BIOCATALYSIS: MORE BIO IN PRODUCTION NETWORKS

REACTION TECHNOLOGY: GOING MOBILE WITH MICRO

ELEMENTS

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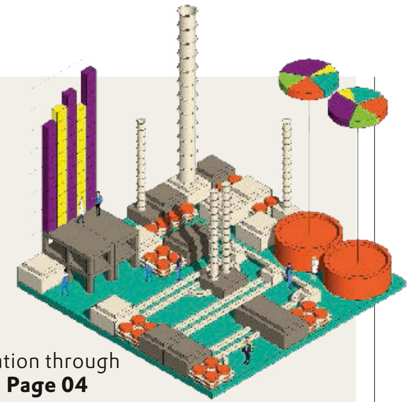
DATA STREAMS: BIG DATA MEANS BIG BUSINESS *

THE INNOVATION MAGAZINE

EVONIK INDUSTRIES



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Cover and back cover: Maximus Chatsky Photography: Dirk Bannert / Evonik, Stefan Wildhirt / Evonik

EDITORIAL

Fundamental

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Undertake more partnerships, communicate openly—according to an innovation study commissioned by VCI, these are the key elements that pave the way to innovation. This is based on the knowledge that innovation is a complex process that runs in parallel, interrelated steps. Above all, optimizing the process also means dealing with the interface between business and science. This is why we seek to work closely with universities, research institutes, and industry partners: to reach the goal faster together. Some examples include our collaboration with Fraunhofer ICT-IMM in Mainz (starting on p. 22) and our latest venture capital investment in Airborne Oil & Gas (p. 30).

Such partnerships also include open dialogue. Thirteen years ago, we launched the *elements* magazine to keep the scientific community, in particular, up to date on our innovation activities and support our dialogue with scientists. The offer was well received, as our reader survey from fall 2014 revealed. The positive results of the survey encouraged us to continue to refine the content and, especially, the look of *elements*.

The central mission of the magazine, the presentation of our innovation projects, has not changed. But we have added a few new features, including the guest commentary, where we invite university researchers to present their views on research trends.

The finished product raises the same sort of question as a new development: Will it persuade the market—or, in this case, the reader? Tell us what you think. Let us know what you especially like or do not like at all. This is the only way we can improve ourselves and the magazine, and have a dialogue with you. For us, that is fundamental.

Feedback
Tell us your opinion of the new *elements*:
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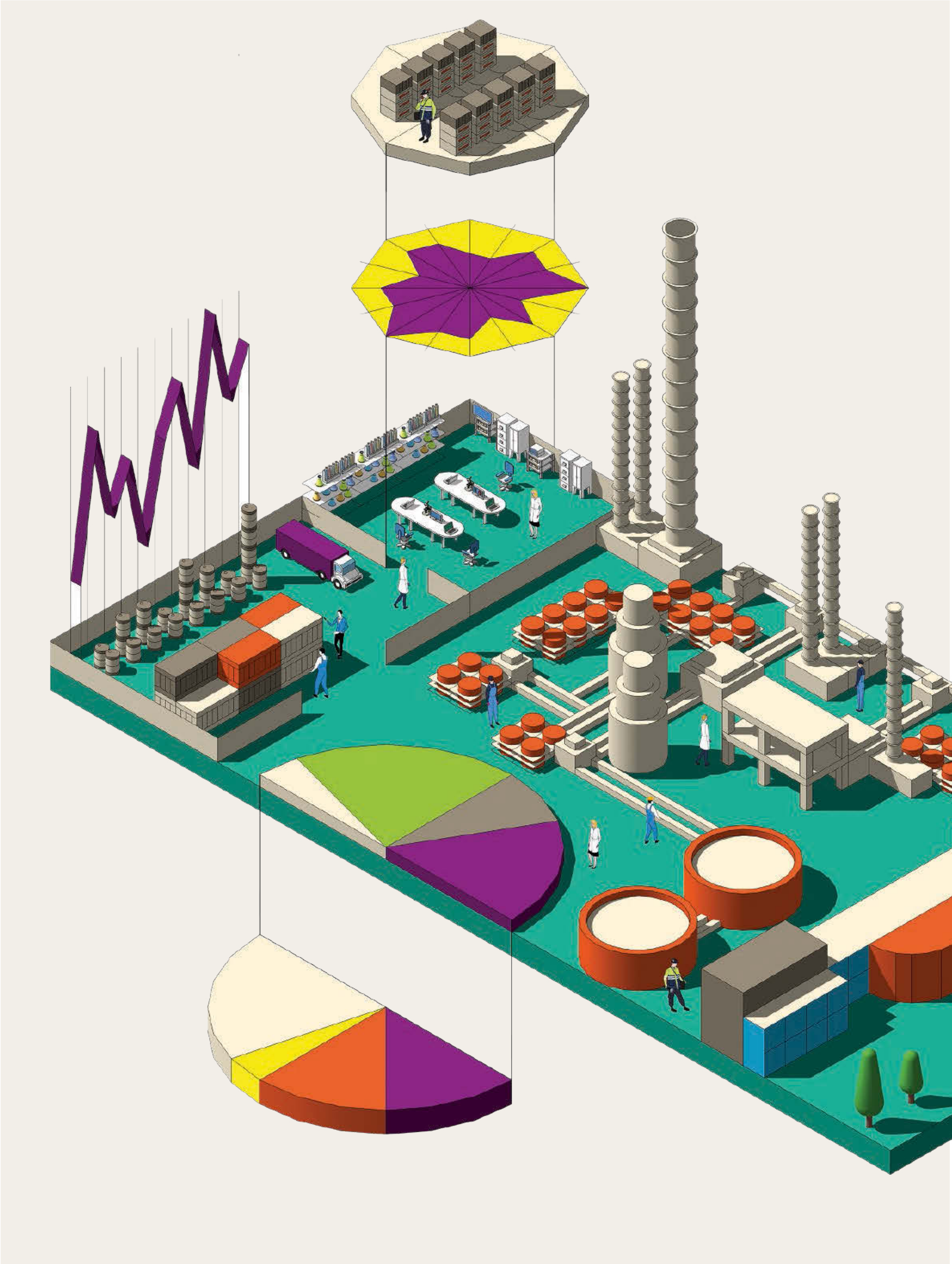
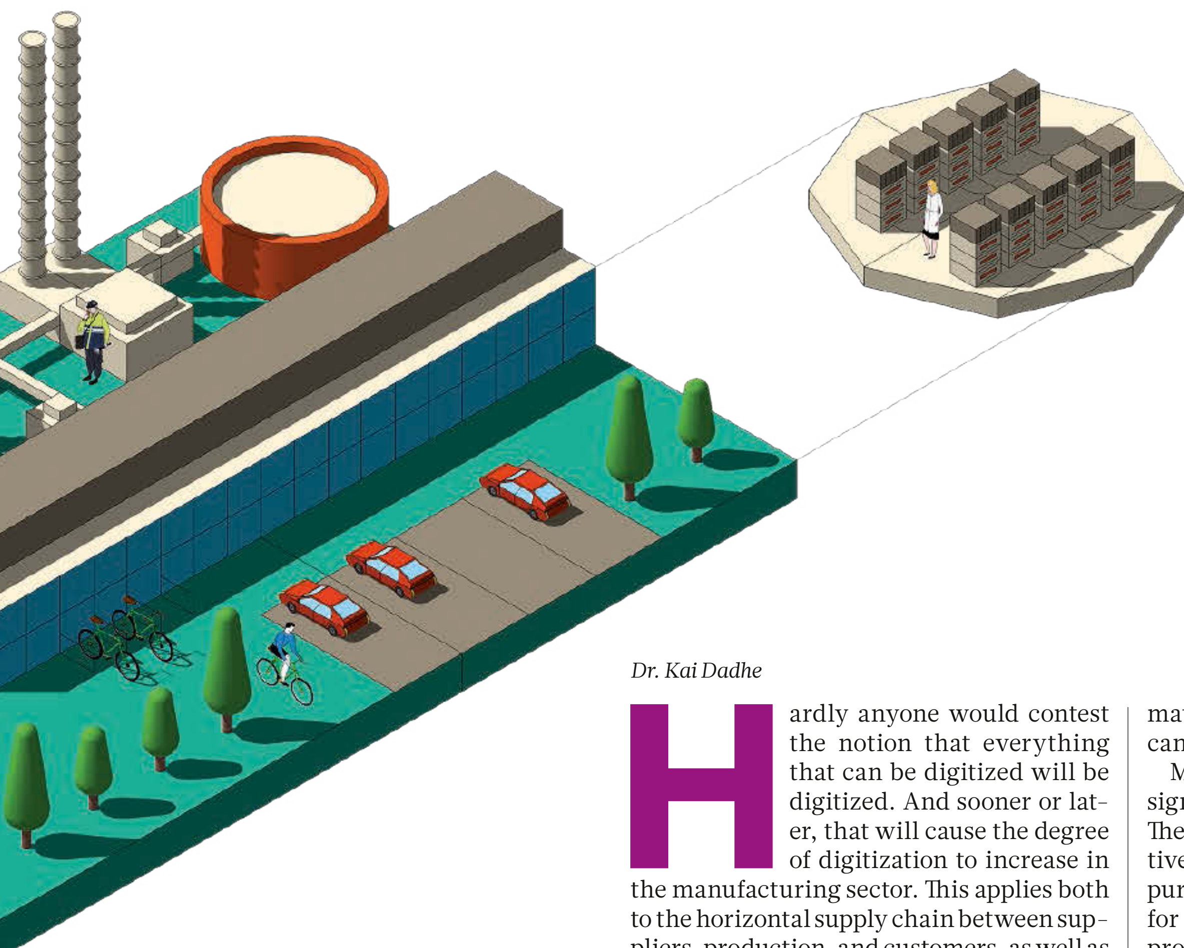


Illustration: Maximus Chatsky

BIG DATA MEANS BIG BUSINESS

Data are the crude oil of the 21st century—but only if they are saved across the board and used productively. An interdisciplinary Evonik team has begun tapping into big data as a new digital process optimization tool.



Plants create a continuously growing data stream. If they are used in the right way, it is possible to manage processes even more efficiently.

Dr. Kai Dadhe

Hardly anyone would contest the notion that everything that can be digitized will be digitized. And sooner or later, that will cause the degree of digitization to increase in the manufacturing sector. This applies both to the horizontal supply chain between suppliers, production, and customers, as well as to the vertical supply chain along the various divisions within a company, from Procurement and Logistics to Sales and Marketing.

Digital intelligence is everywhere today—every component, device, and module yields more data than its predecessor, and company employees and processes generate a steadily growing wealth of digital information. The importance of big data simply cannot be emphasized enough.

Most companies are fully aware of the significance and potential of digitization. The actual challenge here is to make selective use of this wealth of data for the classic purposes of a manufacturing organization: for increasing productivity, optimizing processes, and becoming more efficient. Even though the flow of data is constantly growing in many companies, only a small portion of that data is actually used.

Digitization is likewise in its infancy in the chemical industry. The reason is that developing and improving processes and methods is necessarily slower in the processing industry, where cycle times are far longer than they are in the IT, tele- →

Digital information is a new, rich resource for future process optimization. Nevertheless, experience and expertise will remain as important as ever.

By comparing digital information with expert knowledge, pure data is turned into a profitable tool.

➔ communications, and service sectors. Nevertheless, given changing markets, growing customer expectations, and rising energy and raw materials costs, the chemical industry simply cannot avoid the job of utilizing big data.

Even before the era of fast-paced digitization, chemical companies had always sought to keep their production state-of-the-art. Evonik has been continuously optimizing its methods and processes and adapting them to new demands for a very long time. Cost and energy efficiency are among the most important goals of each individual plant, and innovations form a solid foundation for competitive, sustainable operations.

