ELEMENTS

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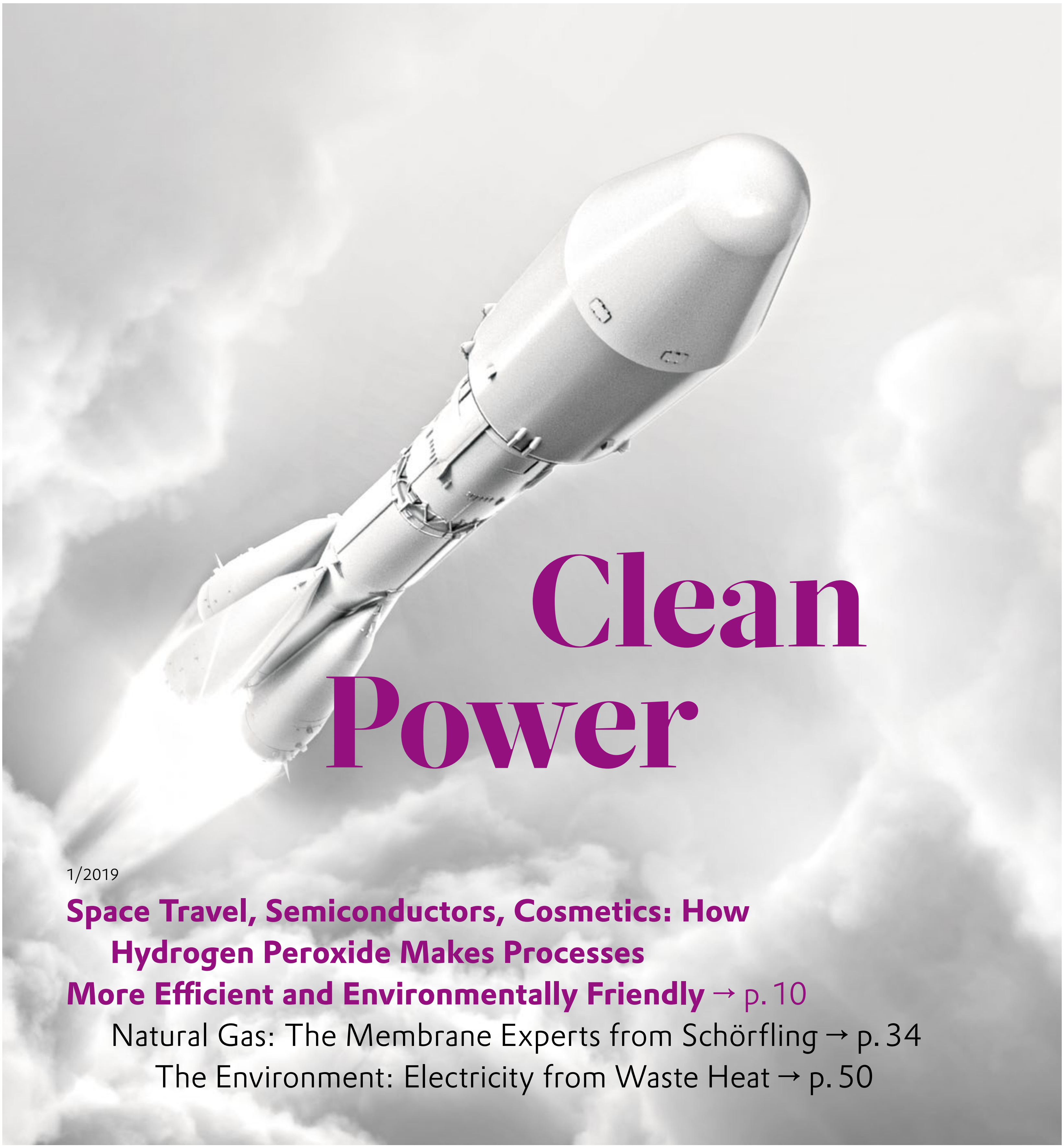

Clean Power

1/2019

Space Travel, Semiconductors, Cosmetics: How Hydrogen Peroxide Makes Processes More Efficient and Environmentally Friendly → p. 10

Natural Gas: The Membrane Experts from Schörfling → p. 34

The Environment: Electricity from Waste Heat → p. 50

Hydrogen peroxide

A versatile compound

Hydrogen peroxide (H_2O_2) is a clear, colorless liquid compound of oxygen and hydrogen. It was discovered in 1818 by Louis Jacques Thénard, as he reacted barium peroxide with nitric acid. Since then, hydrogen peroxide has been used as a powerful oxidizing agent. It's used in the production of bleaching agents, for example, for paper, textiles or hair. It's also used as a household disinfectant and cleaning agent. Hydrogen peroxide decomposes to water and oxygen.

Louis Jacques Thénard: French chemist, 1777–1857
Barium peroxide (BaO_2): A chemical compound of barium and oxygen
Nitric acid (HNO_3): An oxyacid of nitrogen
Oxidizing agent: An element or compound that oxidizes other substances by accepting electrons from them

→ More about hydrogen peroxide starting on page 10

DEAR READERS,

When brunettes suddenly turn blonde, and when teeth, paper, and laundry once again become sparkling white, the credit goes to a multi-talented molecule: hydrogen peroxide, or H_2O_2 for short. This compound, which consists of two hydrogen and two oxygen atoms, is colorless and inconspicuous, but it's absolutely indispensable for many applications. Its use as fuel for space travel is especially spectacular. Today every Soyuz rocket has H_2O_2 on board to power the turbopumps for the blastoff. That's reason enough to take a look in this issue at the future of space travel. And who could be a better guide than Jan Wörner, the Director General of ESA, the European Space Agency?

Schörfling is a pleasant little town located on the banks of Lake Atter in the foothills of the Austrian Alps. It's a hub for high-tech membranes made of synthetic fibers. The use of these fibers, which look like macaroni, is opening up completely new options for processing natural gas. We followed the trail of these membranes, from Lake Atter out into the world.

Plastic waste is polluting our environment almost everywhere on earth. There's plastic in the ocean, in our food, and wherever you look. The EU's proposed ban on plastic drinking straws and cotton swabs on its own obviously won't be enough to solve this problem. That's why innovative companies are increasingly focusing on the option of using plastic as a raw material. For the manufacturers of products based on plastic, this approach seems doubly attractive: They will be helping to promote sustainability while responding to the constantly increasing demand for recycled products. Can a waste-free cycle for plastics be successfully created in this way? The Foresight team at Creavis is devoting itself to answering this question.

On my own behalf, I'd also like to present to you the new digital home of ELEMENTS on the Internet. Just click on elements.evonik.com. Whether you prefer the digital or the paper version, I wish you pleasant and instructive reading, and I look forward to receiving your suggestions and comments at: elements@evonik.com

Matthias Ruch
Editor in Chief of ELEMENTS


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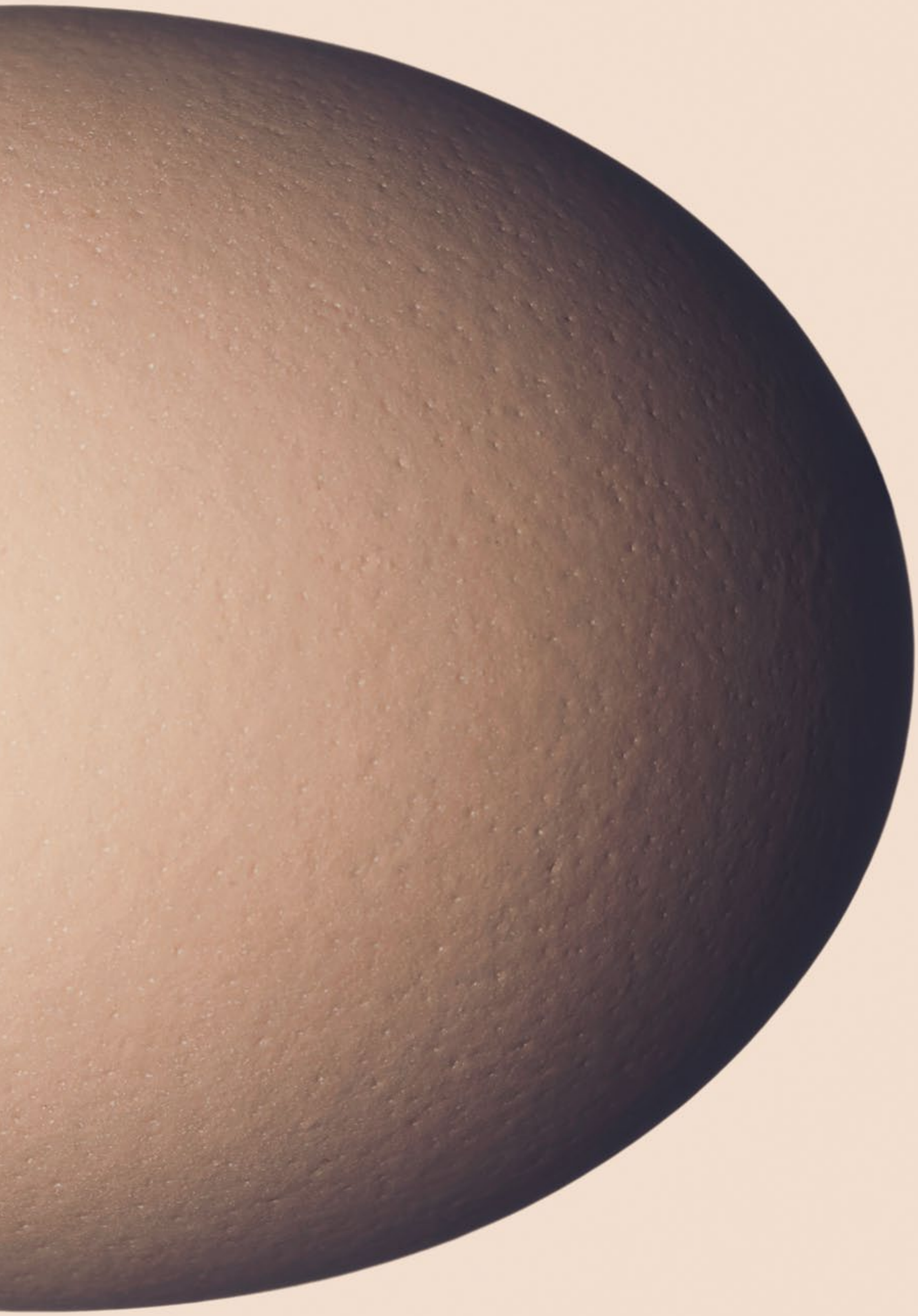
10

ROOSTER OR HEN?

In chicken farming, the gender issue can have existential consequences: Because male chicks won't eventually lay eggs and are not suitable for meat production, millions of them are killed. The Dutch startup In Ovo, in which Evonik holds shares, is combating this practice by offering a method that makes it possible to detect a chicken's gender while it's still inside the egg. In this process, a tiny hole is bored in the eggshell and a sample of the egg's contents is checked for biomarkers with a mass spectrometer. This enables early sorting and avoids subsequent suffering.



Hands-on Art

The mosaic in the new subway station at the former World Trade Center is protected by PROTECTOSIL®

The artwork covers an area of 402 square meters along the subway platforms

The trains of the New York subway system serve 472 stations all over the city—now once again including the Cortlandt Street station in lower Manhattan. This station, which is located under the former World Trade Center complex and was destroyed by the terrorist attack on September 11, 2001, has been reopened. The location's significance is highlighted by the mosaic stretching along both walls of the station. Titled "Chorus," it was created by the multimedia artist Ann Hamilton. In raised script formed by countless chips of white marble, the mosaic displays passages from the Declaration of Independence of 1776 and the United Nations' Universal Declaration of Human Rights of 1948. Hamilton hopes that subway passengers will touch the letters of the texts as they read them. To make sure this work of art, whose value is estimated at more than US$1 million, is not damaged in the process, and to protect it from graffiti and dirt, it was treated with PROTECTOSIL® products from Evonik. "We are very confident that travelers and commuters will be able to enjoy 'Chorus' for many years," says Pete DeNicola, Head of Marketing Americas at Evonik.

18

PERCENT

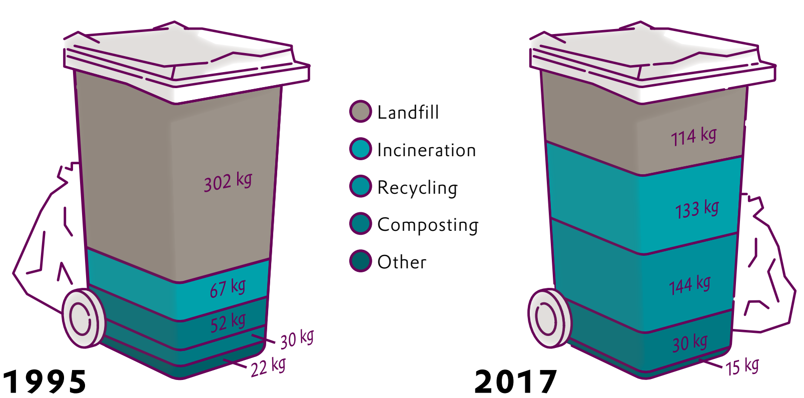
growth was posted by the **3D printing market** in 2018. According to the industry analyst Smartech Publishing, the sales of software, hardware, and materials for additive manufacturing were almost **€8.2 billion** worldwide.

POWER-TO-X BRINGS RELIEF TO GRIDS

The transformation of electrical energy into heat, chemical products or fuels (power-to-X) can be used to relieve the burden on the electrical grid. That conclusion was reached by a consortium of seven research institutes in North Rhine-Westphalia at the end of a three-year research project. The aim was to find out how this technology can be used to ensure a stable power grid and supply security while increasing the use of renewable energy sources. The research results: *strom-zu-gas-und-waerme.de/aktuelles/*

THAT'S BETTER

The Dustbin of History



What happens to household waste in the EU's 28 member countries, per capita

In 2017 each EU citizen generated 467 kilograms of **household waste** on average, 74 kilograms more than in 1995. But behind these figures there's a hidden improvement. Much of the rubbish that is being collected today was previously disposed of illegally—especially in the EU's new members from Eastern Europe. In addition, the volume of rubbish that goes into landfill has been reduced by 62 percent, and **175 percent more rubbish is being recycled or composted.** These figures are still growing.

Source: Eurostat

GOOD QUESTION

“Professor Stadtler, Why Do We Understand Texts on Paper Better Than on a Screen?”

There’s a lot of evidence indicating that when we read printed factual texts we use different reading strategies than those we use for reading displays. We’re accustomed to reading challenging texts on paper intently and thoroughly. This strategy results in an in-depth understanding of the text. By contrast, we’ve learned to take in a flood of short texts from our displays, such as pop-ups and instant messages. We can manage this flood more effectively if we merely skim these texts. If we transfer this rather superficial reading method to difficult texts, things become problematic. In several studies, subjects who read factual texts under time pressure showed less understanding of the texts if they were on a display. We assume that they continued to use their superficial reading strategy, even though concentrated reading was required.

Prof. Marc Stadtler is a professor of education at Ruhr-Universität Bochum

Rewards and Punishments

What AI researchers are focusing on today

Reinforcement learning is playing a growing role in the field of artificial intelligence (AI). This was pointed out by an article in the MIT Technology Review whose authors had analyzed 16,625 scientific papers written over a period of 25 years. The authors analyzed the texts to find out which keywords were used especially often. Around 2000, the frequency of concepts related to machine learning (“data,” “network,” “performance”) started to increase. After the breakthroughs in the field of visual recognition, the increased frequency of related terms showed a shift of interest to neural networks. Recently there’s been a boom in articles on “reinforcement learning,” in which an algorithm learns through rewards and punishments how to behave in certain situations. This trend received a major boost when the AlphaGo program beat the world champion in the strategy game Go in 2015.

