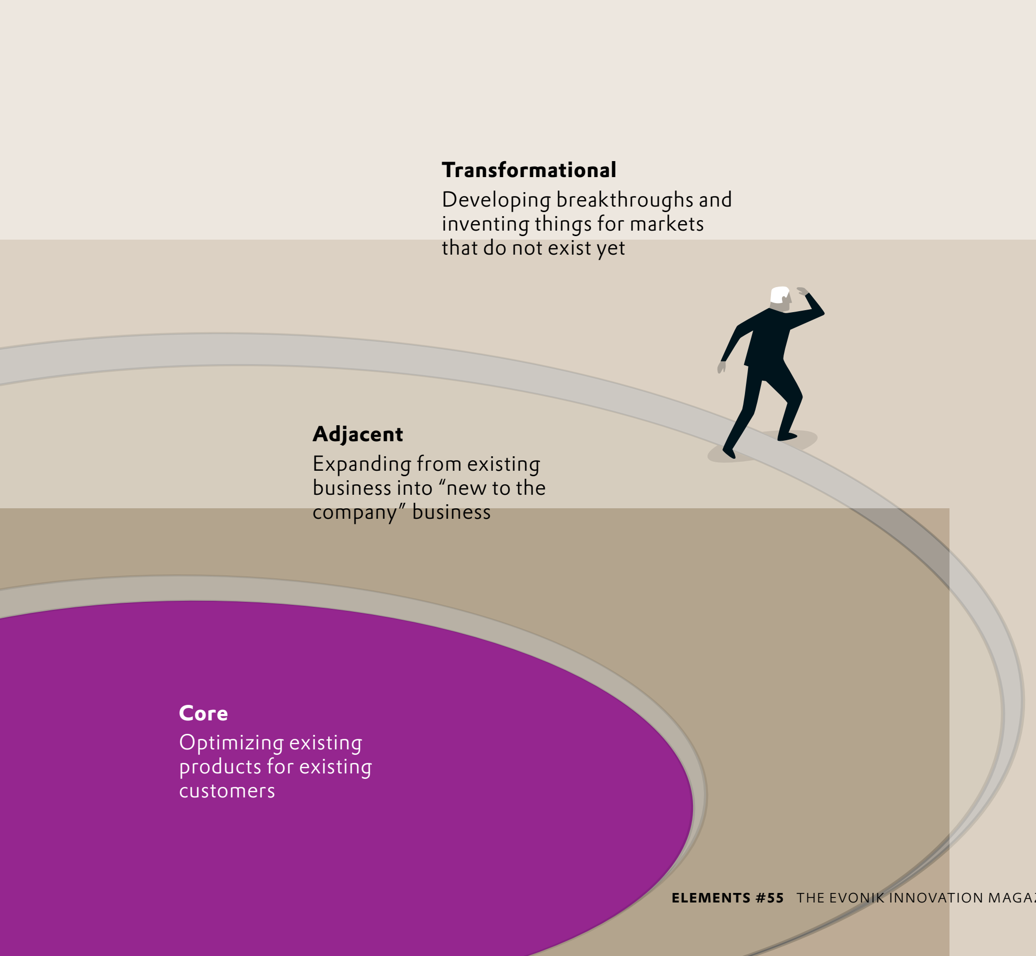
The task, then, is to identify the ideas that have potential markets from the multitude of ideas that are constantly arising. The main difficulty is that customers often have no idea what they are lacking—or at least are unable to describe it. The demand is latent but not obvious. "Who would have expressed the desire for a computer mouse before it was invented," said Kuester.

Moreover, when it comes to pathbreaking innovations, the opportunities lie "outside the comfort zone of companies." They lie, in fact, in the areas the company knows little or nothing about, which means projects are clouded with uncertainty. Without doubt, the main focus of innovation investment should be refining existing products for existing markets—or so-called "core innovations." But there should also be innovation in adjacent markets and customer segments, and ultimately, transformational innovation resulting in completely new inventions ("New to the world"), explained Kuester, with reference to the innovation types defined by Nagji and Tuff (Fig. 1).

"On average, companies invest 70% of their resources in core innovations, 20% in adjacent markets and customer segments, and only 10% in transformational innovations. Interestingly enough, the numbers run exactly opposite when we look at return on investment. Here, the ratio is 10:20:70," says Kuester.

The three types of innovation

Innovations are classified by how close they are to the company's core business. The most profitable are genuine novelties (after Nagji and Tuff, 2012).