Yet the tools we have been using for optimizing processes and increasing efficiency are reaching their limits. There are several reasons for this. For one thing, improvements traditionally focus on an individual process step or subprocess. The way these relate to upstream and downstream links in the supply chain is often obscured or only partly taken into consideration.

Classic process optimization is reaching its limits

This is compounded by the fact that although the digital information needed for optimizing processes may, in fact, be available in isolated data silos, linking and networking these silos together remains difficult and fraught with obstacles. Much of the digital information available today is lost because it simply cannot be saved. If nothing else, data usually have to be processed and analyzed by hand—a slow, complex process subject to error. The result? Our view of the overall production process is obscured, preventing us from recognizing optimization potential and capitalizing on improved efficiency.

This list of shortcomings also contains the key to the solution, however: Collecting, filtering, processing, and linking all of the available digital information will give rise to a uniform language for the entire system. Just as only a few puzzle pieces reveal very little about the entire picture, we cannot tap into new opportunities for interdisciplinary, strategic optimization of our supply chains unless we see the puzzle in its entirety.

The future of the chemical industry will not include big business unless we optimize our use of digital intelligence. The words “big data,” however, are often met with reservations or even fear. Does this mean people will become irrelevant? Are computers taking over? What does big data actually mean for production?

Big data couples human and digital intelligence

Big numbers like terabytes, petabytes, and exabytes are not the issue here. Big data does not mean that digital intelligence will one day be making decisions about processes and work sequences, or that each individual employee will be his or her own IT and statistics expert. Digital information instead represents a rich new resource for future process optimization.

It will not be the only resource, however: Experience and expertise will remain as important as ever. In the future, human and digital intelligence will complement each other and be closely intertwined. Comparing digital information with existing process knowledge and expertise will turn raw data into practical, profitable tools. In other words, big data means using modern methods and technologies to carry out all-encompassing, interdisciplinary optimization programs aimed at enhancing value.

What does that mean in actual practice? Big data can produce benefits in all areas of the supply chain—benefits that are especially important in day-to-day production. Today’s modern sensors, flow meters, and motors, for instance, deliver more than just standard data—they also provide continuous reports on performance problems, fluctuating operating parameters, and communication errors.

Collecting, storing, and strategically using all of this information make operations more efficient, allow personnel to identify operating conditions with greater precision, and make error analyses simpler and more accurate. Another advantage is the ability to adapt repairs and maintenance for each individual piece of equipment. Managing and analyzing operating conditions foster reliability and transparency. Digital intelligence also benefits areas outside of production: Big data can be used, for instance, for simulating profit margins as a function of the cost of raw materials. And analyzing databases intelligently allows companies to accelerate patent and market research, estimate the volatility of individual markets more accurately, and react to market changes more quickly.

Turning data into practical tools

Integrating digital intelligence is comparable to a technological evolutionary process in which certain basic prerequisites must be met. The company needs a certain infrastructure, for example, if it is going to make use of all of the available data. What is helpful here is that the large amounts of memory and the enormous computing power that are needed are economically feasible today. All of the necessary tools are already on hand as well, with distributed computing and horizontally scaled databases now routine, and parallel algorithms making modern data organization and communication possible.

This is not just about the tools, however. Visualization is crucially important as well—if you don’t understand your computer, you won’t work with it. In their day-to-day jobs, each and every employee must be able to make intuitive sense out of the information, charts, and diagrams generated from the data and to make the right decisions. Although it is indispensable, this process of translating raw data into everyday language also represents a challenge that we cannot afford to underestimate.

Meeting that challenge requires more than just specific IT tools—above all, it requires an understanding of day-to-day processes. What are the problems that arise with a given process? Where are its weak spots? Where can digital intelligence be applied to improve the situation? The end results are practical, customized tools that do more than just make operations more efficient and reliable—contrary to many ex- ➔

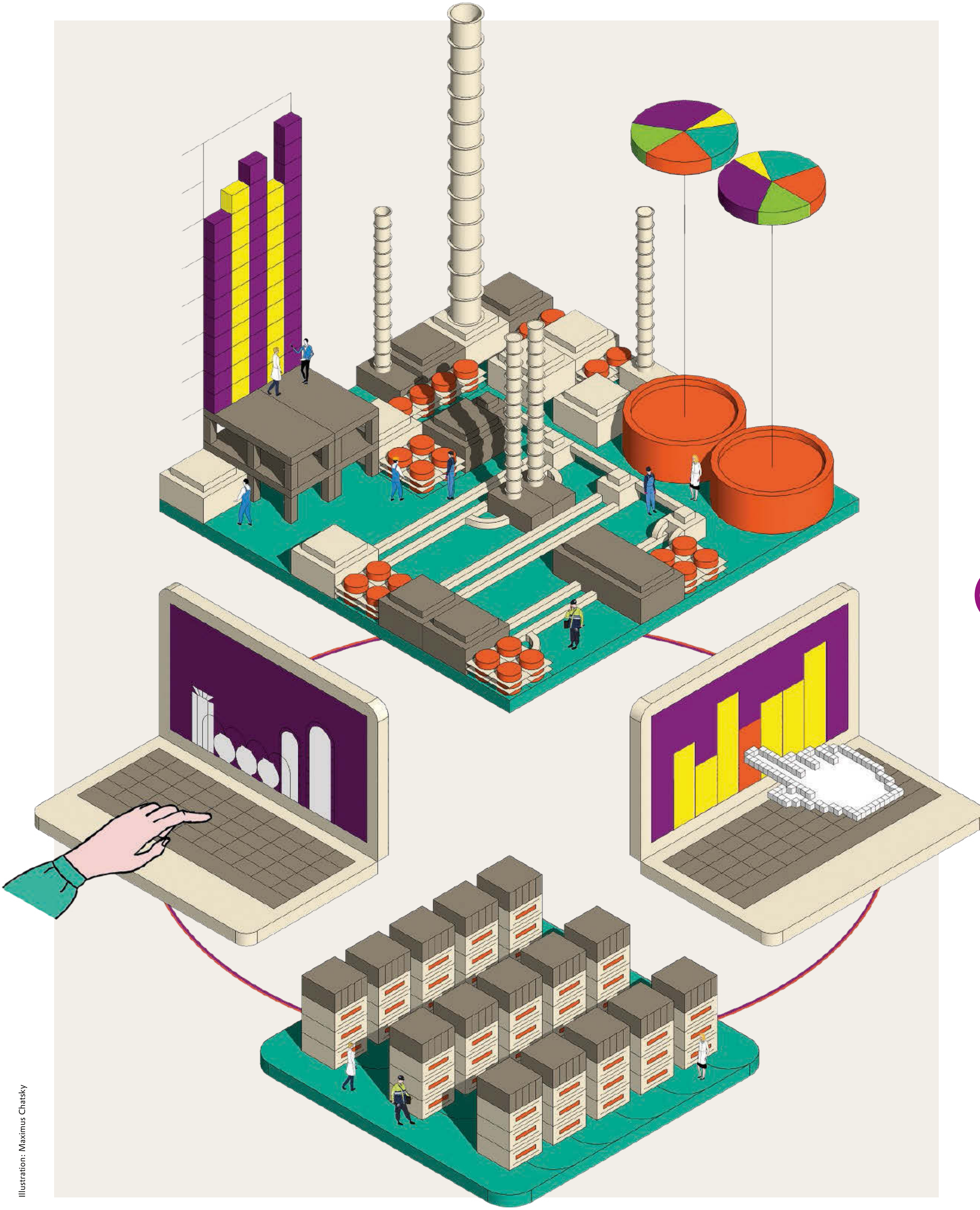
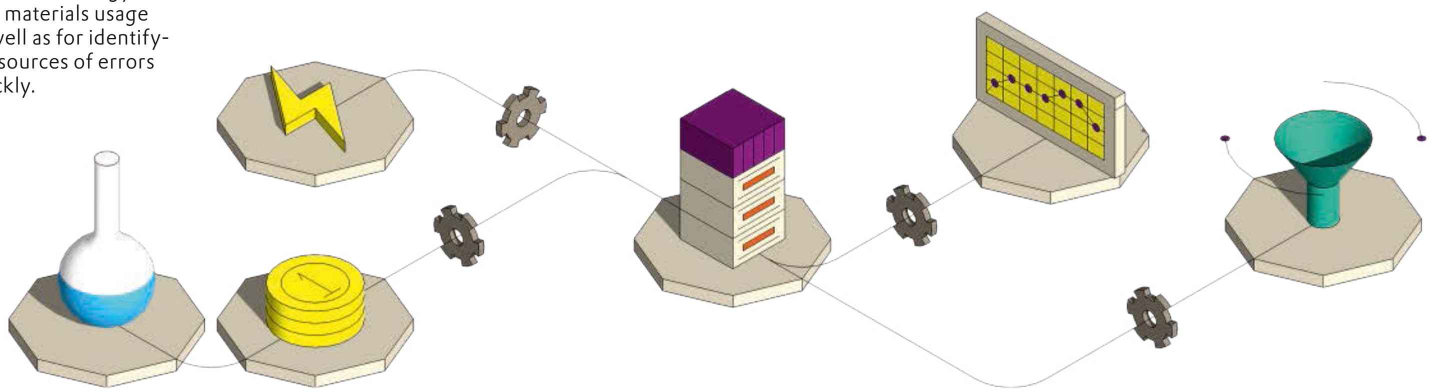


Illustration: Maximus Chatsky

Performance Materials has done away with data silos and combined digital information from different sources. This is the basis for optimizing production processes, maintenance procedures, and energy and raw materials usage as well as for identifying sources of errors quickly.



BIG DATA IN THE REAL WORLD: PROCESS OPTIMIZATION AT THE TOUCH OF A BUTTON

How much energy is my process using right now? Is catalyst activity still at the optimal level? Are all of my machines working smoothly? These are questions that crop up every day in production. Big data should help to provide answers more quickly.

It is not always that easy to know whether a process is already running optimally. Determining the corresponding parameters can be very time-consuming. Traditional processes, after all, are generally based on predefined schedules and a great deal of empirical data. This is why, for instance, equipment maintenance is usually performed in defined cycles, why catalysts are refreshed according to fixed schedules, and why the consumption of energy and raw materials is only monitored at long intervals.

But we can do much more than this if we use all of the digital information available: We can manage and monitor processes the ideal way every time, using all of the digital information available to selectively optimize important parameters. This approach yields snapshots that focus on individual machines and record the flow of energy and electricity at every second along the way. Digital intelligence even delivers forecasts that show how a reaction is going to proceed or indicate the exact moment when equipment or components will need to be repaired or replaced.

Over the past few years, Evonik's Performance Intermediates Business Line has begun studying the advantages of using big data to address specific issues. The business line used process engineering applications to demonstrate how energy consumption can be markedly reduced. Digital data can also provide clear information about the exact point at which a catalyst needs to be replaced and can even provide a basis for calculating the financial losses associated with a momentary loss in selectivity.

These initial steps are now being followed by a tremendous leap: This summer the business line teamed up with the Process Technology & Engineering Business Line (part of Technology & Infrastructure) and Evonik's Global IT & Processes Department to pursue a project aimed at taking a more detailed look at the potential that digital information holds for defined production processes. The project explores how to use big data for optimizing processes from the technical, methodological, and business perspectives, incorporating expertise from throughout the entire company. The objective of the project is twofold: implementing predictive maintenance and addressing concrete process issues.

Underlying the issue of predictive maintenance is the question of whether digital intelligence can be used successfully to create more efficient and flexible maintenance and repair routines for specific machines. Production operations to date have shown these machines to be particularly susceptible to material deposits, which have a negative impact on process efficiency and are associated with increased repair work. By using and analyzing all of the digital measurement data available, the team hopes to explain how the deposits arise in the first place, what process parameters encourage their formation, and how they can be reduced. The objective is to develop suitable maintenance tools that will minimize this negative influencing factor and save money.