PEOPLE & VISIONS

“We Want the First People on Mars to Have a Flourishing Greenhouse Waiting for Them”

Paul Zabel also raises cucumbers near the Antarctic research station Neumayer III

THE MAN

Paul Zabel has been a science fiction fan ever since he was a little boy. His fascination with space led him to study aerospace technology at Technische Universität Dresden and to make aeronautics his career. For the past eight years he has been working at the German Aerospace Center (DLR). In his work, he combines research in the area of space travel with a field of study that is much more down-to-earth: modern agriculture. Zabel specializes in the development of farming methods that produce maximum amounts of food in small spaces with a minimal input of energy.

THE VISION

Paul Zabel and his team grow **vegetables in the Antarctic**—more precisely, in a greenhouse that is surrounded by a hermetically sealed container. Although the outdoor temperatures can drop to -43°C, inside the greenhouse lettuce, tomatoes, and cucumbers are being cultivated under artificial light. The team calculates that if the vegetables can thrive under these conditions, in the future people may be able to grow a supply of fresh food on the moon or Mars. The researchers have already posted initial results: In 2018 they harvested more than 200 kilograms of vegetables.

PEROXIDE POWER

TEXT **BERND KALTWASSER**

Cosmetics, cleaning agents, microelectronics—hydrogen peroxide has been inspiring innovative applications in chemistry for two centuries. As a supplementary propellant for rockets, this compound of hydrogen and oxygen is now playing a major role in ensuring greener propulsion in space

Good to go: A Soyuz rocket in Kourou is being prepared for launch. On board is a supply of H_2O_2.

It's three hours after sunset, and it's now pitch-black in the jungle. The night ends at a barbed-wire fence that stretches across the tropical landscape. Behind it is a space rocket that towers more than 46 meters into the air and is brilliantly illuminated by floodlights. Over a loudspeaker we can hear the voice of the Directeur des Opérations announcing the rocket's imminent takeoff: *"À tous de DDO: Attention pour moins d'une minute."*

We're at the European spaceport in Kourou, French Guiana, and the local time is 9:46 p.m. on November 6, 2018. We're witnessing the countdown for the launch of a Soyuz rocket that will transport the Metop-C weather satellite to its orbit high above the earth. On board is a supply of hydrogen peroxide (H_2O_2) from Evonik. The spectacular launch can be followed on a live video stream offered by the aerospace company Arianespace. It's 20 seconds before takeoff. A flash of light signals the ignition of the powerful engines that will propel the gigantic 300-ton rocket into space. The roaring and hissing of the engines grow louder and louder. The engines' power is increased step by step until finally the booster jets and the main engine are burning more than 450 kilograms of kerosene and 1,100 kilograms of liquid oxygen per second. The control center makes another announcement: *"Attention pour le décompte final."* The final seconds are counted down: *"…trois, deux, unité."* The entire launchpad is enveloped in an orange glow. *"Top, décollage…"* The rocket rises majestically into the sky. It flies ever higher in a sweeping curve. About an hour after the launch, a spokeswoman of the European weather satellite organization Eumetsat announces that the first signals sent out by the Metop-C have been received. The mission is a success.

Evonik has played a major role in this success. "Today every Soyuz rocket has about ten metric tons of ultrapure, highly concentrated H_2O_2 on board. It's used for driving the turbopumps, which force the actual propellants into the combustion chamber at high pressure," says Dr. Stefan Leininger, who is in charge of business operations for special applications of H_2O_2 at Evonik's Resource Efficiency Segment. Ten metric tons are still a manageable amount. Evonik is one of the world's leading producers of hydrogen peroxide. The Group can produce more than 950,000 metric tons of it annually at 13 locations on six continents.

This liquid compound of hydrogen and oxygen has been known for two centuries (see the timeline on page 18), but it's still conquering new markets. Today H_2O_2 and other peroxides are used in a wide variety of areas such as semiconductor production, paper manufacturing, and food technology. "That's largely due to this material's excellent environmental compatibility and its efficiency," says Leininger. →

Paper production in Eilenburg/Saxony: In the bleaching process, hydrogen peroxide replaces chlorine-based agents that harm the environment

"The fact that H_2O_2 keeps conquering new markets is due to its excellent environmental compatibility and its efficiency"

DR. STEFAN LEININGER,
BUSINESS DIRECTOR SPECIALTY CHEMICALS

These properties are also becoming increasingly important in the aerospace industry. The aerospace market is in a state of transition. Private suppliers such as SpaceX, the company founded by the Tesla inventor Elon Musk; its competitor Blue Origin, which was founded by Amazon CEO Jeff Bezos; and other companies such as OneWeb and Rocketlab are moving to the forefront. A total of 114 rockets—more than ever before—were launched in 2018. Meanwhile, the average size of the satellites these rockets are propelling into space is shrinking. Nanosatellites (with a mass of 10 kilograms or less) and microsatellites (up to a mass of 100 kilograms) are being launched more and more often. As many as 2,600 of these small artificial satellites may be launched in the next five years, according to a forecast of the consulting company Spaceworks Inc. There's also a trend toward using smaller rockets.

"At the moment, the entire market is experiencing the next evolutionary step," says Leininger. "During this phase, H_2O_2 is playing an important role as a propellant because of its excellent handling properties." Previously, other compounds such as hydrazine and its derivatives were used for this purpose. However, hydrazine is suspected of being carcinogenic, and its use may be banned in the EU in the future. H_2O_2 would be a clean alternative. When it's used as a rocket propellant and comes into contact with a suitable catalyst, it develops tremendous heat and decomposes to form water vapor and oxygen.

GREEN ROCKETRY

Thus H_2O_2 is driving a global trend. Under the banner of "green rocketry," numerous companies and organizations are now attempting to make space travel more sustainable and more environmentally friendly. In addition to the economic aspects, these are also the goals of the Future Launchers Preparatory Programme (FLPP), in which the European Space Agency (ESA) is researching technologies for the next-but-one generation of rockets. "From our perspective, environmentally friendly propellants are important," says Johann-Dietrich Wörner, the Director General of the European Space Agency (see the interview starting on page 22). Wörner explains that the ESA has been promoting sustainable development on earth for many years and will continue to do so in the future.

One step in this direction was made possible by the Hyprogeo project, which was funded by the European Commission as part of the Horizon 2020 framework program for research (funding code: 634534 HYPROGEO). The goal of Hyprogeo was to construct a hybrid rocket engine that burns polyethylene as the solid propellant, using hydrogen peroxide as an oxidant. “Our task as a project partner was to produce H_2O_2 that was as highly concentrated as possible,” Leininger explains. For this purpose, Evonik developed a dedicated process that produces H_2O_2 in concentrations of up to 98 percent—a peak value for industrial production. “The actual manufacturing process of H_2O_2 produces a 40 or 50 percent solution, but the subsequent distillation and crystallization processes enable us to reach the desired final concentration,” says Leininger.

SPICK AND SPAN

Hydrogen peroxide also develops its innovative power in environmental applications such as soil remediation and wastewater purification. In the USA, sewage treatment plants often chlorinate wastewater before channeling it into rivers or lakes. For the past few years, the US Environmental Protection Agency (EPA) has been promoting the use of alternative methods of water purification. One of them is the treatment of wastewater with H_2O_2 or peracetic acid (PAA). This is an environmentally friendly solution, because the only byproducts of these two peroxides are water and acetic acid, which is readily biodegradable.

The peroxides, which are strong oxidizing agents, combat the pathogenic organisms in the wastewater. Viruses, bacteria, and other microbes are killed via non-specific mechanisms of action. “The peroxides penetrate the cell envelope of microorganisms and change it so that it loses its barrier function,” says Leininger, the expert from Evonik. In addition, the enzymes in the cell’s interior are oxidized and thus irreversibly damaged. Both of these processes cause a breakdown of the cell’s metabolism. PAA has proved to be an especially potent disinfectant. It requires only a hundredth of the corresponding dose of H_2O_2 to achieve a comparable effect. “PAA can penetrate the cell →

Green processes, thanks to H_2O_2

Hydrogen peroxide and electric current have had a close relationship for a long time. The Weißenstein process for producing H_2O_2 on an industrial scale, which was invented more than 100 years ago, is based on electrolysis. Nowadays industrial companies almost exclusively use the anthraquinone process (see the box on page 20), in which hydrogen peroxide is produced with the help of a reaction carrier. The Danish company HPNow, a startup based in Copenhagen, is now developing a process that harks back to the origins of H_2O_2 production. It has developed a technology that uses a fully automatic system to transform water, air, and electricity into hydrogen peroxide. This technology looks so promising that Evonik’s venture capital arm acquired a minority share in the young company as part of its Series A financing round at the end of 2017. “HPNow can help the electrochemical production of H_2O_2 to achieve a breakthrough,” says Bernhard Mohr, the Head of Venture Capital at Evonik.

Far from the factory: Distributed H_2O_2 production in a greenhouse in Denmark

The core of the system is a modular generator that can produce hydrogen peroxide. In a catalytic cell, water and oxygen are converted into H_2O_2 in a single electrochemical step. Thanks to this distributed approach, the peroxide could be used in the future even in places where its use has been limited because of the costs of transportation and storage—for example, in greenhouses for vegetables or flowers. To make sure that the hoses for drip irrigation don’t get clogged, they have to be rinsed regularly. In the past, many growers used fairly aggressive cleaning agents or chlorine-based products instead of environmentally friendly hydrogen peroxide. The use of H_2O_2, whose only byproduct is water, used to be too expensive for growers. “The technology developed by HPNow is making it possible for the first time to produce hydrogen peroxide when it’s needed and to use it directly on site,” says Mohr.
The new system has already passed the first set of practical tests with great success.

HYDROGEN PEROXIDE: 201 YEARS OF INNOVATIONS

1818

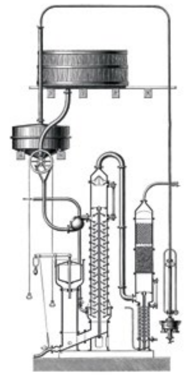
Hydrogen peroxide is produced for the first time by the French chemist **Louis Jacques Thénard** by means of a reaction between barium peroxide and nitric acid

1857

The English hygiene expert Benjamin Ward Richardson discovers that hydrogen peroxide can be used in the **treatment of wounds.** Today it is still used for disinfecting medical equipment

1873

The first plant for the **industrial production** of 3 percent hydrogen peroxide from barium peroxide is built by the Schering company in Berlin. This solution gradually becomes popular in German households as a hair bleach and an antibacterial cleaning agent



1894

Pure hydrogen peroxide is produced for the first time by the German chemist Richard Wolffenstein through a **vacuum distillation** method

1906

Otto Margulies, the founder of Österreichische Chemische Werke (ÖCW), acquires a patent for an electrochemical method for manufacturing hydrogen peroxide. The factory that will use this method is built in the town of **Weißenstein** in the Austrian state of Carinthia

1907

Degussa delivers its first order of sodium perborate to the Henkel company for producing the laundry detergent **Persil.** This active ingredient is now made from hydrogen peroxide

1910

Degussa acquire shares in the ÖCW company. The Weißenstein factory goes into operation in January. The production of **highly concentrated hydrogen peroxide** (30 percent) is now possible for the first time

membrane especially easily because of the lipophilic properties of the acetyl part of the molecule," Leininger explains. In addition, PAA—unlike H_2O_2—cannot be decomposed by a special enzyme called microbial catalase. As a result, no resistance mechanisms against PAA have been discovered to date.

More and more municipalities in the USA are starting to appreciate these benefits. For example, a few years ago the city government of Memphis, which has a population of 650,000, decided to begin using PAA for its wastewater treatment. It concluded a "take or pay" contract with the US company Peroxychem to secure a long-term supply of PAA. As a result, two years ago Peroxychem began to plan the construction of a new PAA factory in the region. At the beginning of November 2018, Evonik announced its intention to acquire Peroxychem.

Peroxides such as H_2O_2 and PAA do more than just reducing the germ load. They also eliminate the persistent organic trace substances that can cause problems when sewage treatment plants channel purified water into surface water. In addition, hydrogen peroxide is used to decontaminate wastewater containing cyanide, which comes from electroplating works, hardening plants, blast furnace gas, and mines. H_2O_2 oxidizes cyanide to form cyanate, which is then hydrolyzed to form ammonia and carbonic acid. Hydrogen peroxide is also used in electroplating works to oxidize nitrogen oxides, which have been generated from nitric acid in the etching process, back into nitric acid.

However, some contaminants cannot be eliminated by H_2O_2 alone. For example, if benzenes and phenolic compounds have to be eliminated from wastewater, chemists use a certain trick. Hydrogen peroxide molecules can be split by either bivalent iron ions (Fe^{2+}), UV radiation or ozone to form hydroxyl radicals (•OH). This radical is one of the strongest oxidizing agents in existence, and it reacts with almost all organic compounds.

AN ENVIRONMENTALLY FRIENDLY ALTERNATIVE

Demand for H_2O_2 is booming, especially in Asia. Semiconductor manufacturers there use ultrapure hydrogen peroxide, either alone or in combination with sulfuric

1935

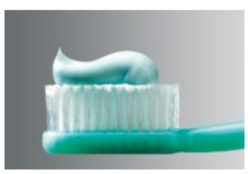
Hellmuth Walter is the first German inventor to use hydrogen peroxide as an **engine fuel.** Hydrogen peroxide is subsequently also used as a propellant in rocket technology

1953

The first industrial-scale production plant to use the **anthraquinone autoxidation process** is opened by the DuPont company in Memphis, Tennessee

1989

The first patent application is submitted for a **teeth-whitening gel** based on hydrogen peroxide



1995

Degussa is the first company to transport hydrogen peroxide **by ship,** from Alabama to Lemont, a suburb of Chicago

2018

Evonik Industries signs a contract with One Equity Partners for the takeover of **Peroxy-Chem,** a US manufacturer of hydrogen peroxide and peracetic acid

acid, to remove photoresists from silicon wafers and coat them with an oxidation layer that is only a few nanometers thick. The combination of hydrogen peroxide and sulfuric acid is also used as an etching agent in the production of circuit boards. According to Dr. Jürgen Glenneberg, Head of Process Engineering at the Active Oxygens Business Line, “Hydrogen peroxide/sulfuric acid etching agents are used often on account of their low cost, high degree of effectiveness, and relatively low disposal problems.” H_2O_2 is also being increasingly used in the production of liquid crystal displays (LCDs). Here, hydrogen peroxide solutions are used to etch out the copper circuits that supply the LCDs with electricity.

H_2O_2 is also used in a series of industrial-scale syntheses—for example, in the production of epoxidized soybean oil, which is an important plasticizer for PVC plastisols and is also being increasingly used in other plastics. In this process, a mixture of hydrogen peroxide and formic acid oxidizes the carbon-carbon double bonds in the fatty acid chains while forming the corresponding epoxides. In recent years a process based on hydrogen peroxide has become widely used for the synthesis of caprolactam, which is used to manufacture nylon fibers and other products. In this process, ammonia is oxidized selectively with H_2O_2 to form hydroxylamine, which reacts in situ with cyclohexanone to form caprolactam. In contrast to traditional procedures, this process makes it possible to avoid the formation of thousands of metric tons of sulfate-containing waste products. →

Germ-free: Peroxides combat microorganisms in wastewater

How H_2O_2 is produced: The anthraquinone process

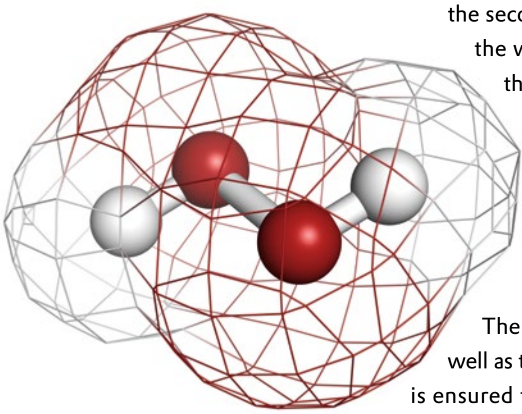
The industrial production of hydrogen peroxide began in the town of Weißenstein in the Austrian state of Carinthia. This is where the Österreichische Chemische Werke company operated the world's first hydrogen peroxide factory using electrolysis. Today this production plant is part of Evonik. The Weißenstein process made it possible to produce hydrogen peroxide on an industrial scale for the first time. Today this plant uses the autoxidation process, as do almost all the other hydrogen peroxide factories in the world. This process was developed by Georg Pfleiderer and Hans-Joachim Riedl at IG Farben in Ludwigshafen between 1935 and 1945, and since then it has been continuously refined. The process is based on the cyclical reduction and oxidation of an alkylated anthraquinone.