Completely new products make more profit

The return on investment primarily comes—albeit somewhat delayed—from completely new products and markets. For Nespresso, for example, it took 20 years from patent registration to break-even. Still, every company can draw motivation from this example to orient itself to the search for the unfamiliar new markets.

Kuester showed how this approach can succeed by citing the example of Procter & Gamble. At the end of the 1990s, the company set itself the goal of becoming a growth factory. So it redirected research expenditures and made targeted improvements to its structures and mindsets. Creativity workshops and specially appointed employees ensured a supportive innovation climate. Restructuring and clear documentation, as well as communication of innovation processes and methods gave the business units the tools they needed to develop completely new products.

The approach was a success: Between 2000 and 2010, the percentage of Procter & Gamble's innovations that reached profit and revenue targets rose from 15 to 50 percent. There were successful new developments for emerging markets (such as a product for water purification), and there were completely new business models (such as the franchise-based dry cleaning concept Tide Dry Cleaner in the United States). In this connection, Kuester noted that for the development of successful innovations, the entire value chain should always be part of the equation. It is not only the direct customers who are important but also the indirect customers.

Slaughtering sacred cows

To break out of their comfort zone and develop completely new ideas, a company's employees need, more than anything else, the right mentality. Often, our mentality and, therefore, our thinking is limited by unconscious assumptions, said Kuester. It is necessary to slaughter a few sacred cows, such as the conviction that "We know what is occurring in the market and what our customers want."

Recognizing assumptions and, above all, questioning those assumptions is a prerequisite for thinking creatively in companies. Often, however, creativity is hampered by structural or cultural circumstances. Kuester then provided some approaches and suggestions for promoting creativity and, therefore, innovation. At the very top of her list is: "Allow employees to experiment; don't punish failure, learn from it."

Established thinking patterns should also be questioned, as should bureaucratic structures. Rewards for good ideas, teamwork, good exchange of information, an open discussion culture, and a democratic strategy process are among the recommended resources. Naturally, innovation projects must also be guided by economic principles, and for the innovative process in companies, employees must be able to "think ambidextrously"—which means the ability to implement both incremental and revolutionary changes.

Kuester presented several methods that can help to more systematically recognize latent customer needs and focus on them strategically. These include the three circle analysis developed by Urbany and Davis, which integrates the analysis of company, customers, and competitors. In this analysis one circle represents how customers perceive the own company's offerings. Another circle depicts the customers' needs. The last circle represents how customers perceive the offerings of the company's key competitor(s). If these circles are shown as a Venn diagram (Fig. 2) the resulting seven areas are all of strategic importance. "Area A are clearly where the company's advantages are, but Area G is the most exciting are because it represents desirable latent customer needs and untapped markets," said Kuester. The method is therefore well suited to developing differentiation strategies but also to identify areas for future growth.

Analysis instead of magic

The value curves by Kim and Mauborgne are another diagnostic tool. Their model maps the key factors on which competition in a particular market is based. A company can use its own value curve to compare itself to competitors. The value curve approach can be used to develop "blue ocean strategies," which help to open up new markets. The results obtained with this method sometimes seem to be produced in a miraculous way, but in reality they come from a disciplined analysis and understanding of the market situation, says Kuester.

Kuester cited Lycra as an example of a systematic implementation of a blue ocean invention. Up until the late 1980s, growth was slow for sales of the elastic synthetic fiber elastane developed by DuPont. After the launch of the Lycra brand and expansion of market activities to the sport and leisure segment, elastane became an extremely profitable business, with a return on investment of over 20 percent and a global market share of 70 percent in 2004.

"You need a product that generates value for the end customer and you have to work the entire value chain," stressed Kuester. DuPont achieved this by addressing the end consumer directly and integrating clothing manufacturers, designers, and retailers into the innovation activities. The disciplined scrutiny and understanding of customer needs were the basis for the success of this strategy.

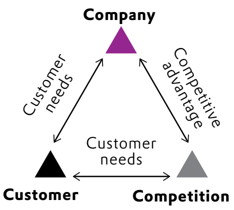
Her overall message: "Complement your technical expertise with skills in recognizing latent customer needs, and create a culture that doesn't stifle innovation but promotes it."

Prof. Dr. Sabine Kuester has held the Chair for Marketing & Innovation at the University of Mannheim since winter semester 2005/2006. There, she is also vice dean of the Department of Business Administration and scientific director of the Institute for Market-Oriented Management.
Her primary areas of research and teaching are marketing strategy, innovation marketing, marketing management, and international marketing.