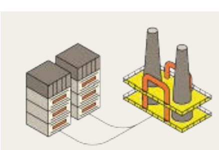
The second subproject focuses on undesirable fluctuations affecting a specific material property in a large-scale technical process—a phenomenon that frequently arises in chemical production. Here the team hopes to use big data to clarify why this parameter varies and which preceding process step is responsible. Could it be the result of fluctuations in the composition of precursors or intermediates? These studies clearly demonstrate that finding errors and sources of error quickly and with certainty means having to look at the entire supply chain.

The pilot project is pursuing multiple objectives. Existing data can be used as a tool for validating or refuting expert hypotheses regarding the sources of error. Employees are learning to identify cause-effect relationships within a complex digital space and to apply that knowledge to real-life production issues. In other words, they are learning to use and to trust data. If the project is successful in its aim of improving efficiency and system availability while ensuring product characteristics, the benefits will extend beyond the directly affected area of the company. Success will instead confirm that the tremendous potential that big data holds for the entire supply chain is more than just theory.

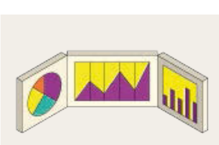
Companies that utilize big data for their own ends are readying themselves for the questions and challenges of the future.

Big data analysis in plant operation

Benefits
Transparency and greater insight, fast solutions to special problems, fast decisions, greater efficiency, and cost optimization.



Prerequisite
Big data analysis is more than IT: The requirements come from operating activities. Methodological and technical conditions must also be in place and the employees must be trained.



Objective
All employees have at hand, at any time of day, all the information they need to act optimally. The data for this is automatically prepared in graphic form so that it can be quickly understood.

➔ pectations, they also frequently simplify processes as well. The Performance Materials Segment has already had some initial experience with a few of these evolutionary steps through its Performance Intermediates Business Line. Various optimization projects related closely to production have opened up data silos, merging the resulting digital information and correlating this information in context. Because the latter is such an important step, the business line developed what is known as a context model. A context model is a modeling blueprint that defines a logical way of merging data from different areas, making the information usable for specific issues. This model (for which a patent application has since been filed) allows us to untangle the Babel-like chaos of data, creating the possibility of querying certain data quickly and easily and developing important process KPIs.

Digital intelligence is becoming a trusted partner

Big data is a completely new challenge for the processing industry, with many questions remaining open: What is an acceptable degree of transparency? Who should have access to which (previously classified) information? Different types of expertise have to be bundled in just the right way—how do we do that?

What is clear about big data is that it changes the way individual parts of the company deal with data, makes digital information more important, incorporates this information in every decision-making process, and blurs the boundaries between disciplines and divisions within the company—it's a challenge for everyone, in other words, and one that requires professional moderation and support.

Based on the initial experience in Performance Intermediates, we already know that employees are extremely interested in using new digital tools for process optimization, and that this opens up the door to ideas and suggestions that were previously impossible. After all, the value of this approach is obvious to everyone: It allows the company to dispense with activities that are of little use and that create little value, freeing up employees to pursue new tasks and more complex issues. It also prompts people to consider their own work from a whole new perspective and adapt it to the challenges that lie ahead.

The ultimate aim is to create an interdisciplinary analytical culture that links process, IT, business, and method expertise into a highly interconnected network. Ideally, if we generate the company's own big data expertise, exploiting digital intelligence for day-to-day business will simply be the obvious course. The world of data is dominated by a fast, dynamic pace. In a certain sense, that also applies to implementation—if you want to have a hand in setting the pace of the digital revolution and help guide its development, you have to start early to make strategic use of big data for your own purposes.

Channeling the flood of data into an ordered flow of information, turning that wealth of data into practical tools, and creating a solid foundation for the changes that need to take place in work and organizational processes—these abilities are simply a matter of being ready for the future. Besides enhancing productivity, processes, and performance, the impact of these competencies outside of the company should not be underestimated: Companies that utilize big data for their own ends prove to be innovative employers, they ensure their technological leadership, and they cement the trust of their suppliers, customers, and partners. Most of all, however, these companies are readying themselves for the questions and challenges of the future. ■

The Expert

Dr. Kai Dadhe heads the Manufacturing Intelligence Group in the Performance Intermediates Business Line, with a focus on process management, process information management, and optimization. The group takes a holistic approach to technical as well as work processes, using modern methods and systems.
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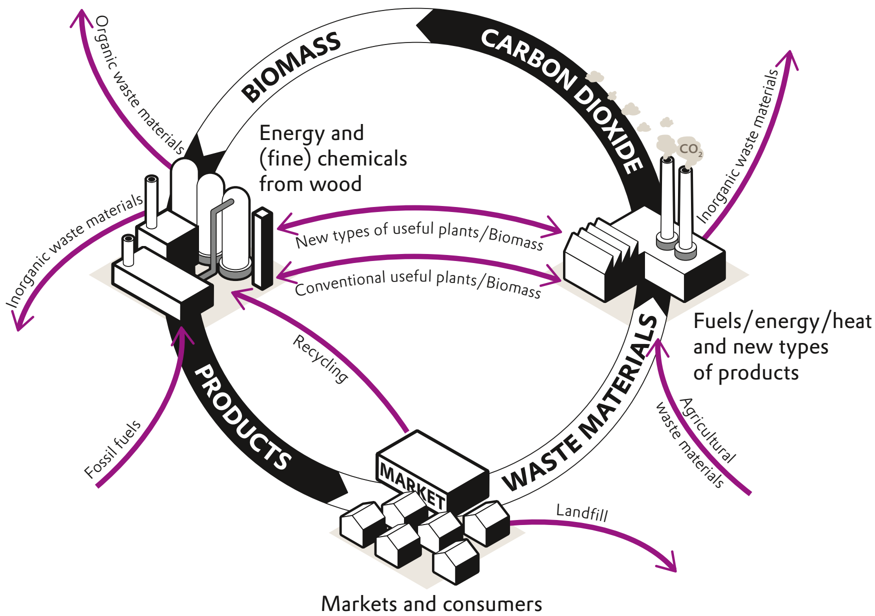
Illustration: Maximus Chatsky Photography: Evonik

With the help of a new enzyme system, Evonik can convert short-chain fatty acids to 1-alkenes. Now experts are working on transferring the enzyme system into living cells—for example *Escherichia coli.*

MORE BIO IN CHEMICAL PRODUCTION NETWORKS

Industry thrives on networks: Carefully devised integrated production sites ensure that production processes benefit from one another. These synergies create efficient value-added chains. The goal of Evonik researchers is to integrate biotechnological processes into this established system as seamlessly as possible. Now they have established the basis for a biocatalytic process that can be used to obtain an important chemical intermediate.



Schematic of a biorefinery that intelligently links chemistry and biology.

Source: Biokatalyse 2021, Clustermagazin, Issue No. 2

Dr. Thomas Haas

Without crude oil, the modern world would come to a halt. But it is not only our mobility and energy supply that need "black gold": The chemical industry also relies on secure sources of oil. Plastics, medicines, coatings, paints, textiles, and much more are all based on this fossil resource. In order to produce this diverse range of products through a variety of process routes, industrial plants need the molecular building blocks of petrochemicals—primarily hydrocarbons of various chain lengths.

On the basis of these raw materials, the chemical industry has built and established highly efficient value-added chains and integrated production networks. What one company generates as a by-product can often be used by another company as a raw material. And the unique thing about chemical production is that specialty chemicals are not produced in isolation from base materials; rather, the two are inseparably linked in production. This allows the realization of valuable synergy effects that ultimately make the integrated production network economical.

Intelligently linking chemistry and biology

Dwindling petroleum resources, climate change, and CO_2 debates, however, mean the chemical industry will be dependent on alternatives from renewable sources in the future. To prepare, Evonik is working on increasing the share of sustainable raw materials in its production processes. Biotechnological processes play a particularly important role in the preparation of biomass. Here, microorganisms such as bacteria, fungi or special enzymes are responsible for the chemical conversion stages. At Evonik, however, it is not just about switching to biotechnological processes to produce established products. The experts have also set themselves the goal of integrating these processes and their intermediate products based on sustainable raw materials into the integrated production networks. Only then will it be possible to harness fossil and biogenic raw material flows and thereby preserve and expand the established, efficient value-added chains of industry, as well as the chemical process expertise developed over many years, along with the existing infrastructure. Whether raw materials, products or processes, only integrated concepts will make industrial sites successful on into the future. Such networks enable us not only to profit from the advantages of biotechnology but to continue to operate existing integrated production sites.

Many industrial products, such as polyethylene and other plastics, are extremely hard to produce on a completely biotechnological basis—intermediates along the way, on the other hand, are not. The Evonik experts track down these molecular interfaces and develop alternative processes based on renewable raw materials.

Some key substances, for example, are 1-alkenes, which are hydrocarbon chains with a terminal carbon-carbon double bond. Evonik uses propene, for instance, as the starting compound for the production of acrylic acid, which is used in the production of superabsorbers and methionine, which plays a role in animal nutrition. Evonik sells 1-butene as a raw material, but it is also used by the Group to manufacture such products as plasticizers.

A team from Evonik's innovation unit Creavis, working in cooperation with scientists from the University of Graz, has →

Figure 1. Focus on sustainability

A main focus of research at Evonik is biotechnologically utilizing third-generation raw materials.

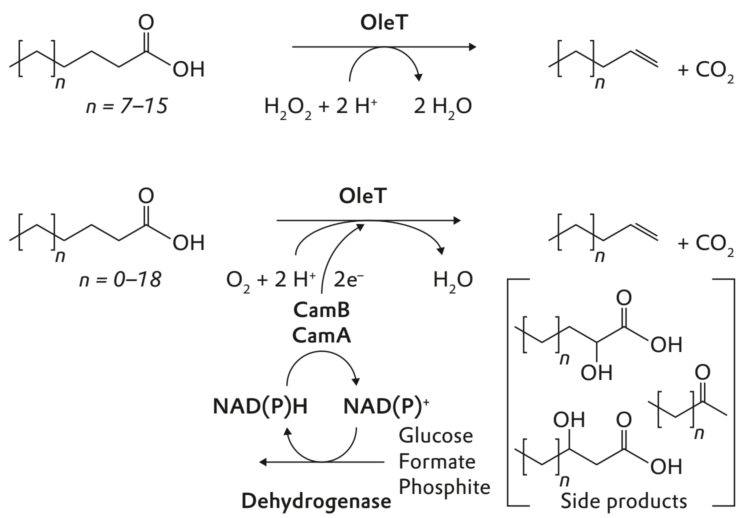
	Raw materials	Biotechnology
First generation	Vegetable oils Wheat Corn Sugar	Direct fermentation
Second generation	Residual biomass from agriculture and forestry	Lignocellulose hydrolysis Integrated fermentation
Third generation	Municipal waste Plant residues Industrial waste gases	Syngas fermentation

No matter what we are dealing with—raw materials, products or processes—only concepts that integrate biotechnology into chemical production will make industrial sites profitable in the future.

Photography: Callista Images/Cultura/Corbis Illustration: C3 Visual Lab

Figure 2. New enzyme system uses atmospheric oxygen

The oxidative decarboxylation of saturated fatty acids to 1-alkenes with the OleT enzyme. By the method shown above, hydrogen peroxide is used to transform long-chained fatty acids (C12 to C20) into 1-alkenes. By the method shown below, the newly developed enzyme system uses oxygen to decarboxylize fatty acids with a chain length of between 4 and 22 C atoms.