The first step, hydrogenation, takes place in a reactor full of a solution of the anthraquinone (the "working solution"). "In the reactor, in the presence of a palladium catalyst hydrogen combines with the reaction carrier, a quinone derivative, to form a hydroquinone," explains Dr. Jürgen Glenneberg, Head of Process Engineering at the Active Oxygens Business Line. The catalyst is then completely filtered out of the working solution. In the second step, the oxidation stage, huge compressors pump air into a bubble reactor that is full of the working solution. When the hydroquinone in the organic phase comes into contact with the oxygen in the air, it oxidizes spontaneously back into quinone, forming hydrogen peroxide in the process. Because this reaction takes place without the presence of a catalyst, it is called an autoxidation process.

In the third step, extraction, the working solution is poured into a separation column. The H_2O_2 in the working solution is extracted by adding water to the solution in a counter-current process. The result is a 35 to 50 percent aqueous solution that can be processed further by means of vacuum distillation or additional purification steps, for example.

The working solution in itself poses a special technical challenge to the process. The quinone as well as the hydroquinone must remain dissolved in the solution without flocculation. Their solubility is ensured through the choice of a suitable alkyl substituent and the composition of the solvent mix. "Typical alkylated anthraquinone derivatives such as 2-ethyl-, 2-tert-butyl-, and 2-amylanthraquinone are used for this purpose," says Glenneberg. In order to keep the quinone in solution, nonpolar substances such as C9/C10-alkylbenzenes are often used as part of the working solution. Polar substances such as tris(2-ethylhexyl) phosphate, diisobutyl carbinol or methyl cyclohexyl acetate take over this function for the hydroquinone.

To make sure the process unfolds successfully, it's important to regularly purify the working solution in the facility. Theoretically, the working solution can be used indefinitely. However, if only 0.1% of the quinone were to be irreversibly damaged in each cycle, the entire process would break down within two months. The oldest working solution at Evonik is being used at the plant in Antwerp. It was originally mixed in 1969.



Oxygen (red) and hydrogen (white) form an energy-rich compound: a molecule of hydrogen peroxide

In addition to hydrogen peroxide itself, a number of derivatives are also used. When H_2O_2 reacts with sodium carbonate (soda), the solid adduct sodium percarbonate is formed. On account of its outstanding properties, this adduct is used as a bleaching agent in heavy-duty laundry detergents and as a bleaching and disinfectant in dishwashing detergents. Another "solid hydrogen peroxide" is percarbamide, a compound of H_2O_2 and urea, which is used for bleaching hair and teeth. An especially important H_2O_2 derivative is peracetic acid, which is actually an equilibrium mixture of acetic acid, hydrogen peroxide, and peracetic acid. Because of their strong germicidal effect, various formulations are primarily used for disinfection processes in the food industry and for animal hygiene, laundry disinfection, and environmental applications.

Today the broadest single application of hydrogen peroxide is in the synthesis of propylene oxide, an important starting material for the production of plastics based on polyurethanes. These plastics are used in the upholstery of car seats and furniture and as insulation material for cooling appliances, for example. In the HPPO process, H_2O_2 is used as an oxidizing agent to epoxidize propylene into propylene oxide, with water as the only joint product.

Thanks to the catalyst titanium silicate (TS-1), which was developed especially for the HPPO process, this reaction can take place in relatively mild environmental conditions. "This process is very cost-effective,

Healthy and durable: In the food industry, PET bottles are sterilized with hydrogen peroxide before being filled

because it utilizes the raw materials with extreme efficiency, the catalyst is especially powerful, and the investment costs are relatively low," explains Dr. Florian Lode, who is a Vice President Strategic Projects at the Active Oxygens Business Line.

A PARTNERSHIP FOR PLASTICS

The process was developed by Evonik and ThyssenKrupp Industrial Solutions, and the two companies are now also issuing joint licenses for it. ThyssenKrupp Industrial Solutions is primarily responsible for building the production plants, and Evonik is supplying the licensees with hydrogen peroxide and the catalyst, TS-1. "The HPPO process is enabling our customers to minimize their environmental impact and also to manufacture their products sustainably and cost-effectively," says Lode. "It's a perfect example of resource efficiency in the chemical industry."

One of the places where this can be seen in practice is Tiszaújváros, a town of 17,000 inhabitants in northern Hungary. Here the Hungarian MOL Group is currently building a gigantic HPPO plant that is expected to go into operation in the first half of 2021. The plant is part of an investment program worth a total of almost US$2 billion, through which MOL aims to become the leading chemical company in Central Eastern Europe as well as the only integrated polyol producer in the region. The HPPO process has been used successfully in Asia for several years. The first two commercial facilities were established in Ulsan (South Korea) and Jilin (China).

"Hydrogen peroxide makes multifaceted chemistry possible—and decomposes into water and oxygen when done"

DR. FLORIAN LODE, VICE PRESIDENT STRATEGIC PROJECTS, PERFORMANCE OXIDANTS

The aerospace industry, microtechnology, environmental applications, chemical syntheses—H_2O_2 is a powerhouse that has become an essential part of our world today. But according to the Evonik expert Lode, the power of hydrogen peroxide has still not been fully exploited. "Hydrogen peroxide makes multifaceted chemistry possible—through processes whose only by-product is water. In this era of heightened awareness of the environment, that makes it very exciting to search for new applications of this product."

The All-rounder

Hydrogen peroxide (H_2O_2) is an essential component of numerous applications. Evonik, one of the leading suppliers of this bleaching and oxidizing agent, produces 950,000 tons of it annually. From thirteen locations on six continents, the Active Oxygens Business Line supplies H_2O_2 in various concentrations and grades of purity to its customers all over the world

INFOGRAPHIC **MAXIMILIAN NERTINGER**

KEY

2,000
2
70 60 50 35 30

Purification stage 1
Purification stage 2
Purification stage 3

35 Available concentrations, in percent

2,000 Market volume in metric tons per year, in terms of 100% H_2O_2

2 Market growth in percent (average annual growth rate, 2017–2023)

1. PRODUCTION

HYDROGENATION

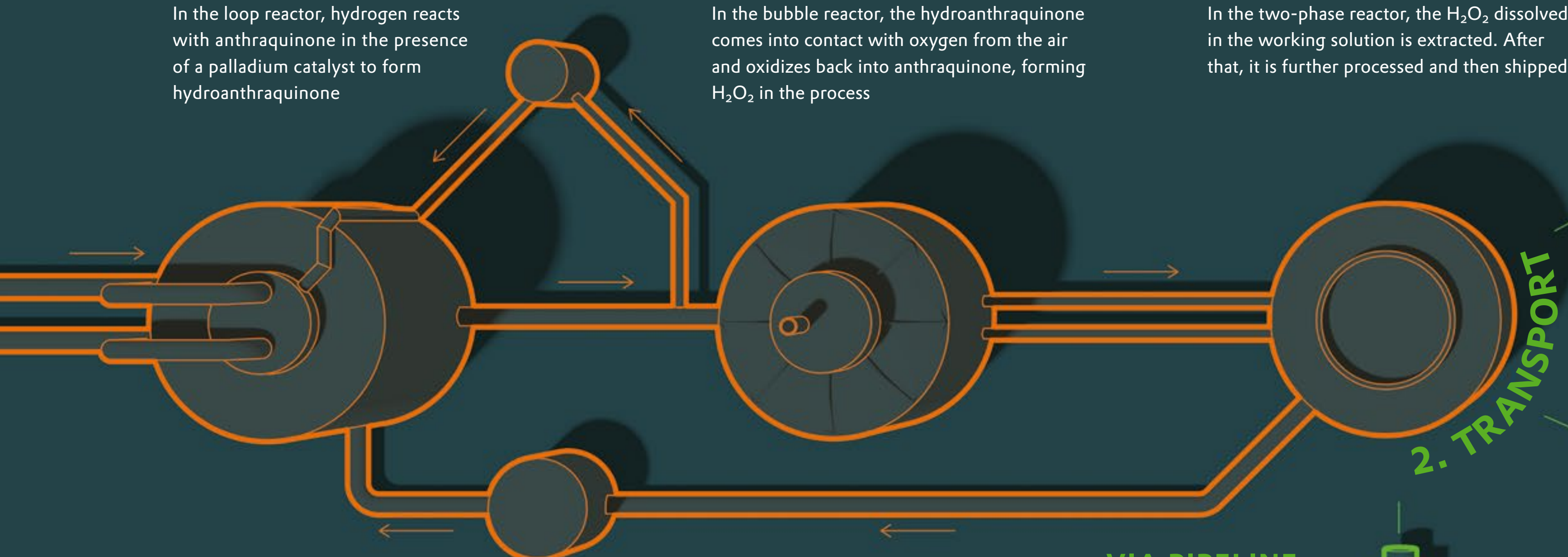
In the loop reactor, hydrogen reacts with anthraquinone in the presence of a palladium catalyst to form hydroanthraquinone

OXIDATION

In the bubble reactor, the hydroanthraquinone comes into contact with oxygen from the air and oxidizes back into anthraquinone, forming H_2O_2 in the process

EXTRACTION

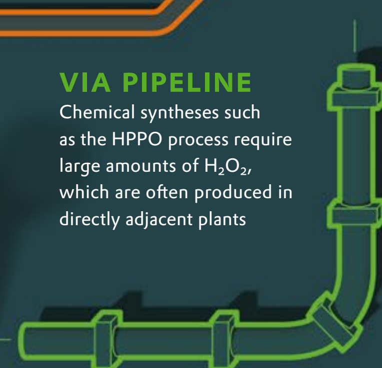
In the two-phase reactor, the H_2O_2 dissolved in the working solution is extracted. After that, it is further processed and then shipped



2. TRANSPORT

VIA PIPELINE

Chemical syntheses such as the HPPO process require large amounts of H_2O_2, which are often produced in directly adjacent plants

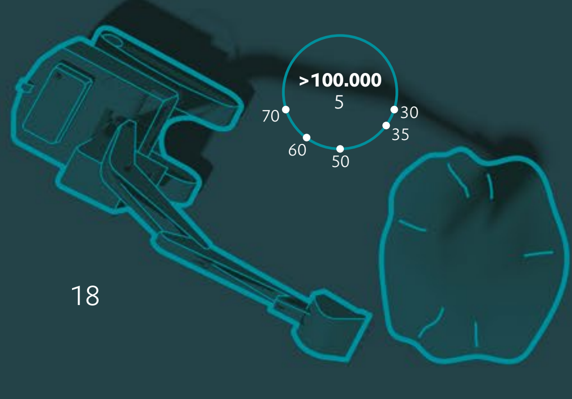


3. USE

MINING

Hydrogen peroxide is often used as an oxidizing agent in metallurgical process steps such as ore leaching or elutant treatment

>100.000
5
70 60 50 35 30



CHEMICAL SYNTHESIS

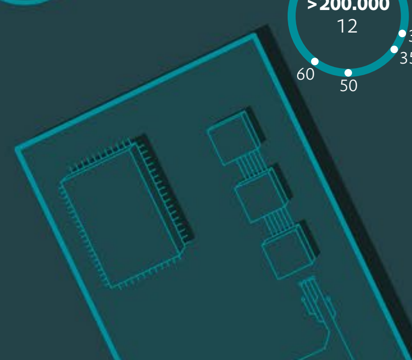
The products derived from H_2O_2 include acetic acid, persalts, and propylene oxide (e.g. for plastics production)

>1.500.000
13
70 60 50 35 30

MICROELECTRONICS

>200.000
12
60 50 35 30

Ultrapure H_2O_2 can be used to treat wafer surfaces, remove photoresists, and etch microstructures



AQUACULTURE

>40.000
5
50

H_2O_2 is used as a disinfectant. The oxygen generated by the decomposition of H_2O_2 also provides fish with optimal conditions for growth

AEROSPACE

98
87,5
82,5
>100
5

Evonik produces H_2O_2 in concentrations of up to 98 percent for use as a rocket propellant

Safety is the top priority: Evonik monitors the transportation of very highly concentrated H_2O_2 **by satellite**

OTHER APPLICATIONS

Hydrogen peroxide has proved its worth in many other markets, such as oil and gas extraction, the disinfection of animal stalls, and keeping pipes for drip irrigation clear

BY SHIP

The Rheinfelden plant produces very highly concentrated H_2O_2 for space travel. The H_2O_2 is transported in special GPS-monitored containers, e.g. by ship to the European spaceport in Kourou, French Guiana

BY TRAIN

In North America, Evonik uses tank cars to deliver highly concentrated H_2O_2 to distribution stations, where it is diluted. Trucks then transport the product to the end customers

BY TRUCK

One advantage of transportation by truck is its great flexibility. This enables customers all over the world to receive H_2O_2 at the right time in the exact concentration and degree of purity they require

FOOD AND BEVERAGES

>50.000
5
35

>50.000
5
70
60
50
35
30

The H_2O_2 solution Oxteril® is used to sterilize PET bottles, plastic containers, and cardboard packaging

BY PLANE

H_2O_2 in concentrations of less than 40% can also be transported as air freight. This is practical in situations when relatively small amounts of H_2O_2 are needed very quickly

INTERIORS AND LIFESTYLE

>500.000
2
70
60
50
35
30

Hydrogen peroxide is one of the most important components of hair dyes. Skin-bleaching cosmetic products are popular in Asia

PAPER, TEXTILES, AND CELLULOSE

>1.500.000
2
70
60
50
35
30

H_2O_2 was initially used for bleaching textiles. Later on it was also used for bleaching paper. It is still used today for bleaching pure white packaging

PHARMACEUTICALS AND HEALTHCARE

>2.000
2
70
60
50
35
30

H_2O_2 in low concentrations is ideal for disinfecting surfaces and treating wounds, as well as cleaning contact lenses

THE ENVIRONMENT

>150.000
5
70
60
50
35
30

H_2O_2 and peracetic acid are especially environmentally friendly oxidizing agents that are used for the treatment of drinking water, for example

"FORWARD TO THE MOON"

The European Space Agency ESA, just like the Americans and the Chinese, has set its sights on the moon. ESA Director General Jan Wörner talks about the race for space, environmentally friendly fuels—and the inspirational power of space travel

TEXT **CHRISTIAN BAULIG AND BERND KALTWASSER**
PHOTOGRAPHY **RAMON HAINDL**

Millions of people are familiar with the main control room of the European Space Operations Center in Darmstadt because they've seen it on television. This is where technicians of the European Space Agency ESA monitor the trajectories and systems of rockets and modules during missions such as the launch of the Mercury probe BepiColombo last October. On this winter day, the control room is reserved for the Elements interview with the Director General of the ESA, Johann-Dietrich "Jan" Wörner. Wörner strides into the room briskly and throws his blue service parka across a table. Its right sleeve bears the logo of the Horizons mission, which ended last December when the German astronaut Alexander Gerst returned to Earth from the ISS. "I have to do a little PR work here," he says with a laugh. Then he sits down in one of the chairs that are usually occupied by his technicians.