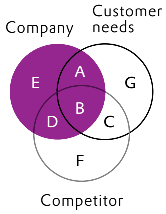
Kuester studied at the University of Cologne and earned her doctorate at the London Business School. Previously, she held professorial positions at the ESSEC (France), New York University (USA), and Vienna University of Economics and Business Administration (Austria).

The 3-C analysis

The goal:
Identification of new market opportunities (source: Urbany and Davis, 2007).



The method:
Consider customer needs, competitors' activities, and a company's own expertise as a single integrated whole.



The result:
Latent customer needs and new markets become visible in area G.

Infographic: C3 Visual Lab | Photography: Evonik

Prof. Martyn Poliakoff (68) is a British chemist and expert in supercritical fluids with a focus on green chemistry. He teaches and researches at the University of Nottingham. Sir Martyn has received several awards and is Foreign Secretary of the Royal Society. In 2015 he was knighted by the Queen for services to chemical sciences. He has become a popular figure outside his field of work through his Periodic Videos, which have been appearing on YouTube since 2008 and have now registered over 130 million views.

Periodic Videos: **www.periodicvideos.com**

WHAT I HOPE FOR FROM SCIENCE

Sir Martyn Poliakoff

SCIENCE HAS TO BE FUN!

I wish that science could be more fun for more people. When science is fun, scientists think laterally and become more creative. Science used to be fun but, sadly, I think that the recent focus on metrics and impact across the world have removed much of the excitement from research. Indeed, some scientists now consider good metrics as being one of the most important outcomes of their research.

Of course scientists should use taxpayers' money responsibly and explain why they are doing their research. But the pendulum has swung too far. Funders want to back winners, but nobody can predict which piece of research will turn out to be truly transformational.

Scientists need space for imagination and exploration, and without that space, we are in danger of stifling creativity. Funders and universities need to realize that the major output of most research is new generations of innovative scientists, trained to provide the scientific infrastructure that underpins modern society. Removing the fun produces people who regard science as just another job. Bringing the fun back will provide the enthusiasm and new thinking needed to address the challenges facing humanity in the 21st century.

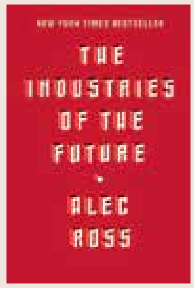
NONFICTION BOOKS

on industries of the future, life's complexity, and success in business

Unpredictable: Life

Is life the result of rigorous thought and strategic planning? Far from it! Why life is far too complex to bring under control is the topic of the latest book by Vince Ebert. He sums it up this way: We can all do the right thing—and still be wrong. And conversely, some people do almost everything wrong by objective criteria and are still highly successful. Coincidence is the gray area of life, according to this cabaret artist with a degree in physics. For instance, tesa tape was originally supposed to have been an adhesive bandage. This and other examples in:

Vince Ebert,
Unberechenbar: Warum das Leben zu komplex ist, um es perfekt zu planen
Rowohlt, Reinbek 2016



In transition: Industries

He advised Hillary Clinton on innovation when she was the United States Secretary of State, and he traveled the world multiple times in this role. Alec Ross is one of the most prolific international innovation experts. Early this year, he published a New York Times bestseller on the industries of the future. He examines the specific fields that will most shape our economic future, for example computer security and the commercialization of genomics, and describes the international consequences of disruption—how emerging countries can develop their own Silicon Valley, for example.

Alec Ross,
The Industries of the Future
Simon & Schuster, New York 2016

Better planned: Careers

For a long time now, it has been the case that just as many women as men graduate with a degree in the natural sciences. For the most part, the challenge on the career highway is encountered later, when it comes to mastering a career entry or balancing career and family. Karin Bodewitz, Andrea Hauk, and Philipp Gramlich accompanied women working in natural science during their career decision-making and wrote a career guide that also contains a lot of valuable advice for men.

Karin Bodewits, Andrea Hauk, Philipp Gramlich,
Karriereführer für Naturwissenschaftlerinnen. Erfolgreich im Berufsleben
Wiley-VCH Verlag, Weinheim 2015

THE COVER #55

About 15 million metric tons of surfactants are used annually all over the world, and growing prosperity is giving more and more people access to modern cleansing and body care products. Evonik has developed new surfactants for this attractive growth market—biosurfactants with outstanding cleansing properties that are especially environmentally friendly and gentle to the skin, as well as betaines that can now be produced more cost-effectively thanks to an optimized process.

Photography: Anne-Katrin Purkiss, PR (3)

Masthead

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