➔ now found biotechnological access to 1-alkenes. Their breakthrough is based on a known research method, which they refined.

Short-chained alkane acids, or saturated fatty acids, which occur naturally during anaerobic bacterial processes, served as the starting material for the 1-alkenes. An established enzyme system, the OleT P450 monooxygenase, was used to produce the desired 1-alkenes from the short-chained fatty acids. This enzyme system catalyzes the corresponding chemical reaction—oxidative decarboxylation—extremely efficiently and substrate-specifically. This selectively and quantitatively produces propene or 1-butene.

In addition to the enzyme system, however, the reaction also needs an oxidizing agent. While hydrogen peroxide has been used up to now, it not only results in unwanted secondary reactions but it can also damage the enzyme system. The team of Evonik experts and scientists from the University of Graz has found an ideal alternative: A cascade of two other enzyme systems now ensures that the electrons required for the redox process are no longer absorbed by H_2O_2 but by oxygen in the air.

A promising start: Researchers at Creavis were able to quantitatively synthesize propene as well as 1-butene with OleT in the laboratory.

Next step: Transfer to living cells

To achieve this, the research team had to find an enzyme combination that displayed optimal interaction and compatibility. They met this objective in less than a year, and are now working on transferring the enzyme system to living cells. For later commercial-scale production, which means taking another long path in development and upscaling, this in vivo production offers a number of advantages. Because the starting materials—the short-chain fatty acids—are extremely small molecules, they can easily pass through the membrane of bacteria. The new enzyme system helps the bacteria convert this starting material in their cells into the desired 1-alkenes. Owing to the high volatility of the 1-alkenes, they can be easily extracted from the aqueous solution by creating a slight vacuum.

As a result, the 1-alkenes form a molecular interface and thus enable a biotechnological synthesis route to be linked with the downstream petrochemical process. With the help of Evonik's new enzyme system, butyric acid can now be converted into 1-propene, which is used to produce superabsorbers and the animal feed additive methionine. Valeric acid offers access to 1-butene—and that, in turn, opens up paths to C4 chemistry, which involves compounds based on four carbon atoms.

But biotechnological processes can also be coupled with an integrated production network through another raw material: syngas. Syngas consists of a mixture of carbon monoxide or carbon dioxide and hydrogen. It is produced from municipal or agricultural wastes, as well as industrial waste such as the flue gas from steel production. It has been used in chemical synthesis for decades, as bacteria are able to make larger chemical building blocks from the small gas molecules.

In laboratory experiments, Evonik researchers have been able to get microorganisms to generate pure 2-hydroxyisobutyric acid (2-HIBS for short), the basic component of PLEXIGLAS®. The short-chained fatty acids used here as raw materials are particularly easy to produce biotechnologically from syngas. With the tests involving 2-HIBS, Evonik has opened up another point of access to basic chemicals using syngas.

To intelligently connect biology and chemistry, Evonik is continuing its research into this "third generation" of biotechnology. The goal of this third generation is not only to make syngas from sugar or vegetable waste and use it as a raw material but also to make syngas from other types of waste materials, such as municipal waste and industrial waste gases.

The approach will allow industry to become less dependent on both fossil raw materials and several renewables, because all efforts to establish biotechnological routes and bring them to market maturity are linked to the price of oil. "Black gold" remains the main raw material flowing through the veins of industrial operations. This is why it is even more important to retain the integrated production networks and place them on a broader foundation—in other words, enable the use of black and green raw material sources, depending on economic conditions and the supply situation. ■

The Expert

Dr. Thomas Haas heads the Science & Technology unit at Creavis, which combines the technological expertise of the strategic innovation unit in industrial biotechnology, chemistry, physics, and engineering.

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[2] M.A Rude, T.S. Baron, S. Brubaker, M. Alibhai, S.B. Del Cardayre, A. Schirmer, Appl. Environ. Microbiol. 2011, 77, 1718-1727

Guest commentary

Biocatalysis meets petrochemistry

Prof. Harald Gröger has held a Chair of Organic Chemistry at Bielefeld University since 2011.
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Prof. Harald Gröger

Biocatalytic processes, which in a more narrow sense include the conversion of chemicals in just a few defined steps using isolated enzymes or microorganisms containing such enzymes, are already widely used in industrial chemical production. In particular, biocatalysis has already become firmly established in the fields of fine chemistry and pharmaceutical active ingredients.

Interestingly enough, many of the starting compounds for these products are petrochemistry-based chemicals that are then further "refined" in biocatalytic production processes. This underscores the enormous synthetic potential of enzymes as "natural catalysts," even for reactions with non-natural molecules. In the industrial segments of pharmaceutical and fine chemical products, with their complex target structures that require numerous individual steps to build, one criteria for the success of biocatalysis is the high selectivity of the enzymes.

In contrast, the expansion of the range of applications in biocatalysis to basic, bulk, and broad areas of specialty chemicals has been viewed up to now as a largely unmet challenge. These starting compounds, which are also typically based on petrochemistry, may be structurally simpler and significantly less expensive, but they are required in considerably higher production tonnages and tend to have a significantly lower price per kilogram. A suitable catalyst for this product class should display high activities and space-time yields, as well as long dwell times,

"As biocatalysts, enzymes have an enormous synthesis potential, even for reactions with non-natural molecules."

along with high stability. Until recently, hardly any production processes that meet these technical requirements could be developed with the enzymes available.

One of the exceptions, which also illustrates the potential of biocatalysis for the field of basic and bulk chemistry, is the enzymatic production of acrylamide on the scale of several tens of thousands of metric tons. Because of the striking developments in molecular biology, with the construction of tailor-made enzymes and highly efficient microorganisms as whole-cell catalysts, biocatalytic production processes may play a more important role in this area of industrial chemistry in the future. Coupled with advanced approaches in process engineering, it should therefore also be possible to transfer more and more of the advantages of biocatalysis to the field of petroleum-based bulk, basic, and specialty chemicals in the future. For example, a series of processes recently developed in the field of oxidation chemistry, some of which have already been tested on the pilot scale, has provided impressive proof of this great synthetic potential of biocatalysis.

Photography: Dieter Debo, Frank Preuss/Evonik Illustration: C3 Visual Lab

ACETONE FROM WASTE GAS

The CO_2-based Acetone Fermentation (COOBAF) project has shown that industrial waste gases containing carbon dioxide can be valuable raw materials for the biotechnological production of acetone.

Dr. Marzena Gerdom, Dr. Jörg-Joachim Nitz

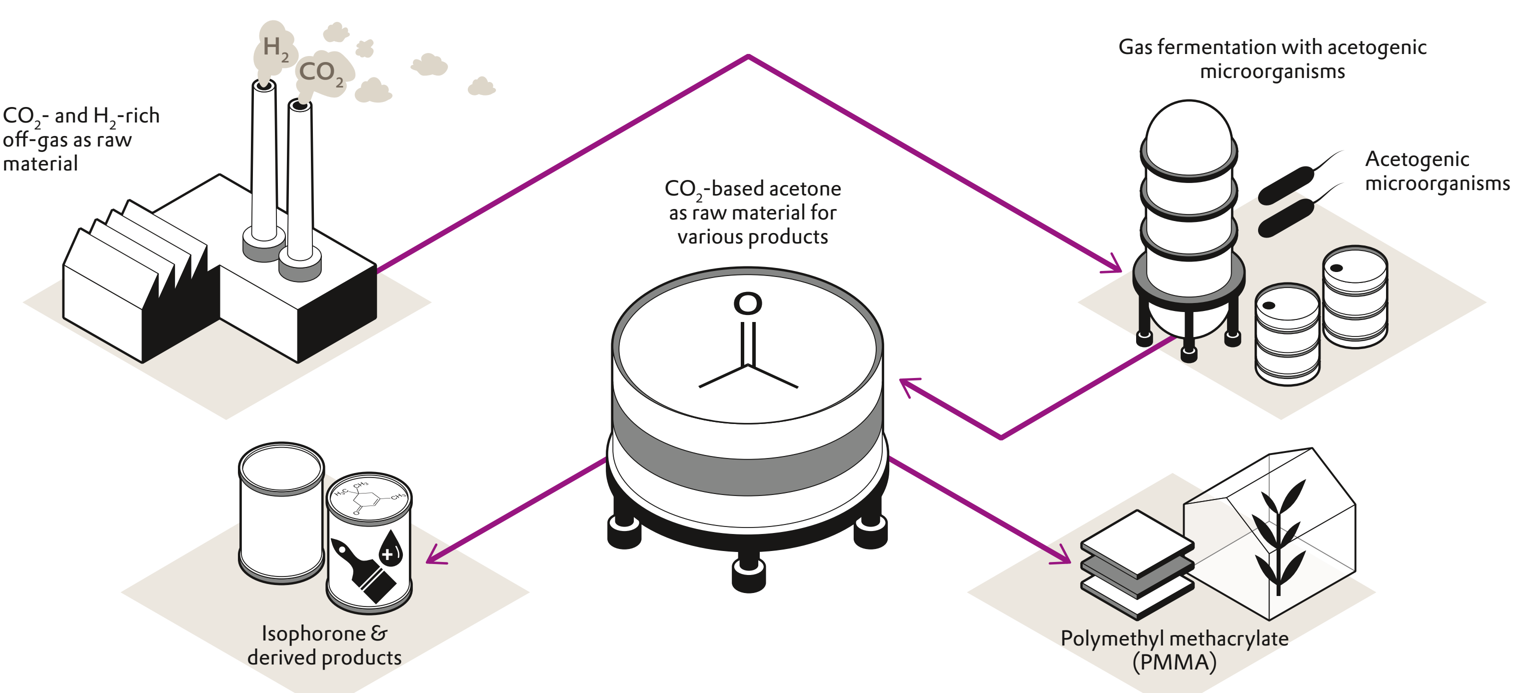
According to a widespread belief, carbon dioxide is a problematic greenhouse gas. However, as a waste product of numerous combustion processes, carbon dioxide actually has potential for beneficial use. Researchers at Evonik were able to demonstrate that carbon dioxide is a useful raw material for the production of basic chemicals. Using biotechnological methods, carbon dioxide can serve as the sole carbon source for the climate-friendly and cost-effective production of acetone.

Within the scope of the VALERY project (see *elements* 49), Evonik researchers had successfully cooperated with academic partners to develop a synthetic pathway for valeraldehyde that uses carbon dioxide as a source material. In the recently completed COOBAF project, Evonik and its academic research partners were able to come up with feasible proof that industrial waste gases can be turned into products such as acetone **(Fig. 1)**.

Problematic interdependencies

Some six million metric tons of acetone are sold annually in the global market. It is produced almost exclusively with the Hock Process of phenol synthesis, in which benzene and propene react with oxygen in a radical reaction to ultimately become the

Figure 1. The idea behind COOBAF
Acetogenic microorganisms convert waste gas streams into acetone, which is then used as a raw material for isophorone or PMMA.



coproducts phenol and acetone. This process has a number of disadvantages: On one hand, it is based on petrochemical raw materials, which makes it dependent on their availability and the price of petroleum. Furthermore, since the production of acetone is tied to the production of phenol, decreased demand for phenol can easily result in a reduced acetone supply as well.

Evonik does not produce acetone, but some of its business lines need this colorless solvent, for example for the production of isophorone and its derivatives, but also for polymethyl methacrylate (PLEXIGLAS®). This led to the idea to search for an innovative, biological synthetic pathway. The objective was to generate acetone and water from carbon dioxide and hydrogen—typical components of industrial waste gases—with the help of microorganisms **(Fig. 2)**.

The production was to entirely rely on existing byproducts and not use any raw materials in order to remove several tons of carbon dioxide from the atmosphere. In the past, the bulk of industrial waste gases with this composition had at most been used for thermal applications. In other circumstances, they had simply been burned off at the exit point of smoke stacks, returning the carbon dioxide to the atmosphere.