Professor Wörner, the Chinese have just successfully sent a probe to the moon, and the Americans are also preparing for a new moon mission. How come the moon is celebrating a comeback these days, almost 50 years after the Apollo 11 landing?

JAN WÖRNER The trend is actually not "Back to the moon"—it's "Forward to the moon." This time it's not a competition between two superpowers. Instead, all of us will be working together. The landing on the far side of the moon is a huge success for Chinese space technology. I would be delighted if the international cooperation in space becomes even closer in the future. For this reason, I believe that the moon has great geopolitical value.

You yourself have proposed the establishment of a "Moon Village." What's behind this idyllic space scenario?

The concept didn't come from me, but I've adopted it because I like the analogy. If you set up a village here on earth, it's not because of a government decree but because lots of people with very different interests have come together. In the same way, the Moon Village is aimed at bringing together various interests, such as robotics or astronautical projects, on a shared platform. The stakeholders are national aerospace agencies, research institutes, and industrial companies.

Why is there currently so much interest in the moon?

For rational reasons. If someone believes that astronauts can fly to Mars in just a few years, I can explain to that person very quickly why this wouldn't work. Mars has an atmosphere and a gravitational force that is about →

Jan Wörner has been the Director General of the European Space Agency ESA since July 2015. He has a degree in civil engineering and worked for a long time in the area of earthquake safety. He has taught at the Technische Universität Darmstadt and served as the Chairman of the Executive Board of the German Aerospace Center (DLR) from 2007 to 2015. Wörner's current contract at the ESA will continue until June 2019

Big plans: The Europeans are also planning a mission to the moon

40 percent as strong as the Earth's. A spacecraft that is landing on Mars and being launched from it must overcome factors that don't exist on the moon. In other words, it needs a rocket and propellant. In addition, if human beings are traveling such a long distance in space, you have to do something to maintain their health. I can't imagine people traveling for two years without having any access to medical care. And there's the constant high level of radiation.

What insights do you hope to gain from a new mission to the moon?
We have relatively little knowledge about the moon. All of the moon landings in the 1960s and 1970s took place near the moon's equator, where the surface is dry and dusty. But if you go to the poles, you'll find water. We could build observatories on the far side of the moon and look out at space from there.

Do you expect deposits of raw materials to be discovered on the moon?
There are companies that hope to transport raw materials from the moon to the earth. I'm skeptical in this regard, because I think our rockets are simply too expensive for that. But I can imagine companies transporting tourists to the moon. Fortunately, human beings have an inborn desire to travel to places they haven't been to yet. Incidentally, that's also a reason why I'm placing my bets on space travel by astronauts. People obviously believe that personal experience is very important.

A cooperative enterprise on the moon—that sounds intriguing. But shouldn't we be worried that other participants could siphon off the knowledge that Europeans have gained?
Imagine that you're an alien and that you're able to see, hear, and understand everything that happens on Earth. Would you be confident that you could immediately tell the good people from the bad ones? I doubt that. Besides, in our global system isolation has never worked, and it's never helped anyone. Openness is the only thing that has gotten anything done. The ESA cooperates with many countries all over the world—but of course we're being cautious.

In the USA, more and more private companies offering space travel, such as Blue Origin, SpaceX, and Virgin Galactic, are entering the market. Is Europe missing out on this trend?
It's simply not the case that we're lagging far behind. Just look at OHB, the developer of the Galileo satellites. It used to be a very small company: Otto Hydraulik Bremen. At some point it got involved in space travel—and now it's even planning to develop its own small rocket. Arianespace, which launches our booster rockets into space, is also a private company.

"It's good to know that our system gives us the opportunity to put ideas into practice"

Jan Wörner talks to *Elements* editors Bernd Kaltwaßer (right) and Christian Baulig

And it's now under tremendous pressure from its new competitors in the USA.
I won't deny that it's under pressure. So far, Ariane 5 has operated very successfully—not because it was especially inexpensive but because of its reliability and because we've got a favorably situated takeoff site in French Guiana. Ariane 6, which will be launched for the first time in July 2020, will cost only half of what we spent on Ariane 5. Elon Musk obviously has a good business model at SpaceX. But he's operating with special boundary conditions regarding the salaries and social insurance of his employees, as well as the contracts with NASA and other partners. We can't keep pace in this competition as things stand...

...and one of the main reasons for that is the structure of the ESA, with its 22 members. How do you plan to convince them that they should invest more money in space travel?
A comprehensive assessment of our activities has shown that every euro that is invested in space travel results in six euros' worth of benefits. But there's another effect that I think is at least equally important: We're suffering from the "European sickness"—pessimism about the future. It's not good for a continent's outlook to constantly be telling the next generation that problems are all we have.

That's why we're asking about the opportunities.
Outer space is fascinating. If we land on a comet, people say, "Wow!" And when Alexander Gerst spends half a year on the International Space Station, they're thrilled too. This is an important positive brain process. Some people note how others are transforming a dream into reality. And a few of them say, "I can do that too." It's good to recognize that our system gives us the opportunity to put ideas into practice. I hope to convey this message to society through the medium of space travel.

Most taxpayers probably pay rather more attention to concrete results. What would you say to them?
Space travel is infrastructure. The precise measurement of time is done via satellites. Modern weather forecasts, navigation, telecommunication—all of these things would be unthinkable without space travel. All of our energy networks are coordinated from space. In addition, through space travel we can develop new materials such as titanium aluminide, an alloy that can be used for turbine blades. In alloying processes you have to check the materials' viscosity. On earth, if you keep the materials at the same temperature for a while, the alloy either falls apart or it solidifies. We're even thinking about producing pharmaceuticals under zero gravity conditions in space. →


FREEZE
operations centre

“Fortunately, human beings have an inborn desire to travel to places they haven’t been to yet”

In the past, industrial companies have not been very interested in space-based research. The only experiment on the ISS that was completely financed by an industrial company was the testing of a cream from Evonik. How do you explain that?
Well, it needs some time to develop. After Michael Faraday discovered electromagnetic induction in 1831, it still took many decades for industry to transform this discovery into products. We have to have patience. We’ve recently started offering companies an inexpensive opportunity to conduct tests on the International Space Station—our “Ice Cubes.” You simply have to send us a device measuring 10 by 10 by 10 centimeters or a multiple of that. We’ll shoot it up into the ISS, where the experiments are conducted. It costs €50,000.

In 2018, 111 rockets were launched worldwide—more than ever before. Don’t you have to give more thought to the environmental aspect of space travel?
The ESA accounted for only a small number of this total, but environmentally friendly fuels are an important topic for us. In our boosters we use solid-fuel rockets, which are actually not very environmentally friendly. That also goes for kerosene and hydrazine, which is used as a propellant in rockets, satellites, and space probes. By contrast, oxygen and hydrogen, the propellants for the central stage of the Ariane, are very clean, just like electric drive systems.

Recently you’ve even been using atmospheric air. How does that work?
The “air breathing” process uses molecules of atmospheric air. As a result, we need a significantly smaller oxygen tank on board. Methane could also be used as a fuel in the future. Hydrogen has to be cooled to -250°C to make it liquid so that it can be pumped into the thrusters. For methane we need only -170°C. Besides, methane is denser and thus can be managed more easily inside the tank. We’re also considering electric drive systems that accelerate ionized molecules in electric fields.

For months, people breathlessly listened to Alexander Gerst’s reports from the ISS about his experiments and his impressions of the Earth. Are you sad because your most important ambassador in space has now come back to Earth?
On the contrary, now he’s available all the time. Thomas Reiter returned from space for the last time in 2006, but today he’s still traveling on our behalf every other day. Even astronauts such as Ernst Messerschmid, Reinhold Ewald, and Ulf Merbold—when they make a public appearance we’re guaranteed to have standing room only. And Matthias Maurer, who hasn’t made his first space flight yet, is surrounded by crowds at events. I think that’s fantastic.

Professor Wörner, you’re 64 years old. What other milestones would you like space travel to reach during your lifetime?
(considers the question) I’d rather not say. The ESA is based on four pillars. If I were to single out just one project, I’d have a problem with the representatives of the other three pillars. All I can tell you is that for me, the progress of the Moon Village project is very dear to my heart.

The European Space Agency ESA

From its headquarters in Paris, it coordinates the space-related activities of its 22 member states. The agency, which was founded in 1975, has an annual budget of about €5.6 billion. Its most important functions include the ongoing development of satellite-supported navigation and telecommunication, conducting observations of the Earth, and researching the solar system. The ESA is a project partner of the International Space Station ISS.

EVONIK NEWS

The Lingalaks aquafarm in Hardanger, Norway

Sustainably Raised Salmon Is Ready for Market

Norwegian aquaculture is replacing fish oil with natural algae oil

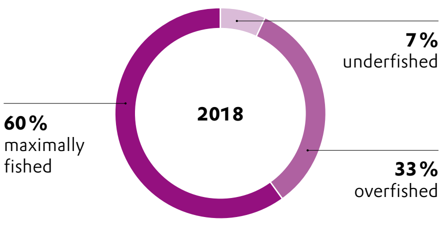
The Kaufland retail chain has teamed up with the Norwegian salmon farming company Lingalaks to offer salmon that has been raised with omega-3 algae oil instead of fish oil. As early as this year, salmon produced with this healthy and resource-conserving method will be on sale in about 660 Kaufland branches in Germany.

The impetus for this innovation in aquaculture came from Veramaris, a joint venture of Evonik and DSM that was founded in 2017. Veramaris produces an algae oil that is rich in the omega-3 fatty acids EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid), which are important for salmon farming. This oil is produced with the help of natural ocean algae by means of a fermentation process on land. It's free of harmful chemicals and is stabilized exclusively with natural antioxidants. Salmon production at Lingalaks does not require the use of wild fish, which plays a key role in conventional aquaculture by providing the fish meal and fish oil that is fed to the farmed fish.

Over the past few years, Veramaris has organized a dialogue between all the partners along the fish farming value chain, ranging from aquaculture operators to exporters and NGOs.

Consumer demand for healthy and sustainable salmon has increased strongly in recent years. Accordingly, Kaufland sees tremendous potential in its partnership with Lingalaks and Veramaris.

COMMERCIALLY EXPLOITED FISH STOCKS WORLDWIDE



Worldwide, 33 percent of the commercially exploited fish stocks are regarded as overfished and 60 percent as maximally fished. Source: WWF/July 2018

Venture capital more than doubles

Evonik is establishing a second venture capital fund. The new investment of €150 million more than doubles the Group's overall investment to a total of €250 million. The new venture capital fund is meant to safeguard the Group's access to future-oriented technologies and innovative business models. This step is also supporting the digital transformation of Evonik, as well as enabling the early identification of potential acquisition targets. Dr. Bernhard Mohr is the Managing Director of Evonik Venture Capital GmbH. "The increase of our funding volume to €250 million emphasizes our ambitious goal of establishing Evonik Venture Capital as one of the world's leading investors in the area of specialty chemicals," he says. As a provider of venture capital, Evonik supports young companies not only with funding but also with the experience and contacts it brings with it as a leading global specialty chemicals company. The Group has made 25 equity investments since 2012. These investments have been aligned with the four business areas that Evonik has defined as its growth engines: Health & Care, Animal Nutrition, Smart Materials, and Specialty Additives.

25

EQUITY INVESTMENTS

have been made by Evonik Venture Capital GmbH to date. The Group has been active in this area since 2012.

A catalyst produced by Evonik is playing a major role in a manned space mission

A catalyst from Evonik is part of the ISS' life support system

The International Space Station ISS has received a new element for its life support system. This component, which is called the "Advanced Closed Loop System" (ACLS), was installed and tested at the end of 2018 by Commander Alexander Gerst. A catalyst from Evonik plays a significant role in the system. The ACLS was developed by Airbus for the European Space Agency ESA as a means of maintaining an efficient life support system on board the ISS. The system is able to remove the carbon dioxide that the astronauts breathe out, generate oxygen for them to breathe, and produce water. It also generates about 40 percent of the freshwater that is needed, thus significantly reducing the amount of water that must be transported from the Earth to the ISS. The transportation of water to the ISS is extremely expensive and complicated. It can cost as much as €60,000 per liter. The system will go into normal operation in the space station in the course of 2019.

New managers appointed to the segment management boards

Evonik has appointed new managers to the management boards of the segments. Johann-Caspar Gammelin, who was previously the Chairman of the Board of Management of Evonik Performance Materials GmbH, will be the Chairman of the Board of Management of Evonik Nutrition & Care GmbH as of April 1, 2019. He will take over this position from Dr. Reiner Beste, who has been appointed as the Regional President charged with merging the two Evonik regions Asia North and Asia South. Dr. Beste's appointment will also take effect on April 1, 2019. Mr. Gammelin's successor as the Chairman of the Board of Management of Evonik Performance Materials GmbH will be Dr. Joachim Dahm. In the future, the expanded Evonik Executive Board will include Mr. Gammelin and Dr. Dahm, as well as Dr. Claus Rettig, the Chairman of the Board of Management of Evonik Resource Efficiency GmbH, and Gregor Hetzke, the Chairman of the Board of Management of Evonik Technology & Infrastructure GmbH. Dr. Rainer Fretzen will join the Board of Management of Evonik Technology & Infrastructure GmbH on April 1, 2019 and will succeed Gregor Hetzke as its Chairman on September 1, 2019. On that date Dr. Fretzen will also become a member of the expanded Executive Board of Evonik.

In-house Innovation Awards presented

In December, Evonik once again honored committed employees and their successful research with the Group's in-house Innovation Awards. The most recent group of winners includes RHEANCE® One, a breakthrough product for the gentle yet effective cleansing of hair and skin. The natural glycolipids in RHEANCE® One are produced by means of a biotechnological process solely on the basis of plant-based sugars and are completely biodegradable. Another award was presented to a new process called SPHERILEX®, which makes it possible to produce spherical silica particles with a controlled distribution of particle sizes and porosity in a continuous process. The first award ever presented in the category "Business Model Innovations" went to an integrated management system for the supply chain of Active Oxygens in North America. The system automatically gathers data from a variety of sources and shows their evaluation on a dashboard.

Once a year, Evonik honors committed employees and their successful research with its in-house Innovation Awards

Thomas Wessel is the Chief Human Resources Officer and Labor Relations Director at Evonik

It's High Time for a Change

Research-based companies receive tax incentives all over the world—but not in Germany. We can no longer afford this competitive disadvantage

by Thomas Wessel

There are only a few industrialized countries in the world that do not grant tax incentives for corporate research and development activities. Unfortunately, Germany—which is often praised as the land of tinkerers, inventors, and engineers—is one of them. Apart from the promotion of individual projects, Germany provides no tax-related support for research and development, or R&D for short—and definitely not for R&D conducted by major companies. That diminishes the innovative power of German companies and holds them back in global competition.

OTHER COUNTRIES ARE SETTING THE PACE

If we take a look beyond our borders, we can see that the countries that invest most heavily in their innovative power are among the most economically successful. Most of the OECD countries and half of the EU member states use funding such as "input promotion" to support their research sectors. For example, France introduced research promotion policies over three decades ago. So did the Netherlands more than 20 years ago. Ireland as well as Norway, which cooperates closely with the EU, have been promoting research through tax incentives in their respective economic systems for almost 15 years.

These investments are paying off. Six years ago Austria restructured its tax-incentive system, which it had introduced in 1988. Since then, its gross domestic expenditure for R&D has grown significantly compared to its national income. This instrument has also had positive effects on Austria's national budget.

> “A pragmatic, manageable variant for initiating tax incentives for R&D would be a policy limiting the tax credit to R&D staff salaries”

The payroll taxes of the scientists additionally hired by companies can in themselves cover almost half of the costs of Austria’s research funding. Offsetting against the payroll tax has a direct effect on the cash flow.

SIZE IS UNIMPORTANT

In Germany, it’s not only the domestic companies that are disadvantaged by the lack of such instruments. The German branches of foreign companies are also negatively affected, because they are at a disadvantage when they compete with branches in other countries for corporate research projects. In the long run, this is a burden on Germany’s economy as a whole.

Let’s not close our eyes to the fact that the relative weights within the global economy are rapidly shifting, especially to the advantage of Asian countries, which are attracting research and development activities—and more—by offering sizable tax advantages. In Germany, the focus of the political debate concerning tax incentives for R&D is not so much on the competition for real investments but rather on accusations that multinationally operating companies are avoiding taxes.

Of course it’s legitimate to ask whether German industry even needs tax incentives, in view of its economic success. After all, it also reliably produces and delivers innovations on the basis of its own economic strength. However, general tax benefits are playing a growing role in the global competition between countries to attract companies. We can see that if we simply look at the drastic reduction of corporate taxes in the USA.

Germany cannot completely withdraw from this global competition, especially in the future-oriented area of R&D. That’s because research and development, as well as intangible assets such as patents and trademark rights, play an outstanding role in the world’s increasingly knowledge-based national economies. It’s high time for a change! Germany should no longer be handicapping itself with its taxation policy when innovative companies are looking for new locations to set up shop and invest their capital.

That’s why I challenge the German federal government to use tax reform to lay the foundation for an even playing field where we can operate at eye level with our neighboring countries and trade partners. Germany’s passive and cautious behavior must end. Above all, we need tax incentives for research, right now, and they must be available to all companies and all technologies.

The goal must be a general tax credit for R&D expenditures for all research-based companies, and this tax credit must include expenditures for commissioned research. It must also be independent of the size of the company, because small and medium-sized companies are just as relevant to innovation as major industrial groups. In many cases, the latter are the system leaders in innovation partnerships and the principal clients commissioning research from small and medium-sized companies.

A pragmatic, manageable variant for initiating tax incentives for R&D in Germany, which would result in little loss of tax income, would be a policy limiting the tax credit to R&D staff salaries. That should not, however, be the ultimate goal—at most it would be a milestone on the road to Germany’s status as a country that is “open to all companies and all technologies.”

In general, it’s important for the support mechanism to be simple and transparent so that the costs of administering it are kept low, not only for the state but also for the companies involved. In addition, like all support schemes, it should be plannable and reliable, and must offer companies legal security and investment protection. All of this is common practice outside Germany and within the boundaries of Europe. The German variant of R&D promotion must also provide all of these benefits.

At long last, Germany’s standstill on this issue seemed to be ending. The introduction of a tax incentive for R&D for small and medium-sized companies was finally included in the coalition agreement. The Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs had already submitted a list of shared key points last fall. However, the constructive participation of the Federal Ministry of Finance is of crucial importance. This means that joint draft legislation could be presented by the German federal government by Easter. It would be very welcome if legislative action were to quickly follow these excellent ideas regarding innovation policy.

NEW INSIGHTS

This legislation would result in far more winners than “only” Germany’s status as a business location. An increase in the research conducted in Germany would intensify the transfer of knowledge between science and business. Simultaneously, tax incentives would offer opportunities to gain new insights into the national economy. For example, they would make it easier to calculate an index of innovators—in other words, the number of innovative companies by comparison with the total number of companies.

Such an index could even be differentiated according to sectors. It could, for instance, create transparency if there is a concentration of ever fewer economic actors operating in increasingly concentrated markets with higher barriers to market entry—that could enable companies to counteract this trend.

It would also provide a clearer view of relocations of innovation centers that are having a negative impact on the local labor market and causing an emigration of know-how. This effect is especially relevant for Germany. That’s because Germany, a country of tinkerers and inventors that is poor in raw materials, has been living for decades on the fact that it’s a leader rather than a laggard when it comes to research and development.

Separate Ways

TEXT **GEORG DAHM**

In order to meet the increasing demand for natural gas, more and more gas fields with a high CO_2 content are being tapped. This is an ideal area of application for the new high-tech membranes from Austria

Natural gas extraction in Canada: Many gas fields have high concentrations of CO_2, which must be separated from methane

Although natural gas is a clean energy carrier, it streams out of the earth in a mixture that is fairly dirty. The hot, crude natural gas that is extracted at the southern tip of the Americas contains methane, which is used as a fuel for stoves, heating systems, power plants, and engines. It also contains lots of CO_2, which has a negative property: It reacts with water to form an aggressive substance, carbonic acid. Stoves, heating systems, power plants, and engines would probably break down fairly fast if they were operated with crude natural gas. That also applies to the pipes through which it flows from the producer to the user.

Acid gas is well known in the energy sector. That's why every extraction system includes separation systems that process the crude natural gas and separate out carbon dioxide and other undesirable substances such as water and heavy hydrocarbons. However, for some time now the volume of acidic natural gas has been increasing. "The demand for natural gas is so high that more and more deposits with very high proportions of CO_2 are being opened up," says Patrick Schiffmann, a process engineer at the plant construction company Linde Engineering. "We're seeing increasing proportions of CO_2 because the carbon dioxide that has been separated from extracted natural gas has been forced back into the soil for a number of years now." As a result, natural gas extraction and purification are becoming increasingly complex.

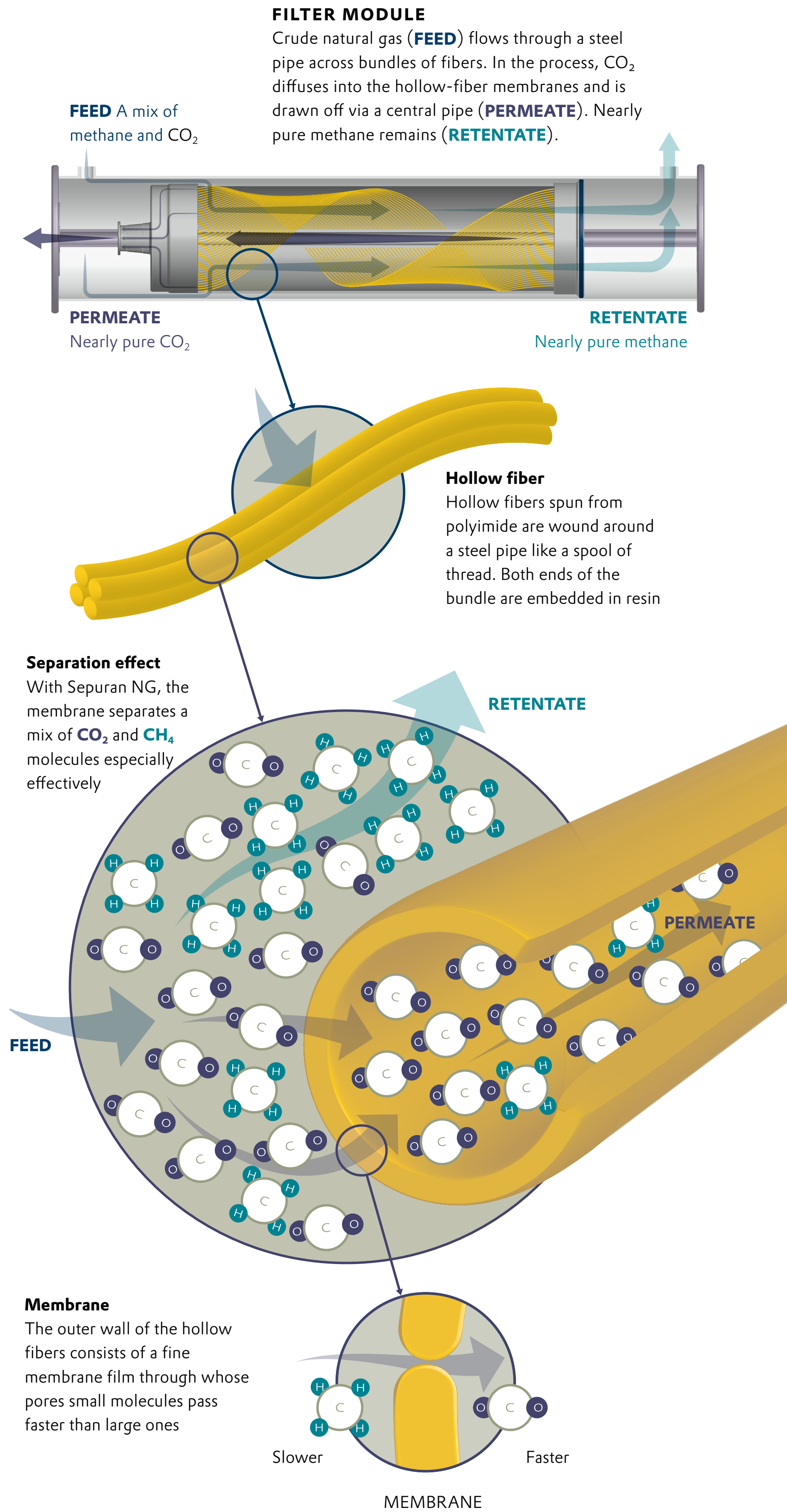
For over a year, the plant construction company has been operating a new separation technology in a natural gas field in southern Argentina. This technology, which is known as "gas sweetening" in the international natural gas sector, has the potential to basically transform natural gas processing. The technology is based on a product from Evonik that has already proved its worth in other natural gas markets: Sepuran, a plastic membrane that functions differently from all the other competing products. As a result, Sepuran can play a key role in efforts to meet the growing demand for natural gas.

POLYIMIDE INSTEAD OF CELLULOSE ACETATE

In the region where Linde is using the membranes from Evonik to optimize its customer's processes, the natural gas has a CO_2 content of up to 50 percent. However, the threshold value for the CO_2 in the natural gas to be fed into pipelines is only two percent. According to Schiffmann, until now the operator only managed to produce natural gas with ten percent CO_2. The →

REMOVING THE CO_2

The latest generation of the Sepuran modules has been designed to purify natural gas by removing aggressive carbon dioxide



sensitive core element of the extraction plant is the conventional membranes made of cellulose acetate, a type of wood-based plastic fiber. “It’s actually a wonderful material,” says Götz Baumgarten, who is responsible for the Membrane market segment at Evonik. “However, it has two problems. Firstly, the membranes don’t last very long, and every time they are changed the production must come to a halt. Secondly, this type of membrane is not particularly selective.”

Selectivity is an important factor in the cost-effectiveness of a membrane’s operation. Ideally, it lets only one kind of molecule through and keeps other molecules out. In the case of crude natural gas, pure methane would accumulate on one side of the membrane and (undesirable) CO_2 on the other. Unfortunately, things are not so simple under real conditions. The membrane doesn’t “recognize” which molecules are about to pass through it, and as a result some of the valuable methane always diffuses through the membrane and escapes.

The separation effect occurs because different kinds of molecule pass through the membrane at different speeds. The greater the difference between the speeds of two types of molecule, the more thoroughly the gas can be separated out. “When our customer used traditional products, ten percent of the methane was lost,” says Schiffmann, the expert from Linde. “Through the Evonik technology, we’re reducing the loss to two percent. At an output of 25 metric tons of natural gas per hour, that’s a lot of money that is no longer being wasted, and a lot of greenhouse gas that is no longer escaping into the atmosphere. This makes it possible to utilize our limited natural gas deposits much more responsibly.”

Unlike conventional membranes, Sepuran consists of polyimide, a high-performance plastic that Evonik has developed in-house and is now producing and processing into fibers. The last two steps of the processing take place in the town of Schörfling in Austria (see the report starting on page 34). Baumgarten believes that the intense vertical integration of the manufacturing process is a huge advantage compared to the competition. “We control the entire process ourselves, from the design of the molecules and polymers to the way we wind the fibers and insert them into a membrane module,” he says.

The complex structure of the membrane can be seen by means of an electron microscope (see the graphic on page 31). Each fiber is hollow, like a straw, and inside it is material that is as porous as a sponge. “This structure makes the fiber robust,” Baumgarten explains. “By contrast, its surface is formed by a smooth film that creates the separation effect.” Inside the membrane cartridges, the fibers are wound around a steel pipe. The result looks like a gigantic spool of thread. As the crude natural gas flows alongside the fibers, CO_2 molecules diffuse through the surface of the membrane into the interior of the hollow fibers. As the natural gas makes its way through the cartridge, its CO_2 content continues to decrease.

TOUGH STUFF

Sepuran has been on the market for the past eight years. During this time it has established itself—for example, in biogas plants, where it helps to purify methane. It’s also used to extract nitrogen from ambient air and to concentrate valuable gases such as helium and hydrogen. All of these applications have one thing in common: In all of them, the feed gas is channeled into the interior of the hollow fibers. The gas that diffuses through the membrane, which is known as the permeate, is separated from the other gases, which are known as the retentate. In other words, the separation process goes from the inside to the outside of the fibers.

For the new application, Evonik has reversed the direction of the separation and changed the design. “When the membrane is used to purify natural gas, it’s subjected to greater stress, because the pressure and the temperatures are higher,” Baumgarten explains. “That’s why we came up with a structure that involves wound fibers. That gives us the durability we need.”

The membrane is in fact so tough that Linde could not detect any loss of performance even after several months of continuous operation. “For cellulose acetate membranes, there’s already a noticeable drop in performance after one month, and after three months you need to replace some of the cartridges,” says Schiffmann. “With Sepuran, we had the same separation performance after six months as we had in the beginning.” For plant operators, this means they less frequently need to partially or fully stop the facility in order to change the membranes. A further benefit is that if liquid hydrocarbons temporarily form inside the plant, the Sepuran membranes regenerate themselves. “If that happens to a cellulose acetate membrane, the membrane is destroyed,” says Schiffmann.

ONE LESS SEPARATION STEP

In a test, the separation effect was so good that it affected the entire design of the natural gas processing plant. “You often need two separation stages,” says Schiffmann. “After the first stage, the permeate still contains so much methane that we have to compress it with a compressor and send it through a second membrane stage. That way we can separate out most of the methane.” This calls for an immense amount of energy and capital, he adds. “But with the hollow-fiber membranes, the retentate is already so pure after the first stage that we can sometimes switch these machines off or operate them at half power. All of this saves money and increases availability.”

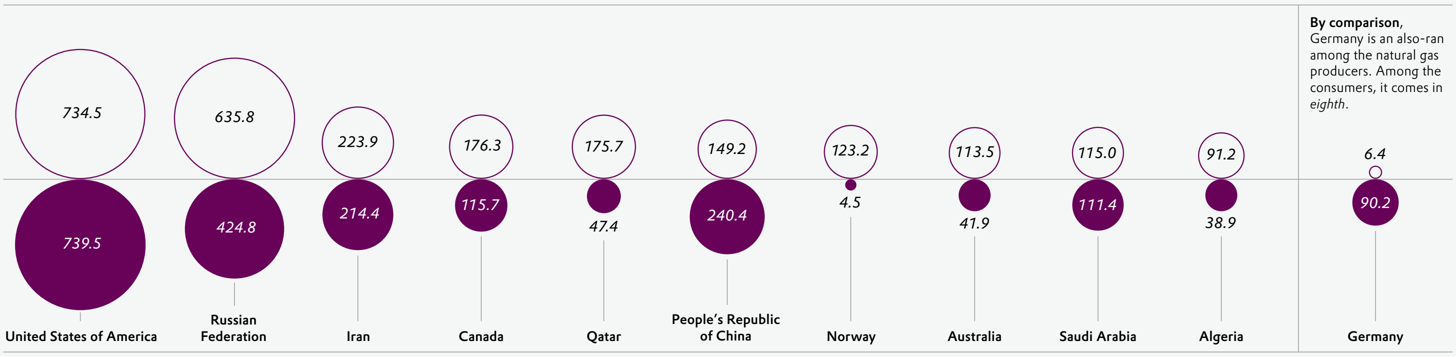
Schiffmann’s team uses the operating data from the plant and from their own lab to plan new plants and retrofit existing ones. But that’s not all: “We also transmit our data, information, and knowledge back to Evonik so that the construction can be refined.” It’s a win-win situation for both partners.