In cooperation with academic partners at Ulm University (working group of Prof. Dr. Peter Dürre) and Rostock University (working group of Prof. Dr. Hubert Bahl), Evonik therefore initiated the COOBAF project in late 2011 with funding from the Federal Ministry for Education and Research (promotional reference 01RC1105A). While the Evonik team concentrated on the development of the fermentation and downstream process, the academic partners focused on microbiology and gene technology aspects. The first challenge was to identify microorganisms that were able to use carbon dioxide in their metabolism—not a widespread ability outside of the plant kingdom.

Demanding requirements for microorganisms

Scientists actually made use of bacteria for acetone production as early as 1916. This development was pioneered by Chaim Weizmann, who would later become the first President of Israel. The bacterium *Clostridium acetobutylicum* was used until the mid-20th century for the industrial-scale production of acetone, ethanol and butanol in the so-called ABE fermentation process that relied on a carbohydrate substrate. However, ultimately the acetone yield of this process was no longer sufficient to compete with Hock synthesis.

In contrast to ABE fermentation, the COOBAF project did not use carbohydrates. Instead, it used carbon dioxide as the source of carbon. For that purpose, the researchers tested a number of lesser-known acetogenic bacteria, which may even have played a role in generating the first life on earth.

These microorganisms had to meet several requirements to be considered for further development. They had to be able to quickly convert CO_2 to products in large quantities, using the Wood-Ljungdahl pathway **(Fig. 3)**. They also had to be long-lived and sufficiently resistant for economic fermentation, and needed the ability to grow in the presence of carbon monoxide, a common component of industrial waste gases that is toxic to many microorganisms.

Using gene transfer, the team trained the most promising strains to metabolize the naturally formed acetyl-CoA into acetone. The project ultimately reached a major milestone in mid-2012, when the researchers came up with proof that their bacteria had turned carbon dioxide into acetone. With molecular biologists at Ulm and Rostock universities now focusing on the further ➔

Figure 2. Comparison of industrial and biotechnological production of acetone

The biotechnological method of acetone production does not involve phenol.

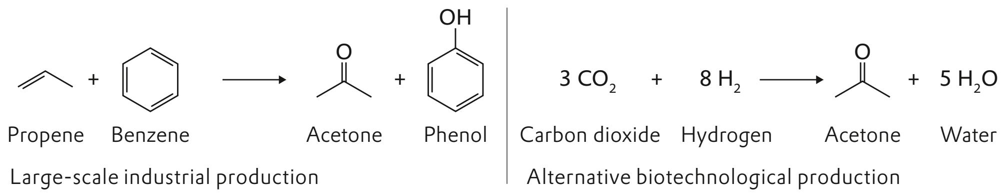


Figure 3. Pathway of acetogenic bacteria

Genes for the production of acetone were transferred to bacteria that had the ability to convert CO_2 to acetyl-CoA via the Wood-Ljungdahl pathway.

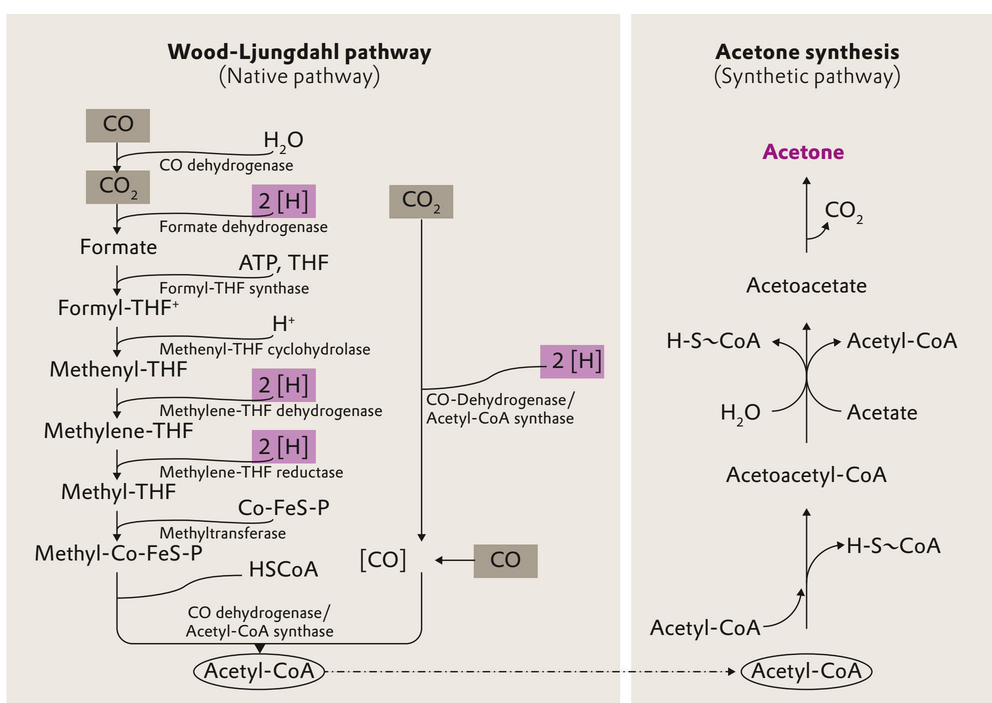
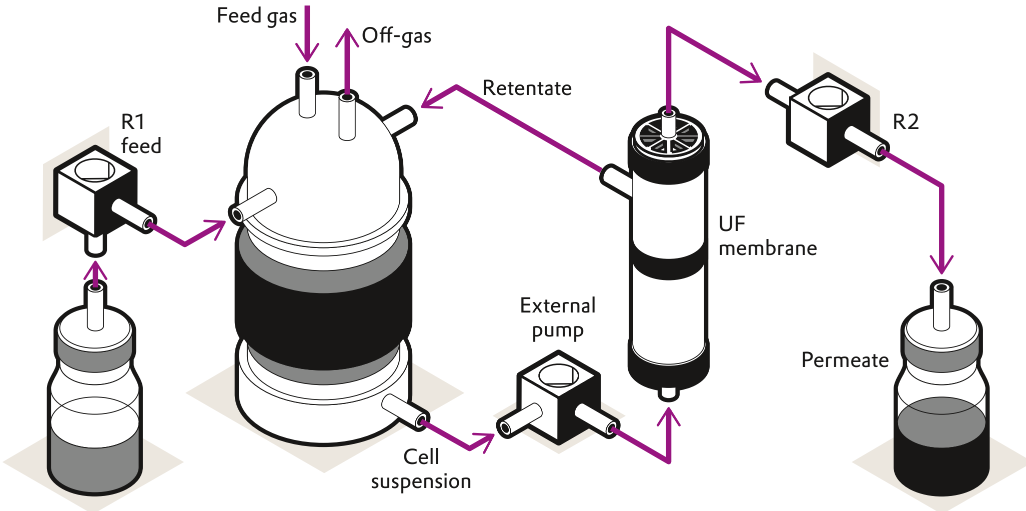


Illustration: C3 Visual Lab

Figure 4. Continuous process management

Growth of the bacteria can be increased significantly by continuously removing the byproducts from the fermenter.



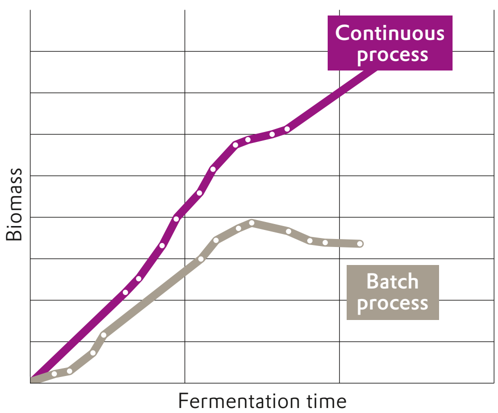
➔ optimization of the organisms' genetic makeup, Evonik began to develop the fermentation process. The first challenge was to find a laboratory that had the necessary safety equipment for working with hydrogen and carbon monoxide. The Reaction Technology laboratory in Marl fit the bill, particularly since the Marl Chemical Park also offered convenient access to suitable industrial waste gases. The researchers restructured the laboratory to meet the requirements for biological work at the S1 level.

The Evonik team came up with a fermentation process at the two-liter scale. To accommodate higher pressure levels, the associated laboratory fermenter was made of steel instead of the glass variety customarily used in laboratory facilities. Hydrogen and carbon monoxide are only moderately water-soluble at atmospheric pressure, but had to easily reach the bacteria in the bioreactor's nutrient solution as a substrate.

The researchers also examined gases with different compositions, which revealed that the gases typically emitted by steel mills offered favorable conditions for acetone production. The cell supply was further improved with alternative gassing concepts.

Figure 5. Faster growth

A comparison of growth rates for continuous and batch process management.



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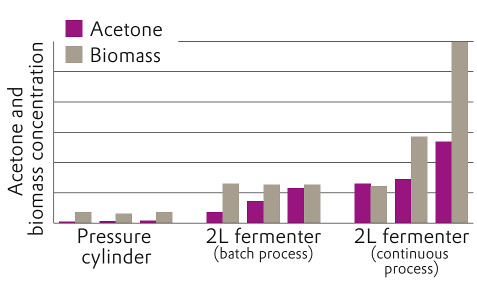
Typical waste gas from steelworks is especially suited for the production of acetone using acetogenic bacteria.

Continuous fermentation process

Then the team encountered a sudden problem. The bacteria kept stopping their growth at a certain point in the fermentation. Was an important nutrient missing? Did the process generate a product that inhibited growth? It was ultimately discovered that the problem was caused by the interaction of multiple factors, primarily led by the concentration of the byproduct acetic acid. The batch process therefore had to be converted to a continuous process, which included the consistent removal of this byproduct. At the same time, a part of the cell output had to be returned to the reactor because the microorganism growth was relatively slow **(Figs**

Figure 6. Higher productivity

Process development resulted in a continuous increase in the volumes of acetone and biomass.



S1 laboratory with anaerobic workstation (left) and two-liter fermenter.

Photography: Evonik Illustration: C3 Visual Lab

Figure 7. The downstream process

The absorption-based process delivers high yields and purity.

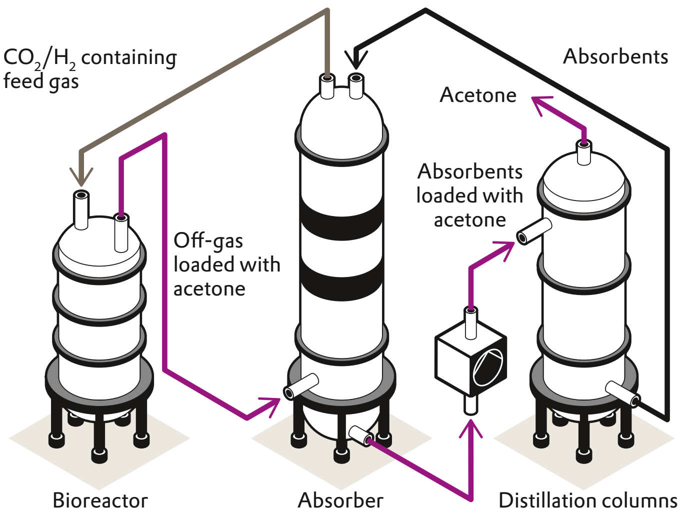
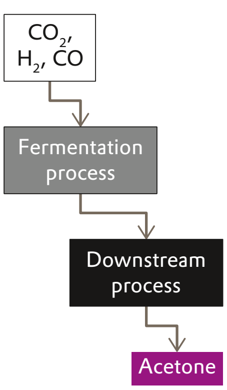


Figure 8a. LCA

Production phases for which an LCA was conducted.