According to Götz Baumgarten, even if one starts with pessimistic assumptions, the new technology has tremendous market potential. The higher the CO_2 content of a natural gas deposit, the more likely it is that membranes will be used rather than the still widespread chemical purification processes such as amine scrubbing. “In the market for natural gas sweetening, membranes have a market share of just eight percent, and until now 80 percent of these membranes have been made of cellulose acetate,” says Baumgarten. He estimates that a market worth several hundred million euros is waiting for the sector to catch on—and Evonik aims to secure a large part of that market for itself.

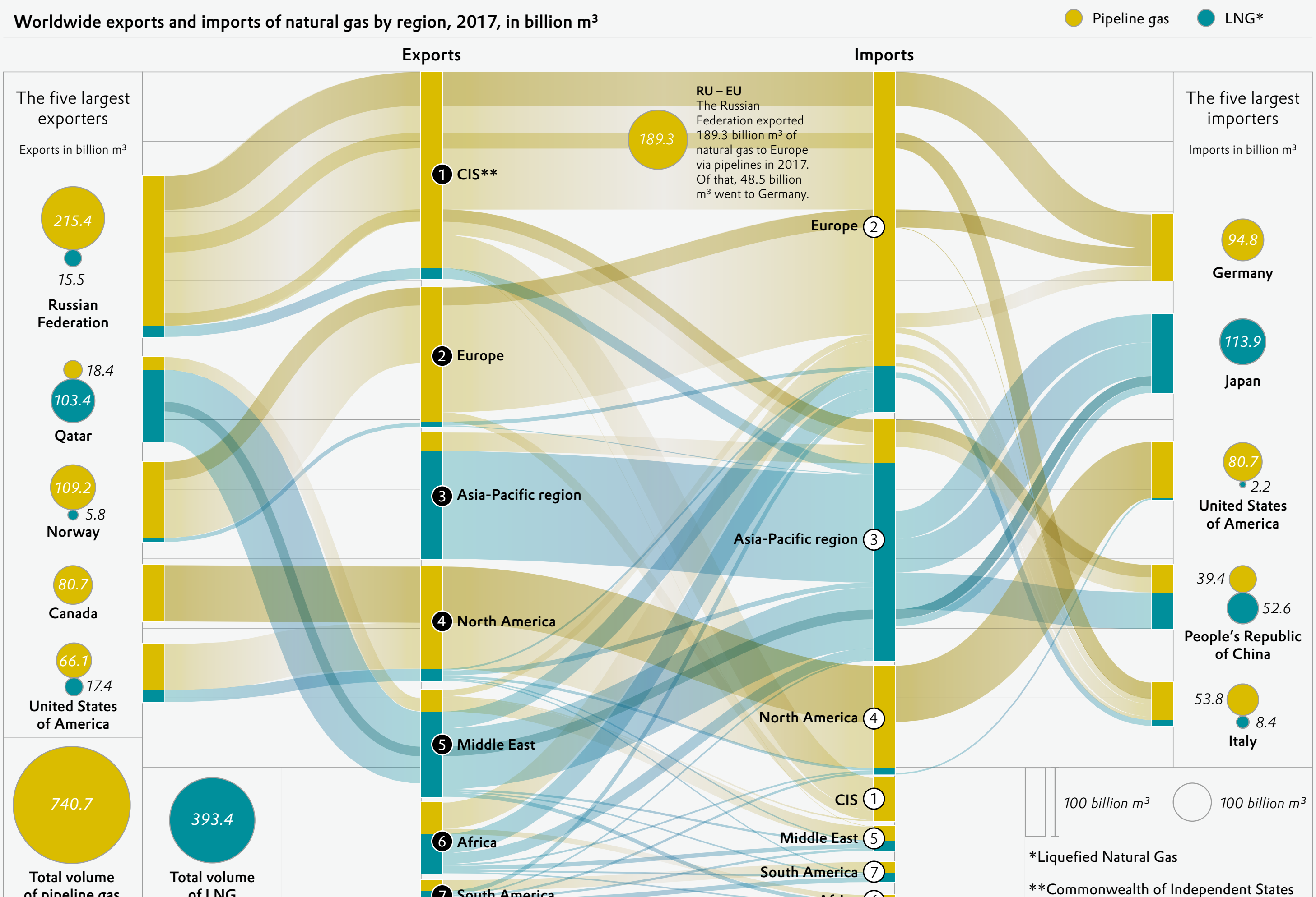
Natural Gas

Natural gas is used to heat homes and generate electricity. It also produces heat for industrial processes and serves as a fuel. However, its deposits are generally not in the places where the demand is greatest. Here's an overview of the reserves and transportation routes of one of the most important fuels.

The 10 largest producers of natural gas and their consumption in 2017, in billion m³



Worldwide exports and imports of natural gas by region, 2017, in billion m³



*Liquefied Natural Gas

**Commonwealth of Independent States

in billion m³	CIS**	Europe	Asia-Pacific region	North America	Middle East	Africa	South America
Pipeline gas exports	1 282.9	2 192.8	3 26.8	4 146.4	5 30.9	6 45.0	7 15.4
LNG exports	15.5	8.3	155.0	17.4	122.5	55.4	19.1
Pipeline gas imports	1 62.3	2 423.4	3 62.9	4 146.8	5 22.2	6 7.6	7 115.4
LNG imports	–	65.7	283.5	9.2	13.0	8.2	13.8

Source: BP Statistical Review of World Energy 2018

Membrane Makers

TEXT **GEORG DAHM**
PHOTOGRAPHY **ENNO KAPITZA**

A master of membranes: No one knows the spinning machine as well as Peter Aigner. He makes sure only top-quality superfine hollow membranes reach the bobbins

There's a long tradition of producing plastic fibers in Upper Austria. In the town of Schörfling, plastic fibers are used to make membranes that could revolutionize natural gas purification worldwide

Sometimes the pace of progress can be slow. A machine is winding a bunch of fibers in a criss-cross pattern, layer by layer, onto a meter-long coil that is rotating slowly and serenely. Buzzing in a steady rhythm, the spindle moves back and forth again and again along the entire length of the winding machine—until a huge golden plaited braid eventually becomes visible.

Peter Aigner was initially annoyed by the machine's sluggish pace. "The lethargy of the process was the biggest challenge for me," he says. Aigner is a shift foreman at the Evonik plant in the town of Schörfling in Austria. After working for thirty-four years as a chemical process engineer, he's become accustomed to much faster speeds. Here on the shores of Lake Atter in Upper Austria, factories have been spinning plastics into fibers for almost a century—viscose in the early days, polyimide today. Normally, the threads run off the machine at a much faster pace.

However, these are not "normal" fibers like those that are used for functional clothing, bedding, tea bags or baby wipes. In this factory hall in the middle of a small industrial park, the machines are producing hollow fibers—ultrafine structures similar to macaroni, whose interiors can barely be seen by the naked eye. Each of these fibers can separate two gases from each other by enabling one to diffuse into the fiber's interior and leaving the other one outside. Under the brand name Sepuran, these plastic straws are packed into thick bunches and built into steel tubes to serve as high-performance filters for the chemical industry and biogas plants. In its most recently developed func- →

tion, Sepuran is used to purify natural gas, which often contains a large proportion of CO_2 when it emerges from the earth. If the natural gas were used in its unfiltered form, it would quickly erode pipes and connecting pieces.

Visitors who travel from Salzburg to Schörfling during the winter are usually focused on skiing vacations rather than market-leading plastics expertise. Schörfling is not far from the renowned skiing areas Dachstein West and Krippenstein-Obertraun. But the picturesque region around Lake Atter has also been known for decades as a manufacturing center for textile and plastic fibers. The neighboring town of Lenzing is the headquarters of the Lenzing Group, which today is a globally operating company with a rich tradition and from which the Evonik location in Schörfling originated.

Peter Aigner is one of the employees who are responsible for membrane production. This is a job for experts. It's no easy task to perfectly shape liquid plastic into an endless straw with an interior that is slightly porous and an exterior that is a film with precisely defined chemical properties. "I grew up with polyimides, but what we're producing here is completely different," says Aigner.

Gigantic: This machine produces polyimide fibers for the membrane

"I grew up with polyimides, but what we're producing here is completely different"

PETER AIGNER, MACHINE OPERATOR

Not losing the thread: Evonik runs a three-shift operation in Schörfling, where Peter Aigner pulls the strings

4

VARIANTS of Sepuran membranes are offered by Evonik

TURNING TWO INTO ONE

The fibers are extremely delicate, but the machine that creates them seems colossal. The fibers that are now filling the stainless steel coil are flowing out of a gigantic steel construction that's as high as a house and several garages wide. If you approach this structure, climb up one of its steel stairs, and look through the window into its interior, in the entire space you'll see just a few delicate threads being drawn through steaming liquid baths. The threads begin at the other end of the spinning machines, behind a tangle of pipes and cables wrapped in foil. Here you'll find the spinnerets, which extrude a polymer solution as hollow straws.

The starting material is delivered to the factory in two man-sized white plastic tanks from the town of Lenzing, where Evonik produces polyimide. One of the tanks contains the "dope solution," which is gold-colored and as sticky as honey, and the other contains a solvent. Both of these components, the viscous plastic and the volatile solvent, must be brought together in

Control is better: A membrane cartridge is inserted into a pressure tube in order to test its performance

the spinnerets in such a way that they emerge flawlessly and evenly from the ring mold as endless "macaroni." "The external shape isn't the only important feature," says Götz Baumgarten, who is responsible for the membrane business at Evonik. The outer surface of the fiber must also be reliably produced with the desired separating properties. Every single aspect of this machine is a precious trade secret, ranging from the temperature of the water bath to the operating speed and the number of threads that are spun simultaneously.

TACKLING THE NATURAL GAS MARKET

Even though the process itself seems very slow, "our competitors in the gas separation market are amazed by how fast we are," says Baumgarten proudly. He's referring to the speed with which Evonik has established itself in recent years as an important supplier for companies that process nitrogen and biogas—and also to the fact that the company has opened up new areas of application in such a short period of time. Evonik's most recent coup is the use of Sepuran in the processing of natural gas. Here the Group has tackled a conservative market in which there have been no real innovations for a long time. Most of the time, natural gas is purified with the help of nitrogen-based chemicals. This process is expensive, requires intensive maintenance, and is not very environmentally friendly. Today separation membranes still have only a small share of the market, because so far they have not been very efficient or durable. But Baumgarten is confident that many plant operators will switch over to the new material from Austria. The design of the factory in Schörfling enables it to react quickly to increasing demand.

53

EMPLOYEES
are involved in membrane production

The natural gas business is actually not considered a great opportunity for suppliers. Projects in the sector have lead times of 18 to 24 months, and the suppliers typically fill a huge order and then have no more orders for long time. "Once we've configured the machine, we can produce plastic fibers for months without a break," says Aigner. "We operate 24 hours a day, seven days a week, all year long." The question now is: How can the factory manage to stay in continuous operation? →

Cooperation: Evonik manager Götz Baumgarten (right) developed the Sepuran production process together with Peter Aigner and his colleagues

The answer can be found a few meters behind the winding machine, which shapes the bunches of fibers into natural gas filters. Here there is a second assembly line, in which an apparatus resembling a mill wheel is winding threads onto a polygon with meter-long edges. “This is called a reel or a spool,” Aigner explains. Spinning mills have been using such devices for ages to wind yarn and thread into manageable bunches.

A BRAID OR A BUNCH?

At Evonik, such bunches are formed into membranes for biogas, nitrogen or helium, while the braided shape is used only for natural gas membranes. In other words, the factory produces several different kinds of products whose quantities are increased or decreased according to demand. “That’s how we can serve various different markets simultaneously and have a continuous production process,” says Baumgarten.

Rotation: The fiber bunches are wound onto mandrels

A wide range: Natural gas membranes lie next to membranes for biogas, nitrogen, and noble gases in the distribution warehouse

“Every module we make here is as valuable as an expensive watch”

GÖTZ BAUMGARTEN, BUSINESS MANAGER MEMBRANES

The shape in which the fibers are produced—a braid or a bunch—depends on how the gas is supposed to stream through the apparatus. “For the separation of nitrogen or biogas, we feed the gas through the interior of the fiber; in the case of natural gas, we feed the gas along the outside of the fibers,” Baumgarten adds. Straight fibers are more suitable for the first type of separation, while wound fibers are better for the second type. The winding ensures that the natural gas flows smoothly. The flow should be just fast enough to allow the carbon dioxide molecules to diffuse through the membrane into the hollow interior of the fibers. During this process, the stream of natural gas becomes ever purer—that is, the concentration of methane increases.

In an adjacent production hall, towering furnaces stand along the walls, ready to provide the fresh bunches of fibers with the necessary finish. The technical term for this is “tempering.” This is skilled manual work, just like every other process that takes place as soon as the “harvest” is removed from the spinning machine. Whether the fibers come in a bunch or a braid, shaping them into a membrane module is high-precision work. After all, the final products have to function correctly for many years on production platforms and in refineries.

“Every module we make here is as valuable as an expensive watch,” says Baumgarten. The use of workbenches instead of assembly lines makes the work atmosphere in Schörfling seem more like a workshop than a factory. First, the bunches of fibers are neatly cut off. Next, they are closed at each end with a resin plug in a centrifuge.

TESTING UNDER REAL-LIFE CONDITIONS

“Potting” is the name of this process, which is more complex than it seems at first glance. If you’ve ever cast a leaf or an insect in resin in order to make a transparent paperweight, you probably didn’t mind if your creation contained a few air bubbles. They don’t keep a paperweight from working. But for a membrane module, every casting must be perfect, every fiber must be well-coated, and impermeability must be guaranteed.

70

DEGREES
is the operating temperature of the Sepuran membranes

At the end at which the CO_2 has to flow out of the interior of the hollow fibers, the resin plug is sawed off in order to expose the open ends of the fibers. Later, a stainless steel cap will enclose this end, where the natural gas that is streaming out will accumulate and be channeled away through a pipe.

After the fiber bunches have been packed into a sheet of black heat-shrink tubing and provided with stainless steel end pieces, the modules have to be individually tested to ensure that they are absolutely flawless. The truth waits behind a roller door, in the shape of a compressed air station that simulates real operation for a period of 20 minutes. If a membrane module does not make a clean enough separation of the compressed air that is injected into it during the test, it will probably fail in real operation as well. A roll container full of rejected membranes standing in front of the door shows that Evonik’s claim to excellence is justified.

The prospect that the Sepuran membranes will conquer completely new terrain in the natural gas market, with turnover in the millions and the potential for worldwide application is not causing any anxiety here in Schörfling. Their work goes on, in three daily shifts, and it’s concentrated but relaxed. “If you become hectic, you just make things worse,” says Aigner. Sometimes a sluggish pace is exactly right.

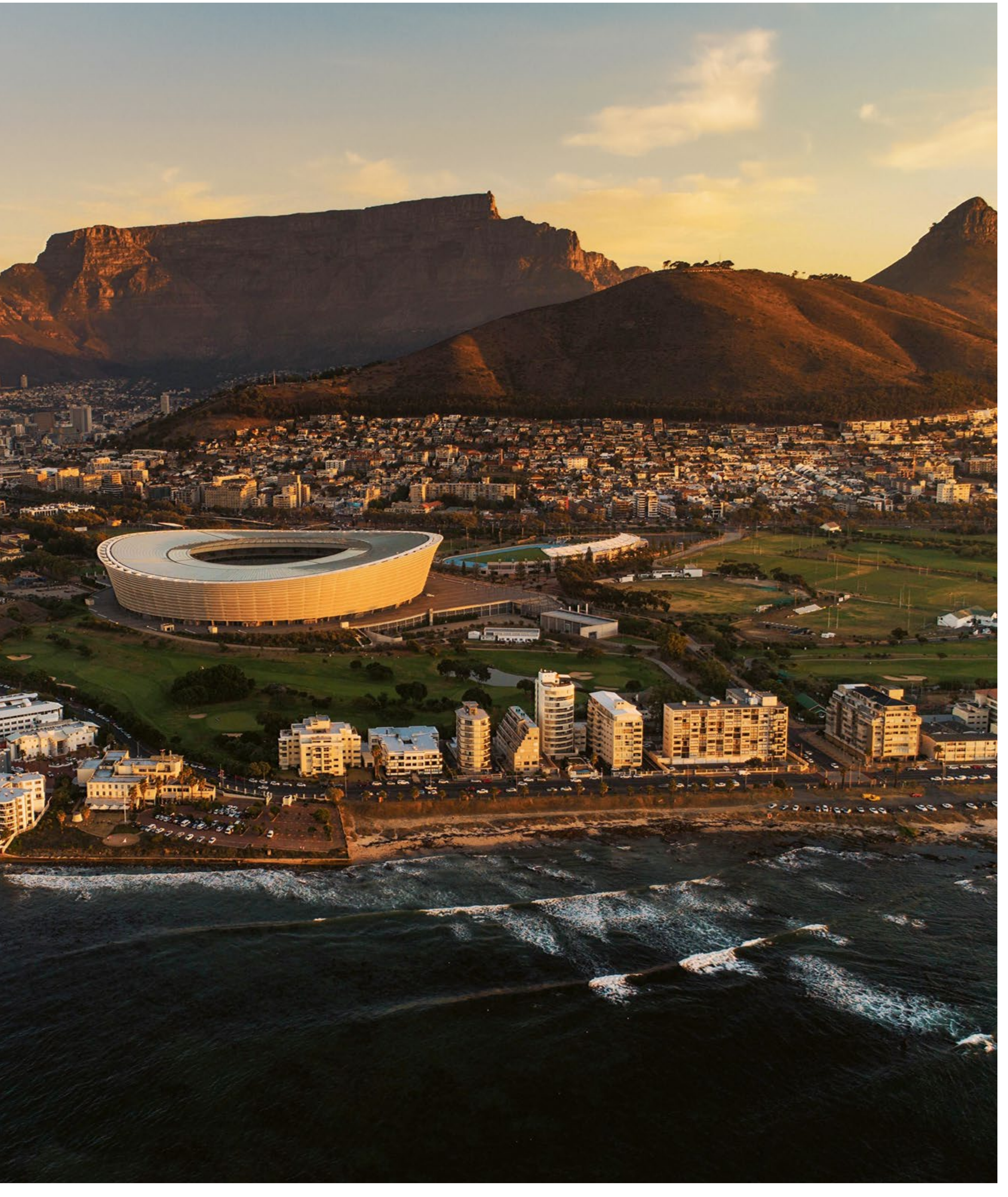
Pristine wilderness, a turbulent history, and a culture in transition: South Africa is a country with many facets

The “rainbow nation” is one of the most dynamically growing economies on the African continent. It’s a promising future market for creative solutions.

TEXT **NICOLAS GARZ**

A bird's-eye view: If you're lucky, you can encounter wild penguins on the beaches of South Africa. This country is renowned worldwide for its biodiversity. In order to safeguard its broad range of species, it established its first nature reserves more than 120 years ago. The best-known one is Kruger National Park, where lions, rhinoceroses, elephants, and many other species live in their original habitat. About ten million tourists visit South Africa every year—and the fascination of pristine nature is a powerful enticement.

Shining bright: Table Mountain towers above a pulsating city. Daily life in Cape Town, South Africa's second-largest city, is shaped by a mix of various cultures. Its residents are said to be comparatively easygoing—and that's not a bad mindset in a major city that is constantly changing and reinventing itself. For example, its cityscape was enhanced with the eye-catching Cape Town Stadium for the Soccer World Cup in 2010. It's an ultramodern soccer arena with lighting pillars made of PLEXIGLAS® that compete brilliantly with the stars above Table Mountain night after night.



Mouthwatering: Barbecuing, which is known as *braai* in Afrikaans, is especially popular in South Africa. Favorite grilled meats include local delicacies such as springbok as well as the more conventional beef and chicken. Livestock and poultry farming play an important role in filling this demand. The amino acid DL-methionine is used here in order to ensure that the animals metabolize their feed optimally.

In transition: A large proportion of the energy used in South Africa is still based on coal, but the conditions are right for an energy transition. There's a lot of sunshine, as well as strong winds along the coasts. Various products from Evonik are supporting the ecological transformation. For example, VISCOBASE® boosts the efficiency of wind turbines, and DYNASYLAN® is an additive for adhesives in solar modules.

Location, location, location: In 2017 South Africa sold about 4.5 million hectoliters of wine abroad, thus becoming the world's sixth-largest wine exporter. Most of this wine is grown in the Western Cape Province in the south of the country. The granulate STOCKOSORB® supports South Africa's agriculture by ensuring that soils stay fruitful even under inhospitable conditions. In addition, silicas in plant protection products help to ensure rich harvests that contribute to the country's reputation and prosperity.

PRODUCTION AND INNOVATION

Evonik operates two production facilities in South Africa. In Elandsfontein in the northeast, the Group produces PLEXIGLAS®; in Umbogintwini it produces hydrogen peroxide (H_2O_2). Evonik's administrative headquarters and sales unit for South Africa are located in Midrand, the third of the company's locations in the country. There Evonik operates innovation centers where research is conducted and new products are developed.

Major Evonik locations

1 Midrand
2 Elandsfontein
3 Umbogintwini
4 Cape Town

Evonik has about

100

employees at

4

locations in South Africa

TEXT **ROD JANSSEN**
ILLUSTRATION **HENRIK ABRAHAMS**

Rod Janssen is an independent energy consultant based in Paris. He is also the President of Energy Efficiency in Industrial Processes (EEIP), a non-profit business and policy platform for industrial energy efficiency

We've Learned a Lot

Climate change seems to be inevitable. Nevertheless, despite many setbacks, an increase in energy efficiency is still the most viable way to limit the effects of global warming

One year ago, Professor Ernst Ulrich von Weizsäcker and Anders Wijkman published their report for the Club of Rome entitled "Come On!" The title indicates the direction in which all of us should be moving. The authors argue that the size of the human footprint on the Earth is increasing fast, and that if this trend is not reversed it will eventually lead to a collapse of the global economy.

Profit maximization and the goal of saving the planet are inherently in conflict. There needs to be a vastly improved balance between human beings and nature, markets and the law, private consumption and public goods, short-term and long-term thinking, and between social justice and incentives for excellence. There is a need for an overhaul of the way that we all interact with our planet. We're still not doing enough. The Intergovernmental Panel on Climate Change has also come to this conclusion. According to a special report published by the IPCC, if we go beyond a 1.5˚C increase in global temperature, the impact will be dire.

So what do we need to do? There are many optimistic case studies and policy proposals that could put us on a trajectory towards achieving sustainability. For example, a move towards a circular economy could help to solve the problem of resource scarcity, significantly lower CO_2 emissions, and increase the number of jobs. Regenerative agriculture can stop soil erosion, enhance yields, and bind CO_2 in the soil. Using waste heat to generate electricity reduces the number of power plants needed to meet worldwide energy demand.

There is no lack of political agendas to get us back on track towards sustainability. Europe has developed, and continues to develop, a policy framework that is designed to achieve long-term goals. The EU is giving clear signals to all consumers and to industry that they must take effective action—starting now.

The climate and energy framework that was agreed on in 2014 for the period until 2030 sets binding key targets including further cuts in greenhouse-gas emissions, a rising share of renewable energy, and significant improvements in energy efficiency. In 2018 those targets were strengthened for energy efficiency and the use of renewable energy. In June, the European Commission, the European Parliament, and the European Council reached an agreement which includes a target to improve energy efficiency in the European Union by 32.5% by 2030. The agreement includes a clause that permits an upward revision of this goal before 2023. The EU member states' ministers of energy also agreed on a renewable energy target of at least 32% to be reached by 2030.

There is also a longer-term vision for decarbonization. The EU's roadmap to a low-carbon economy suggests that by 2050 the EU's member states should reduce their greenhouse gas emissions to 80% below 1990 levels. To reach these goals, all sectors need to contribute.

At the 2015 Paris climate conference, governments committed themselves to a long-term goal of keeping the increase in the global average temperature to well below 2°C compared to pre-industrial levels. The aim is to limit the increase to 1.5°C, since this would significantly reduce the impact of climate change. The politicians agreed on the need for global emissions to peak as soon as possible, recognizing that this will take longer for developing countries, and they promised to undertake rapid reductions in accordance with the best available technologies.

These objectives apply to humanity as a whole, and they affect all of us as individuals, businesses, and nations. Everybody must take action. But where should we begin? It's never easy to answer this question. Fortunately, the EU recently instituted a requirement that large industrial companies conduct mandatory energy audits at regular intervals. That is a good starting point. The only way of avoiding the audit is to adopt the ISO 50001 certification standard, which specifies the requirements for setting up an energy management system in a company. This standard is essentially designed to change corporate culture, because it requires a commitment from all parts of a company, including its senior management. Among other things, the standard requires companies to reduce emissions by using modern production techniques, increase the share of recycled materials in the manufacturing process, and generate energy from waste heat.

Nevertheless, there have been severe political setbacks. The United States and Brazil are headed by presidents who deny climate change. President Emmanuel Macron of France, under pressure from the protesters wearing *gilets jaunes*, suspended plans to raise taxes on gasoline and diesel fuel. The results of the recent UN climate change conference in Katowice showed a lack of determination and also made it clear that there is no easy way to bundle the interests of industrial and developing countries.

But there is reason for hope. The oil crises of the 1970s were a shock to the global economic system, but we responded to them by making energy efficiency a political goal. The latest issue of the "World Energy Outlook" from the International Energy Agency (IEA) states that in the industrial sector worldwide there has been a 2.5% average annual increase of energy consumption since 2000. However, in its "New Policies Scenario" the IEA projects that this increase will slow down to 1.3% per year "as a result of energy efficiency gains and significantly lower growth rates for output from energy-intensive industries."

Why is that? Well, we've learned a lot since the 1970s. We are now in much better shape to take effective action—if the will and the commitment to do so exist. On the downside, there are still obstacles hindering companies from pursuing energy-saving measures, such as financing problems and a lack of confidence in products and technologies. Some companies still do not regard an increase in energy efficiency as a strategic goal. We know that a lot of businesses are missing opportunities to save energy. Surveys show that there are still many low-cost, or even no-cost, opportunities to enhance efficiency on virtually every factory floor.

On the upside, there are more and more technologies available to help reduce energy consumption, and their prices are continuously sinking. Many innovations are making valuable contributions, and the growing number of energy service companies is making it easier to introduce new energy-saving measures. For example, today it's much easier than it used to be to conduct energy audits.

"Some companies do not regard an increase in energy efficiency as a strategic goal"

The finance industry is working towards providing ways to help companies finance energy-efficiency measures. These include efforts to "de-risk" energy-efficiency projects in order to encourage greater investor confidence. These efforts are directed towards energy-intensive and non-energy-intensive sectors alike. There are also efforts under way to improve the capacity of financial institutions to analyze energy-efficiency projects so that they can carry out the required underwriting activities and ensure that such projects can get the necessary funding. On the regulatory level, there have been improvements to the measures supporting energy efficiency, and these will accelerate in the future.

There are good reasons to believe that we can get back on track. The Energy Transitions Commission, a body that includes representatives from business as well as leaders from the public and social sectors, recently concluded that energy-intensive industries, given time, can completely decarbonize their business operations. Until now, no one had thought that this was technically possible.

Fortunately, most companies remain optimistic and are not slackening their efforts. No company wants to give up business or to lose its ability to compete. Improved energy efficiency does not solve all problems, but it does address many of them. So von Weizsäcker and Wijkman are quite right when they appeal to us: Come on!

HEAT IS POWER

TEXT **NADINE NÖSLER**

In industrial plants and households, energy is being lost everywhere in the form of waste heat. Thermoelectric generators can transform this waste heat into electricity. However, thermoelectric generators used to be complex and expensive to manufacture. Experts have now developed a fully automated production process that has great potential for energy recovery

While the pizza on the baking pan is developing a crispy crust, the oven is producing lots of hot air. But as soon as the oven door is opened, this hot air is dissipated into the room. Refrigerators give off heat so that their interiors stay cold, and cars also continuously release heat through their exhaust pipes. In industrial processes, this heat release takes place on a large scale. In engines, pumps, and oil refineries, large amounts of energy are released as waste heat. In Germany alone, 300 terawatt-hours per year could be reused—an amount that would cover the country's power requirements for about seven months. According to some estimates, US$57 billion could be saved worldwide by recovering the energy from waste heat.

THERMOELECTRIC GENERATORS TRANSFORM HEAT INTO ELECTRICITY

Researchers are investigating a number of solutions for utilizing waste heat more efficiently in the future. One promising possibility is the transformation of heat into electrical energy. Thermoelectric generators, or TEGs, can generate electricity from even small differences in temperature. A team of researchers from Creavis, Evonik's strategic innovation unit, and the Process Technology unit, which is a proactive technology developer in the Group, has developed a fully automated production process for this technology. In the future, this process could play a larger role in energy recovery efforts.

A thermoelectric generator has a simple structure (see the graphic on page 54). It consists of two different semiconductors that are connected to each other by an electric circuit. One of the legs serves as the n-semiconductor (n stands for "negative"), the other one as the p-semiconductor (p stands for "positive"). If one end of the two legs is heated up, the electrons there receive additional energy. As a result, more charge carriers move from the hot end to the cold end of the leg than vice versa. A negative charge builds up at the cold end of the n-leg, a positive one at the cold end of the p-leg. That creates electric voltage between the two legs. However, this voltage amounts to only a few microvolts for each degree Celsius of the difference in temperature. That's why a large number of semiconductor pairs have to be connected in series on in order to generate usable amounts of electricity. →

300 °C

EXHAUST SYSTEMS

In the future, TEGs could be used in the exhaust gas systems of vehicles, where temperatures can rise as high as 300°C. In load conditions above the maximum operating temperature, part of the exhaust gas is channeled past the generators in order to protect them. The challenges for the TEGs: vibrations and shocks on rough roads, limited space for installation, frequent and irregular changes in temperature.

INDUSTRIAL PROCESSES

Power plants running on fossil fuels, as well as many industrial operations, generate large amounts of waste heat and are attractive areas of application for thermoelectric generators. For example, furnaces in steel mills can reach temperatures up to 1,300°C. Under these difficult conditions, the generators must remain stable and robust and resist mechanical wear and tear as well as corrosion over the long term.

1,300 °C

A FULLY AUTOMATED PRODUCTION PROCESS

The process seems simple, but its implementation is complicated. The biggest problem is the process of producing the generators. Until now, the legs of the thermoelectric generators—components that are only a few millimeters long—first had to be attached to a carrier material by hand. Producing TEGs in large quantities was complicated and expensive. Nonetheless, thermoelectric generators have been demonstrating their effectiveness in niche applications for a long time. For example, on board the Voyager 1 space probe—15 billion kilometers from the Earth—they have been reliably transforming the heat of disintegrating radioisotopes into electricity for 20 years.