4,5). Furthermore, the researchers recognized that the addition of certain cofactors to the nutrient medium resulted in significant yield increases. Thus, magnesium selectively increased the acetone yield, while other trace elements boosted the entire productivity non-specifically. Over the course of the project, the process development led to the continuous increase of fermentation acetone yields **(Fig. 6).** Ultimately, the initial process productivity was increased by several orders of magnitude.

The next step was to address the downstream process. The low vapor pressure of acetone helped the Evonik team find an option for stripping the acetone from the fermentation broth. In this context, the mix of hydrogen and carbon dioxide proved to be suitable not only as a feed gas but also as a strip gas. The acetone could be removed at the speed required by process management. Was it better to remove the acetone from the strip gas by condensation or absorption? It turned out that absorption was the method of choice due to the higher yields **(Fig. 7).**

The researchers identified a functional absorbent in various simulations. It is able to take up large quantities of acetone and is consumed only in small volumes. What is more, the resulting acetone has a purity level of around 95 percent, which could easily be increased to over 99 percent. Since the only major contaminant is water, which does not interfere with isophorone processes, the next milestone had been reached, and the project was almost done.

The last step involved life cycle assessment **(Figs. 8a, b).** Compared to the mere combustion of industrial waste gases, the CO_2 balance of the biotechnological acetone production was much more favorable (Scenario 1). Even if the researchers took into account that the hydrogen component of the waste gas could be used thermally (Scenario 2), which meant that the lost heat source would have to be compensated with natural gas, the biological process was more favorable than the currently used chemical benchmark process at the large industrial scale.

By the time the project was completed in late 2014, the initial process productivity had been increased by more than three orders of magnitude. Another factor of 20 would now be required for the new procedure to economically compete with petrochemicals at the industrial scale. The project team sees potential for such increases both on the genetic and the process technology sides. All in all, it has been possible to show that it is feasible in principle to produce sought-after valuable materials from the "waste product" CO_2 via biotechnological methods, and to do so in a way that is cost-effective and competitive. ■

The experts

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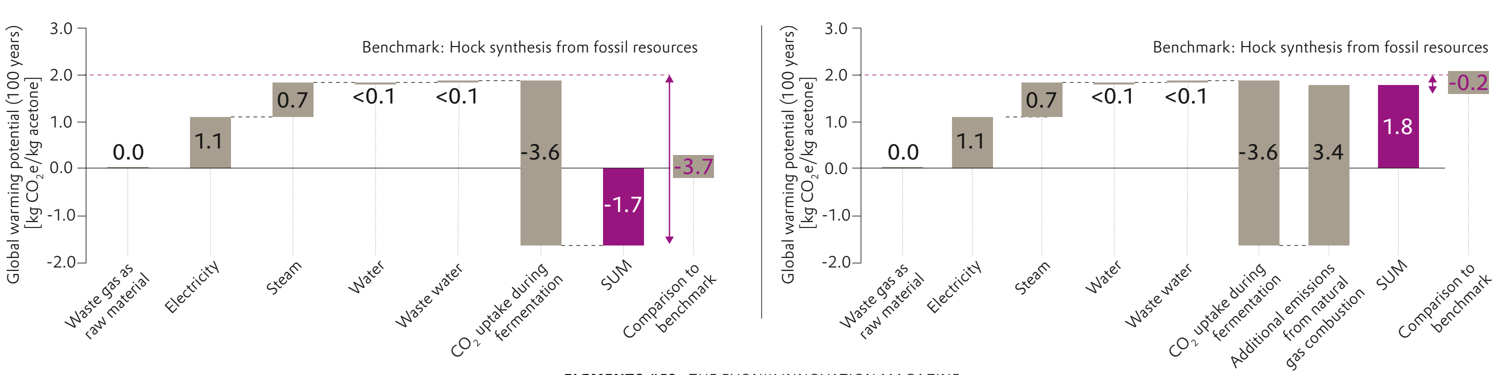
Figure 8b. Results of the Life Cycle Assessment (LCA)

Depending on the scenario, the LCA of the biotechnological acetone production showed a different reduction of the contribution to the greenhouse effect compared to the conventional chemical process. Left: Scenario 1, no substitution of the thermal energy of the feed gas. Right: Scenario 2, substitution of the thermal energy with natural gas.



Photography: Vincent Fournier/Gallery Stock

ROBOTS IN DAILY LIFE

Gentle Machines

Sometimes the future is closer than you think: Robots, for example, already have their own population statistics. In 2013, the International Federation of Robotics counted one and a half million in industry alone. Today, most of the tasks these machines perform are easy to standardize. But more and more, robots are also taking on more complex and even social activities. In Japan, for example, friendly robots sit at the reception desks of hotels or entertain seniors by singing and dancing.

Robotics experts are convinced that the use of robots in places other than the factory floor will continue to grow. But more widespread use also increases the risk of accidents occurring in the interactions between humans and robots, as robots are not (yet) intelligent enough to be able to properly assess all dangerous situations.

Soft robotics offers the opportunity to minimize this risk. Soft robots are made of flexible, deformable materials that give way in a potential accident and can therefore prevent injuries. A few questions need to be answered before they can be used more widely, however: What are the requirements for the different types of materials? What are the best tools and methods for serial production of soft robots? As part of its Digital Futures focus theme, the Corporate Foresight Team is working on the answers to these questions and determining the growth opportunities for Evonik in the field of soft robotics. However, there is one problem that cannot be solved with new materials: Social Interaction with robots is still poorly accepted in everyday situations.

More information
Harvard Biodesign Lab on Soft Robotics:
bit.ly/1X2CzTg

University of Chicago, Jaeger Lab, on Soft Robotics:
bit.ly/1X2Epn5

GOING MOBILE WITH MICRO

In the future, small-scale chemistry could make big headlines. Production plants with a compact design work flexibly, economically, and with precision. EU projects have proven that the EcoTrainer from Evonik with its high-tech infrastructure is ideal for tapping the potential of microreaction technology for sophisticated chemical syntheses.

Dr. Jürgen Lang, Dr. Patrick Löb, Prof. Michael Maskos

Plant designers and engineers in the chemical industry are used to thinking on a huge scale. Some world-scale plants and integrated production sites are larger than a small city, and chemical plants can completely overshadow a church steeple. In the future as well, multi-million-dollar investments will continue to make sense for the production of bulk chemicals for stable or growing markets or multi-use intermediates.

In many cases, however, “big” alone is no longer the key to lucrative processes. Times have changed: Customer expectations grow or change quickly, resources are increasingly scarce, and many markets are more volatile than before. All of that increases the investment risk for new plants. The pace of innovation and the pressure to innovate are also increasing. New or improved substances must be available within a few years, consequently requiring a shortened time to market. Last but not least, the mobility of a production facility has become increasingly important. Chemical syntheses can be lucrative in regions or at sites where there is no room or infrastructure to locate conventional plants or where equipment is needed only for some time.

Building small means keeping risks small

Microreaction technology, combined with a standardized plant infrastructure in a container format, provides an answer to these trends. The idea behind it is simple: If you build small, you also keep your risks small. With small-scale chemistry, it is possible to react quickly to changes in consumer demands and the desires of customers, more effectively predict and influence costs, and minimize land usage and resource consumption. Above all, upscaling from the laboratory to commercial production is faster and more direct. Small-scale chemistry eliminates intermediate steps and interfaces, and process parameters can be transferred directly from the laboratory to production.

Small also means mobile. Because of the REACH legislation, the transportation of reactive substances is subject to strict requirements. If necessary, production can take place on site. A facility measuring just a few square meters can be easily transported to the customer’s site and installed there. Furthermore, milli- and microtechnology have significant advantages for the chemical process itself: Reactions are easier to control, processes become more precise, and systems that are hard to manage become manageable.

For Evonik, microreaction technology is an extremely attractive field of activity. A great deal of the added value of the Group is in fine and specialty chemicals—in other words, substances that the market needs in relatively small quantities but that are decisive for the proper functioning or quality of products. At the same time, requirements for the quality, performance and reproducibility of the substances are exceptionally high.

Currently there are only a few chemical companies and research institutes in Germany that have vigorously addressed the issue of small-scale production. Evonik and Fraunhofer ICT-IMM, the former Institut für Mikrotechnik Mainz, joined forces many years ago to become pioneers in this field. In several publicly funded projects, Evonik’s Process Technology & Engi- ➔

The POLYCAT plant in the EcoTrainer is suitable for producing advanced pharmaceutical ingredients under GMP conditions.

A chemical plant on a hook: the EcoTrainer for POLYCAT at the time of delivery to Fraunhofer ICT-IMM in Mainz in November 2013.

Photography: Fraunhofer ICT-IMM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Hans-Joachim Kost from Fraunhofer ICT-IMM during the final assembly of a modular microreactor in a rack for the process chamber of the EcoTrainer.

➔ neering unit and the experts from Mainz have collaborated with other partners to research the ways small-scale plants can be designed, built, and used for specific production processes.

Several factors work in favor of this research. A good range of small-scale versions of many components such as mixers, heat exchangers, and two-phase reactors is now available. Additionally, the knowledge of flow patterns, heat exchange, and mass transfer processes in small pipings and tiny components has grown. The rapid progress in automation and digitalization also promotes the construction and operation of highly integrated small-scale plants.

Microreaction technology does not, however, simply mean a miniaturization of conventional components. On the contrary, to realize a complete process in the space of just a few square meters, you have to take an entirely new approach. Whereas a voluminous tank serves its purpose in a large-scale plant, small-scale chemistry requires a reaction chamber with a completely new design and function. Heat exchangers, mixers, and other necessary components are built and arranged in such a way that they take up little space, and yet are reliable and easy to maintain. Catch basins, locks, and electrical equipment must be integrated, as well as process control technology, air conditioning and exhaust systems, fire-extinguishing devices, emergency doors, and sufficient storage space for raw materials.

But how small is small? As Evonik has shown, a full-fledged chemical production facility needs no more space than a comparable 40-foot overseas container. The production infrastructure Evonik has developed over the last few years measures just three by three by twelve meters. The processing chamber for the integration of the actual production plant takes up about half of the entire area. This is enough room to address the needs of typical production capacities of as much as 500 metric tons per year.

In the past few years, EcoTrainers such as this one have been used in several EU projects to determine their suitability in practice. As part of the CoPIRIDE project, the cubicle was equipped with a universal supply system for water, process gases, electricity, heat, and electronic data. This ensured a basic configuration that can be used for integrating a variety of production facilities.

The processing chamber in the EcoTrainer: Above, still empty; below, filled with a modular facility for manufacturing an API.

APIs are also suitable for containers

The EcoTrainer was also a central component of the EU POLYCAT project, on which a total of 19 companies, universities, and research institutes collaborated from 2011 to 2014. The objective of POLYCAT was to develop innovative and sustainable synthetic pathways and production concepts for fine chemicals and the pharmaceuticals industry. It aimed to reach this by means of innovative nanoscale, polymer-supported catalyst systems, continuous processing approaches, and a modular, small-scale plant.

Big enough: The reactor from the POLYCAT project.

For POLYCAT, the EcoTrainer concept was developed for the first time to meet the requirements of the Good Manufacturing Practice (GMP) regulations for syntheses of active pharmaceutical ingredients (APIs). The project partners selected the production process for an API as their model synthesis.

For the participating pharmaceutical company, it was important that the synthesis of this active ingredient be transferable as fast as possible from the laboratory to the pilot scale. At the beginning of the project, there was neither a suitable catalyst nor a process for the critical step in this synthesis, the selective hydrogenation of a nitro group in a heterogeneously catalyzed gas-liquid reaction.