Researchers from Creavis wanted to use this potential for applications on earth as well, so they began to develop a cost-effective production process for thermoelectric generators. "This idea was born back when our company was still active in the energy sector and wanted the operation of its power plants to be as environmentally friendly as possible," explains Dirk Lehmann, the Head of Business & Launch Management. After weighing the advantages and disadvantages involved, the researchers opted for the system based on thermoelectric generators. TEGs operate without any mechanical movements, directly transform the flow of heat into electricity, can be combined with other systems, are compact, and operate very reliably. They also have long maintenance intervals. "In order to make the process practicable for large production volumes, we looked at various possible innovations," Lehmann says.

> **"Our process speeds up the production of the generators"**
>
> DIRK LEHMANN, CREAVIS

Their main concern was to reduce the amount of manual labor that was required (see the graphic on the right). They decided to grind the semiconductors for the generators into powder and then to pour this powder into a mold for tablets. A cold compression process is used to form them into legs. "Here you can already see the first advantage of our process," explains Patrik Stenner, Head of Exploration & Electrochemistry in Process Technology. "We no longer have to cut them to fit out of solid material. As a result, we don't lose any material."

After that, a robot fully automatically inserts the legs into the previously bored holes in a special carrier material. Thus the module's basic framework is created in a short period of time. This framework is then sintered in a furnace. This process "bakes together"—i.e. firmly connects—the legs and the carrier material. After that, the module is polished so that no impurities can decrease its efficiency. "Next, the component has to be protected and rendered conductive," Stenner explains. This is done by metallizing the generator—coating →

PRESS, BAKE, GLUE

In order to produce TEGs cost-effectively, the researchers from Creavis and Process Technology had to focus mainly on decreasing the amount of manual work involved. Among other things, they decided to use robots in the production process, thus reducing production costs by up to two thirds.

1 The semiconductors for the generators are ground into powder and poured into a mold for tablets

2 In the mold, the material is **cold-pressed** to form legs

3 A robot positions the legs on a special carrier material fully automatically

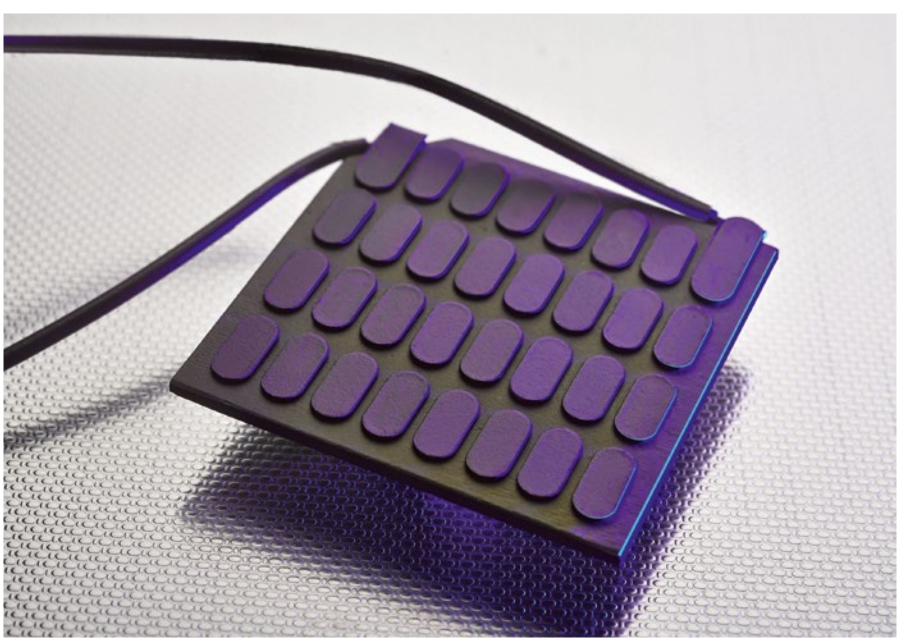
4 The legs and the carrier material are sintered **in a furnace.** Thus they are "baked together"

5 A black top layer insulates the module and protects it from corrosion

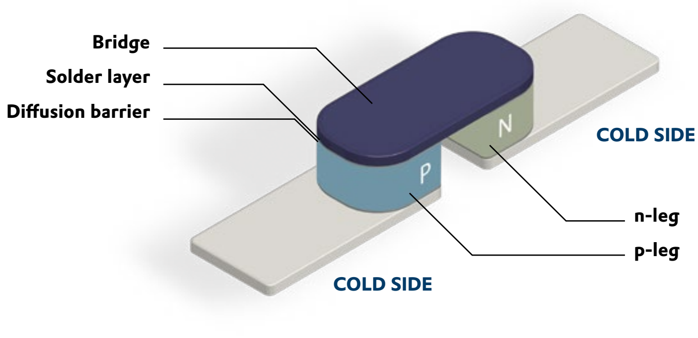
6 The loosely arranged bridges are thermally glued onto the carrier material in a furnace

7 Bridges are used to connect the legs **in series**

8 The generators are **metallized** by coating the legs with thin layers of metal



A finished generator is about six centimeters square



HOT AND COLD

The Seebeck effect, which is used in thermoelectric generators (TEGs) to produce electricity, was discovered by the physicist and physician Thomas Johann Seebeck in 1821. A thermoelectric generator consists of two semiconductors that are connected by a circuit. If one side of the TEG is heated, the electrons in the n-leg move to the cold end of the leg. In the p-leg the electrons move to the hot end. As a result, a negative charge and a positive charge accumulate at opposite ends of each semiconductor. That creates an electric voltage between the cold ends of the two legs of the thermoelectric generator. The components of the generators are connected to one another by means of a soldered contact bridge. A diffusion barrier prevents the materials in the different components from mixing over time.

the legs with thin layers of metal. Nickel protects the semiconductors from destruction due to foreign metals diffusing into the material. Copper serves as a contact layer for the electrical connection. In addition, bridges are added so that the legs are connected in series. A black top layer insulates the module and protects it from corrosion. In the last step, wires are connected to the module's contact points.

Although 64 legs are connected in series in a module, the operational generator is only half as big as a five-euro bill. That makes it flexibly applicable. If a large amount of electricity is needed, several generators can be connected together. They can also be combined with other systems for using waste heat. Thanks to the new production process and the special carrier material, thermoelectric generators are extremely robust and can operate at temperatures up to 260°C. Conventional TEGs can be operated only to a limit of 200°C. In processes using higher temperatures, such as those needed for producing and processing cement, glass, ceramics or metal, the TEG is used in the parts of the plant that are less hot.

According to Dirk Lehmann, the biggest advantage of the new production process is its higher speed: "Because our process is fully automated, it speeds up the production of the generators." It also helps to lower their price, because it reduces the production costs by as much as two thirds.

EXTENSIVE RESEARCH

The researchers from Creavis and the experts from Process Technology invested a great deal of work in this successful project. Firstly, the process had to be developed and perfected. Secondly, the researchers had to prove that not only the process but also the generators produced by it would function reliably. In order to provide this proof, they created a miniseries consisting of 1,000 prototypes and subjected it to field tests. One of the challenges they had to face was a glitch in the process of inserting the legs into the carrier. Initially, this process step ran smoothly. But during the assembly of the 300th generator, the legs suddenly fell right through the previously bored holes. This happened because the drill had become blunt over time and had therefore made the micrometer-precision holes too big. The researchers then had to find a new material for this tool. "We now have an optimal process that works for the production of large runs," says Lehmann. The team was honored for its work in 2016, when it received the German Sustainability Award in the "Research" category.

The team from Process Technology at Evonik is now setting up a process for testing the generators in various plants throughout the Group—for example, in a production plant in Rheinfelden where plans call for the use of waste heat. For this purpose, individual TEGs are being combined to form a huge module. Using a temperature difference of about 70°C compared to their surroundings, the TEGs will be able to generate enough electricity to power on-site measuring equipment. "The generators will play an important role in making our production machinery resource-efficient," says Patrik Stenner.

“We’ve invested lots of development work in the project. We now have an optimal process that works for the production of large series”

DIRK LEHMANN, CREAVIS

But the TEGs’ potential has still not been completely exploited. Because the starting modules are so small, the generators could also be used in autonomous energy systems—for example, in natural gas-driven heater fans in the large tents that are used as emergency shelters. That would make it possible to generate electricity in locations far from power grids.

THERMOELECTRICITY COOLS AND HEATS

In the future, this simplified production process could also be used for modules that reverse the principle behind thermoelectric generators by using electricity to produce heat (or cold). That would open additional markets, such as the one for electric vehicles. “The automotive industry is facing the challenge of boosting the efficiency of lithium-ion batteries in vehicles by means of temperature control or, for example, by using a seat-heating system,” Lehmann says.

Evonik has produced several thousand TEGs to date. But it’s now looking for a buyer for the manufacturing process so that TEGs can be produced in large quantities and the technology can be introduced into as many fields of application as possible. “Evonik is a specialty chemicals company, and its core competencies do not include the production and marketing of thermoelectric generators,” Lehmann explains. “However, we believe in our process, and we want to give other companies an opportunity to benefit from our work.”

SELF-SUFFICIENT ENERGY GENERATION

Because thermoelectric generators are so small, they could also be used in autonomous energy systems—for example, in heating devices that use propane gas to heat air to temperatures as high as 95°C. TEGs could also generate electricity to ensure a secure power supply in places that are far from a power grid.

95 °C

Is this plastic, or is it trash? In a slum of Dhaka, the capital of Bangladesh, a woman examines polyethylene film that is ready to be recycled

WE CAN USE THAT

Is used sports clothing a valuable raw material for new sneakers? Can discarded fishing nets be used to make ladies' tights? Yes, all this is possible if plastic waste is recognized as a valuable and future-oriented resource

TEXT **BJÖRN THEIS**

Plastics are certainly one of humankind's greatest inventions. Thanks to their diverse properties, they have made social and technological progress possible. Without plastics we would have to do without many of the conveniences we enjoy today, ranging from brake hoses in our cars to vinyl records, cling film, and pantyhose.

However, because plastics are so inexpensive to produce they have also changed our consumption patterns. A mindset that sociologists call a "throwaway mentality" has developed in many societies. One example of this mindset is "fast fashion." Some global fashion chains offer 24 different collections every year. As a result, we own more and more clothes that we hardly ever wear because they are going out of style so fast. Another major area of application for plastics is packaging—for example, for the hygienic sale of food and medications as well as the transportation of large package units.

But the massive use of plastics also causes problems. If a plastic item is no longer needed, it lands in the garbage bin. Plastics take a long time to deteriorate. If they are not reused or burned as fuel, they end up as growing mountains of plastic waste on land or islands floating in the world's oceans.

A RETHINKING PROCESS HAS BEGUN

Today there are signs that we've started to reverse this trend. More and more companies are realizing that plastic waste is a sustainable resource. For example, the sports equipment producer Adidas has announced that starting in 2024 it will only use recycled plastics as the raw material for its products. The clothing manufacturer Sympatex promises even more: It aims to close its material cycle by 2020. In other words, it will then be possible to endlessly recycle all of its products. The Italian textile fiber producer Aquafil has introduced a new product called Econyl, which can be recycled any number of times.

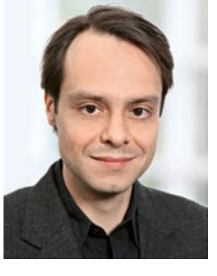
New technological developments are supporting the recycling of plastics. For example, the Dutch initiative Recycled Island Foundation is using recycled plastics to construct platforms from floating elements with the aim of creating a floating park in Rotterdam. Consumers are increasingly regarding recycled products as hip. And companies such as the startup Share, a bottler of mineral water, have realized that the trend has changed direction. Share is the first mineral-water bottler in Germany to offer only bottles that are entirely made of recycled plastic.

These examples are signs that our society is rethinking its attitude toward plastic. A new vision for the plastic industry is evolving. It calls for a closed, waste-free plastic cycle in which the materials that are used can be endlessly reused. This idea harbors tremendous potential, because used plastics are a resource that is available in enormous quantities and is continuously growing.

THE GOAL IS A WASTE-FREE PLASTIC CYCLE

However, a great deal of work is needed in order to realize this potential. For example, the waste management industry and plastics manufacturers need to learn from one another. The recyclers often don't realize what standards industries set for possible recycled materials, and the plastics manufacturers don't understand the problems that recycling involves. For one thing, it's difficult to sort the different kinds of plastics out of piles of waste. As a result, the recycled materials that are available today are of lower quality than their pure original versions. For example, if the widely used plastics polyethylene (PE) and polypropylene (PP) are mixed together, the original materials lose their durability.

All of these factors have been reason enough for the Foresight team of the strategic innovation unit Creavis to devote itself to the future of plastic recycling. The researchers in the team are taking several different approaches. For example, they are "marrying" PE and PP by means of a block copolymer to ensure that the desired properties of these materials are not lost. After all, it would be a shame to go on throwing away masses of something as versatile and useful as plastic.



Björn Theis is a futurologist. As a member of the Corporate Foresight team he develops scenarios for the specialty chemicals of tomorrow

110 281
Ds
Darmstadtium

"How We Discovered Darmstadtium"

Prof. Sigurd Hofmann (74) started his career at GSI in 1974 as a research associate, and after a series of promotions he was appointed to lead the experiments for the synthesis of new elements. He has worked as a guest researcher at GSI since his retirement in 2009. In the particle accelerator, elements are shot at a target consisting of another element

PROTOCOL **NADINE NÖSLER**
PHOTOGRAPHY **BASTIAN WERNER**

Nuclear physicists use known elements to create new ones. We want to understand the structure of matter, and thus to understand the development of the universe. At the Gesellschaft für Schwerionenforschung (GSI), we use a particle accelerator to make two atomic nuclei collide at a speed of 30,000 kilometers per second. The fusion of these two nuclei creates a new, previously unknown element that we filter out using a separator and then investigate. The process of detecting these new elements is complicated. They are unstable, and they decay within a fraction of a second. That's why I have to precisely calculate the energy with which the atomic nuclei are accelerated and adjust our instruments accordingly. We discovered three new elements in the 1980s, but after that we had to do ten years of development work to refine our detection method. In case you're wondering if I ever lost my patience, my answer is "absolutely not"! We always had a lot to do, and we had set our sights on a clearly defined goal: being able to indisputably detect the next element. Our work was eventually successful. I'll always remember the day when we were able to detect Element 110. Two of my colleagues and I were working alone on the experiment. We discussed the measurements we had made to date—and there we had it: the proof of the new element! The number of protons in the atomic nucleus of the newly created element matched our calculations. Naturally, we were eager to announce this important discovery immediately. But if we had done that we wouldn't have had any time to write a paper about it. So we stayed mum and immediately started to write the paper. At 3 a.m. we were finished, and we placed our report on our colleagues' desks. When they read it a few hours later, they were absolutely astonished! On the basis of our precise calculations, we subsequently discovered two more new elements in short order. I'm especially proud of the fact that our team was allowed to name these elements. Following my suggestion, we named element 110 darmstadtium as a tribute to the city where I studied physics and where I've been pursuing my passion for the past 45 years.

Masthead

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The difficulty lies, not in the new ideas,

…but in escaping from the old ones, according to the economist John Maynard Keynes. We'd like to add that "escaping" from old ideas means running forward, into a better future.

But that doesn't happen automatically. In order to come up with ideas that are new, different, and innovative, we need lots of curiosity, strength, and passion. This issue of ELEMENTS presents people who inspire us by summoning up the courage every day to leave the beaten track and, through their work, to literally reach for the stars.

1/2019 **Hydrogen peroxide**