Various alternatives were analyzed in the search for the best process. The catalyst, solvent, reaction temperature, and sequence of processing steps, among other parameters, were varied. A mini fixed-bed reactor with an upstream dispersion unit yielded the most efficient results.

The reactor consists of an approximately one-centimeter-thick capillary tube loaded with catalyst through which hydrogen and the dissolved reaction partner flow. One particularly selective catalyst system was a substrate of hyperbranched polystyrene, which had pores and tubules in which the nanoscale active palladium catalyst is deposited. In this case, the polymer simultaneously provided protection and served as substrate and dispersing agent.

Process costs decline significantly

All told, the project coordinated by Fraunhofer ICT-IMM addressed, solved, and integrated a broad array of scientific problems. The desired product was ultimately produced by successfully using the catalysts and reactors developed in the project in the EcoTrainer. For the first time, the EcoTrainer was equipped and used as a multipurpose plant. Both the EcoTrainer concept and the process design proved to be viable and economical. Optimization potential was found primarily in downstream processing.

The cost accounting for the model reaction showed that, thanks to the continuous processing approach alone, overall production costs were 23 percent lower than with a comparable discontinuous batch-mode process. Converting the work-up of the reaction solution to a continuous operation would further reduce both the production costs and the process time.

The POLYCAT project provided valuable results for the entire industry, as highly selective hydrogenation reactions play an important role in a large proportion of the manufacturing processes for pharmaceutical active ingredients and specialty chemicals.

Microtechnology is not the solution for all processes, however. An estimated 10 to 20 percent of chemical syntheses are suitable for small-scale production. These include primarily highly exothermic reactions such as the synthesis of ionic liquids, which normally generate a significant amount of undesired by-products. They also include mixing-sensitive processes where, for example, the final product quality is determined by how fast and thoroughly the reaction partners come in contact with each other. Anionic polymerization of styrene, for example, can be run continuously in a small reactor at room temperature, and is therefore far less complicated. Ozonolysis, epoxidation, fluorination, and sulfonation reactions can also benefit from miniaturization.

High added value in a tiny space

POLYCAT has shown that through the use of a compact high-performance infrastructure a sustainable chemical production process with high added value can be located in an extremely small space. Consequently, Evonik and IMM plan to continue their research and work in this field. In August the two partners concluded a license agreement on the use of the container technology.

The partners' goals and expectations complement each other perfectly. As a global player, Evonik spots market trends and potential for new products and can identify future applications for the EcoTrainer at an early stage. Fraunhofer ICT-IMM brings in its many years of experience in microreaction engineering and development services, so it can custom-design small-scale processes quickly and precisely for specific customer requirements. An interesting side effect in this context is that cost-effective small-scale chemistry can reduce the barrier to entry into container production for small and medium-sized producers, and thereby expand their customer base.

Despite the successes so far, microreaction technology still faces challenges when it comes to producing chemicals. Syntheses are a result of complex interrelationships and are a component of long value-added chains, so it is not enough to make the reactor and the adjacent equipment smaller—it is also important to modify the entire range of peripheral equipment. This concerns, for example, the product reprocessing through filtration, precipitation or gas separation, which is often extremely expensive and time-consuming.

The automation and digitization of processes is even more important. Digital intelligence is essential for making container syntheses economical and precise. For example, initial synthesis steps and substance analyses can already be automated in the laboratory phase. For production, current automation systems can be used for developing process control systems for chemical microprocesses.

Experts at microprocess technology

The former Institut für Mikrotechnik Mainz GmbH (IMM) was integrated into the Fraunhofer Society in 2014, with the goal of becoming an autonomous Fraunhofer Institute by 2018. Until then, the Fraunhofer Institute for Chemical Technology (ICT) will provide support for it on a partnership basis.

In addition to continuous chemical process technology (primarily the use of microreactors), Fraunhofer ICT-IMM specializes in decentralized and mobile energy technology, medical probes and sensor technology, microfluidic analysis systems, and nanoparticle technologies.

Fraunhofer ICT-IMM in Mainz-Hechtsheim (Germany) is headed by Prof. Michael Maskos and has around 180 employees.

This is why in the future both Evonik and Fraunhofer ICT-IMM will be working more intensively on the issues of digitization and automation. From our current vantage point, a lot is possible: compact small-scale plants with individual synthesis modules that automatically log in and log out and flexibly adapt their capacity to the demand, or even self-optimizing processes that automatically recognize and take countermeasures against deviations in certain process parameters.

Additionally, "smart" EcoTrainers are also suitable as an approach to mobile units for energy use. For electrochemical processes, for instance, they can be equipped to tap the excess renewable power from the network. A new pilot plant building at Fraunhofer ICT-IMM in Mainz, which will largely be used for container plants, will provide room for new developments of this kind.

Economical and ecological benefits

As far as all future developments are concerned, small-scale chemistry is a new tool for integration on a wide variety of levels. From a technical standpoint, it promotes the development of equipment and infrastructure that is not only efficient and reliable but also intelligent and highly flexible. In economic terms, it makes syntheses lucrative, increases their added value, and minimizes cost risks.

The investment costs for conventional batch processes for chemical production are as much as 50 percent higher than for modular systems. Savings in maintenance and human resources and, above all, through fast upscaling and shorter time to market are added benefits. Another beneficiary of intelligent and small-scale production is the environment, as the savings in energy and raw materials can be particularly favorable.

Even though many people still associate a chemical plant with high smokestacks and imposing reactors, the future of numerous high-grade substances lies in the microworld. Intelligent processes in extremely small spaces combine the environmental and economic goals of the manufacturers with the rapid advances in industrial automation and digitization and thereby meet the requirements of advanced and sustainable production. ■

The Experts

Dr. Jürgen Lang works as senior scientist at Innovation Management in the Process Technology & Engineering Business Line. In this position he deals with new technologies, new processes, international collaboration projects, standardization, and modern plant design.

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Dr. Patrick Löb heads the Continuous Chemical Engineering division at Fraunhofer ICT-IMM. The core competencies are the development, realization, and application of microreactors for organic chemical production processes. In addition, he coordinated the EU POLYCAT project.

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Prof. Michael Maskos has been the director of Fraunhofer ICT-IMM in Mainz (Germany) since 2014. In addition, he has been the head of the chair of Chemical Process Technology/Microfluidics at Johannes-Gutenberg Universität in Mainz since 2011.

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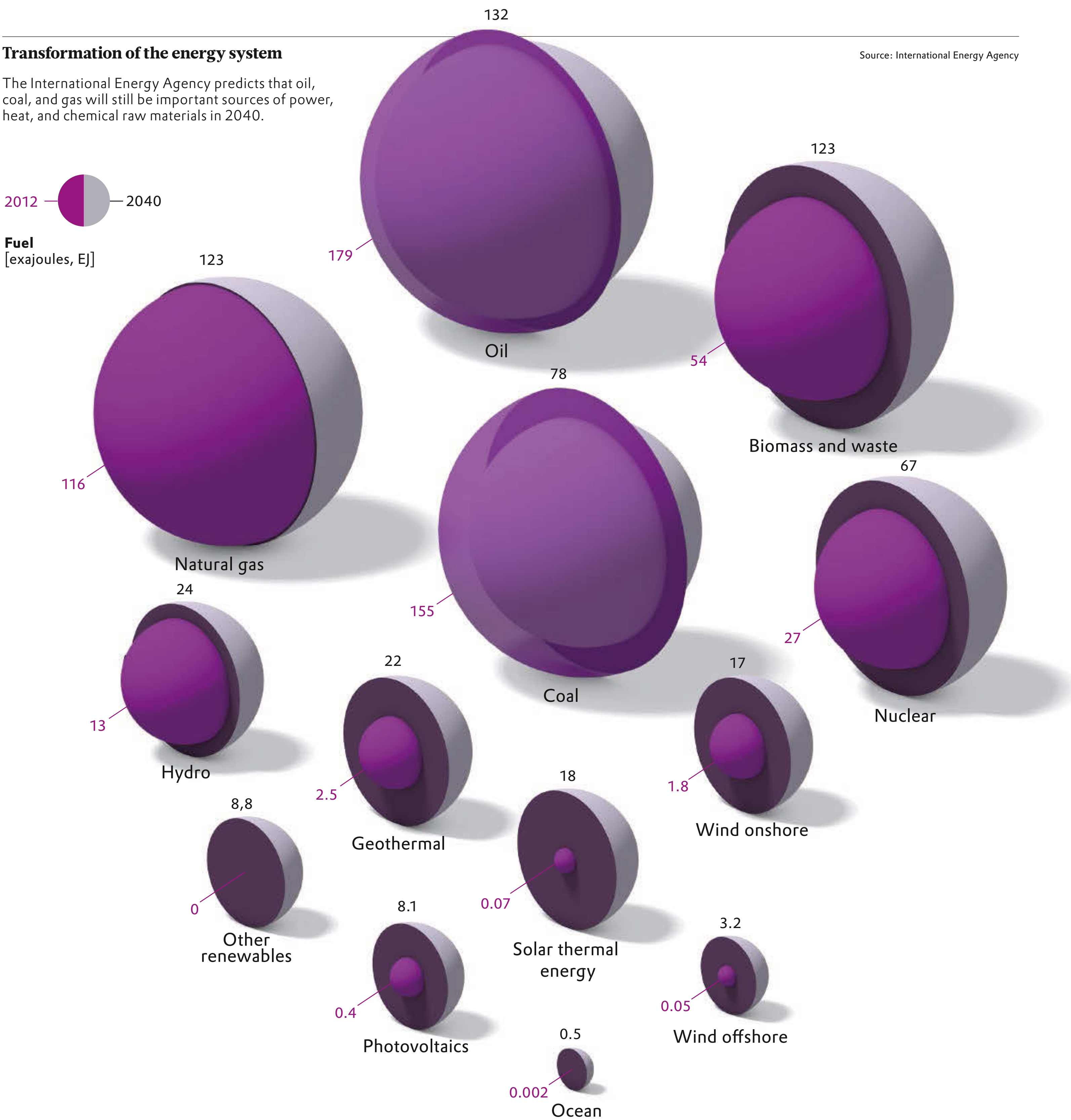
Nineteen companies, universities, and research institutes participated in the POLYCAT project, which was funded by the European Commission.

Photography: Fraunhofer ICT-IMM (5), Stefan Wildhirt/Evonik (1)

Transformation of the energy system

Source: International Energy Agency

The International Energy Agency predicts that oil, coal, and gas will still be important sources of power, heat, and chemical raw materials in 2040.



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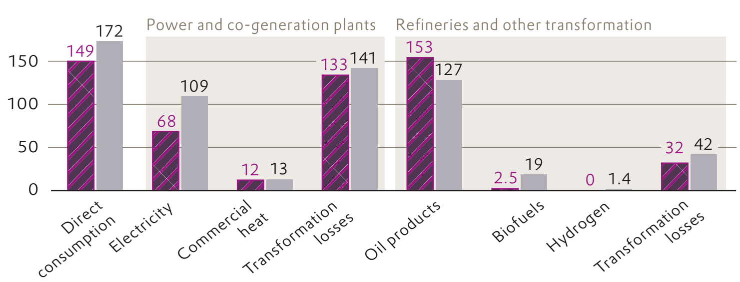

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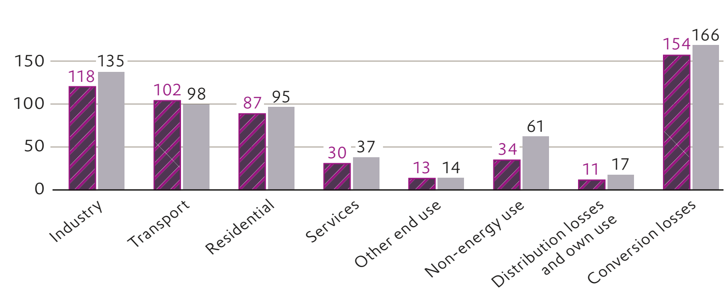

Illustration: C3 Visual Lab

CATALYZING CHANGE

The global energy and raw materials markets are in a state of flux: Raw materials are changing and new systems and processes are replacing the old. Evonik's Catalysts Business Line has responded to the changes by expanding its product range and investing in selected new developments.

Tim Busse, Dr. Hans Lansink Rotgerink

The world's hunger for energy will continue to be satisfied mainly by coal, oil, and gas—even in the year 2040. This was the conclusion drawn by the International Energy Agency in its most recent World Energy Outlook. According to the report, crude oil, coal, and fossil fuel gases will remain the most important energy sources in the foreseeable future, not only for power and heat but also for chemical raw materials. So will it be business as usual, then?

Not by a long shot. For many years now, the energy markets have been undergoing profound change. Within a short space of time, unconventional sources of oil and natural gas, buried deep in rock, (tight oil and tight gas) have perceptibly increased the supply of inexpensive fossil fuels by the use of fracking. Major importers of energy, such as China and the US, are increasing their energy production capacity by creating processing capacities based on their own raw materials. In addition, India, China, and Australia plan to utilize their coal deposits as sources for chemical raw materials more intensively than before.

Evonik is closely monitoring the current changes in the energy markets. The chemical processing industry, and the petrochemical industry in particular, are strongly affected by the energy markets because many of their basic chemicals such as ethylene, propylene, butadiene, and butene are obtained from oil and gas. These processes, as well as the downstream processing of these raw materials to more complex molecules and products of the chemical industry, require catalysts.

Changes in the energy markets also cause movement in the catalyst market.

Increasing need for new catalysts

For industrial chemical and petrochemical processes Evonik currently supplies about one hundred types of catalysts, many of which are for oxidation and hydrogenation reactions. Some of these are used as standard catalysts in the same application by different customers and in different regions.

However, the great majority have been developed by the Catalysts Business Line jointly with the user for a particular process or a defined process step. In this project-based business, Evonik draws on the advantages of its knowledge and many years of expertise in a variety of application areas. This flexible and practical approach is increasingly in demand worldwide, because customized catalysts ensure an optimal, cost-efficient, and sustainable solution for the customer.

Chemical companies usually work with a particular portfolio of raw materials so as to be able to react flexibly to changes in supply structures, process requirements, and prices and availability of raw material. Changes in the energy markets also cause movement in the catalyst market. Customers develop new processes to be able to continue working cost-efficiently, and this gives rise to a need for new catalysts.

A good example is afforded by propylene. This liquid gas is one of the most important base products in the petrochemical industry. About two thirds of global production is used to manufacture the bulk plastic polypropylene, and propylene is also used for the production of important chemical intermediates such as propylene oxide, butyraldehyde (and oxo alcohols), cumene, acrylonitrile, acrolein, and acrylic acid.

Propylene is obtained mainly as a by-product of ethylene production in steam crackers, or in catalytic cracking processes in refineries. In steam crackers a mix of hydrocarbons from petroleum is split into shorter molecules. Each cracker delivers a particular ratio of propylene to ethylene (P/E ratio), depending on feed and operational mode or design. For a long time the demand for propylene and ethylene corresponded roughly to the overall P/E ratio delivered by the crackers. But this ratio has now fallen from 0.38 to 0.30, while demand for basic chemicals and plastics in the growth regions, particularly Asia, has registered a strong increase. The result is that conventional processes for propylene production no longer meet demand and have been supplemented by on-purpose technologies for obtaining propylene, for example from propane or methanol.

Selective hydrogenation in greater demand than ever

Due to the exploitation of shale oil (also known as tight oil) and shale gas (tight gas), the starting material propane is now available in significantly larger quantities and at much lower prices than only a few years ago. As a result, the thermocatalytic production of propylene from propane is becoming increasingly important. About 15 new plants have been established worldwide in the last six years for this propane dehydrogenation (PDH); this corresponds to about seven percent of global propylene capacity. More ➔

Processes based on sustainable raw materials will become increasingly important over the long term. In this area, entirely new fields for catalyst development are opening up.

→ than ten additional plants are in the project development or planning stages.

This has given rise to demand for new specialty catalysts, such as for selective hydrogenation, for the following reason: In the core process of dehydrogenation of propane, undesired byproducts with multiple bonds are formed, which reduce the yield of the process, lead to coking of the reactor system, and prevent attainment of the degree of propylene purity required for PP polymerization. This is where Evonik's catalysts help: They selectively hydrogenate these byproducts, thus permitting the production of propylene of the highest level of purity and, moreover, in an economical process. Evonik's catalysts for selective hydrogenation were developed many years ago, and demand for them has increased steadily ever since.

Sustainable raw materials as a field of development

The transformation in the energy markets also opens up entirely new fields for catalyst development, most particularly in the area of sustainable raw materials. Already today about ten percent of all chemical products are obtained from bio-based raw materials.

In terms of quantities produced, the most important product in this market by a long margin is bioethanol, obtained by fermentation of plant sugars. Enormous bioethanol production capacities have been established within the last ten years, particularly in the US and Brazil. The global output of bioethanol plants today is of the same order as global propylene production. Most of the alcohol is burned as an additive in gasoline. But bioethanol is also increasingly being used as a chemical raw material because consumers are increasingly demanding "green" products, be they sneakers or Lego bricks.

Evonik is following this development, taking a number of different approaches. Various projects, for example, are currently investigating the potentials of bioethanol for new catalytic processes. Working jointly with customers, experts from the Catalysts Business Line in the Industrial & Petrochemicals market segment are investigating the conditions under which, for example, high-grade chemicals such as solvents and monomers can be produced from bioethanol and other starting materials.

Reactions of this kind were carried out as long ago as the 1950s; the challenge now is to develop cost-effective processes for them. This too calls for experience when, for instance, identifying which modified or new catalyst is best suited for a particular purpose, predicting its performance in a commercial-scale plant, and finding the right basic process-engineering operations for scale-up to the optimal catalyst.

Evonik is currently constructing a new, ultra-modern facility at the Marl site to create adequate capacities for the scale-up of new fixed-bed catalysts. This will be used from early 2016 to produce catalysts in quantities ranging from a few kilograms to 100 kilograms and to ensure subsequent transferability, particularly of molding formulations, to commercial production. In the future this investment will allow Evonik to react more rapidly and flexibly to the dynamics of changes in raw materials and the associated changes in catalyst requirements.

All a question of (oil) price

Perspectives for biological alternatives for raw materials are naturally always determined by the current price of oil. When this price is high, investments in new bio-processes are worthwhile; when low, interest in biological processes quickly wanes. Evonik is convinced, however, that processes based on sustainable raw materials will become increasingly important over the long term. They often have better energy and emission profiles, foster innovation, and, not least, reduce dependency on fossil fuels. For this reason, sustainable raw materials sometimes receive political support, even if only temporarily. In view of the long payback times for a new plant, however, such support appears to many potential investors to be too uncertain.

The world continues to need energy, and more of it. Nobody can say today what exactly production structures, suppliers, and markets will look like in ten or 20 years' time. This is why most public discussion on the topic revolves around short-term shifts in supply and demand. Fracking, for example, is indeed in the headlines and the subject of much debate, but its overall contribution to the global supply of energy and raw materials is in fact relatively small. Moreover, the profitability of unconventional deposits waxes and wanes as the price of crude oil rises and falls. The same applies to the boom in biomaterials. The rate at which bio-based raw materials will grow in importance on the global scale depends on a multitude of factors, not the least of which are the political environment and the willingness of industry to make the corresponding investments.

The only certainty here is that the range of raw materials and their global availability will continue to change and require flexible, reliable, and practical action. The aim of Evonik is to develop jointly with customers and partners catalysts that are competitive in economic, technological, and ecological terms, and that will help ensure that highly efficient processes remain available in the future. ■

The Experts

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CompanyNews

REACHING HIGH: C4 VIA NEW PATHS

With new production plants in Antwerp (Belgium) and at Marl Chemical Park, Evonik has expanded its C4 capacities in Europe and thereby consolidated its leading position in C4-based products. The plants in Marl have now commenced operation following the successful start of production in Antwerp at the end of June. Evonik's total investment in both sites is in the triple-digit million euro range.

The new production facilities have resulted in capacity expansion for butadiene (Antwerp), the plasticizer alcohol isononanol (Marl), and the fuel additive MTBE (both Marl and Antwerp). According to market analyses, global demand for these products is growing by two to five percent annually.

The Marl plant marks a technological milestone for Evonik. Thanks to an entirely new process worldwide, FCC-C4 material streams can be used for the production of a wider range of chemicals. Steam or naphtha crackers have so far been the major source for the extraction of basic petrochemicals. However, there are significantly more FCC crackers than steam crackers worldwide.

FCC stands for "fluid catalytic cracking." With this process, refineries transform heavy crude oil components into fuel components. Fluid catalytic cracking produces a C4 material stream that contains other substances besides the components that can be used for chemical processing (olefins). For this reason, the industry has thus far not used this FCC-C4 material stream.

By developing its own new technologies and combining these with others procured externally, Evonik has now succeeded in making this material stream utilizable by separating any unwanted substances from the FCC-C4 stream. The new technology incorporates distillations, chemical reactions, and adsorption techniques, including a 90-meter column that removes butanes that are of less interest to Evonik from the FCC-C4 material stream. Afterwards, the butenes contained in the material stream can be processed further to produce specialty chemicals.

Evonik draws the FCC-C4 material stream by pipeline from the refinery in Gelsenkirchen, about 15 km from the Marl site. Because the residual butanes are a valuable raw material for the Scholven refinery, Evonik returns these by pipeline to Gelsenkirchen.

The centerpiece of the new plants in Marl is a 90-meter-tall column, Evonik's highest. It symbolizes the new technology, which is making special material streams from refineries useful to C4 chemistry for the first time anywhere.

Photography: Evonik

Investment in Airborne Oil & Gas ➜ Fatty acids from algae ➜

New innovation centers for the cosmetics industry

Evonik has opened innovation centers in Midrand (South Africa) and Singapore, which develop product solutions in the area of personal care. The new facilities supplement the worldwide network of laboratories of Evonik's cosmetics business, which also includes sites in Essen (Germany), Guarulhos (Brazil), Hopewell (Georgia, USA), and Shanghai (China). Additionally, Evonik has added a hair laboratory to the applications laboratory that has existed

Testing cosmetic active ingredients' effect on skin cells.

in Guarulhos (Brazil) since 2012. More than one hundred employees worldwide work in research and development for the cosmetics industry.

When it comes to products for hair and body care, consumer demand varies dramatically worldwide. In Brazil, for instance, women often wash their hair twice a day and therefore need more care. Conditioners with regenerative effects, which are not washed out after application, are particularly popular. In Europe, consumers prefer products with a light consistency that are rinsed out.

At roughly five percent per year, the worldwide market for cosmetic products is growing faster worldwide than the global gross domestic product. In Brazil alone, the demand has risen steadily in recent years by about 10 percent. The main driver in emerging economies is the growth of a middle class with strong purchasing power. As a supplier of high-quality raw materials, Evonik's Personal Care Business Line serves all the large cosmetics enterprises. The products include, among others, emulsifiers, surfactants, active substances, conditioners, thickeners, and emollients.

A laboratory for medical devices in Shanghai

Evonik has opened its first application technology laboratory for medical devices. Located in Shanghai, China, the laboratory will provide support to medical device manufacturers who use Evonik polymers in their projects.

Evonik's RESOMER® and RESOMER® Select brands offer a range of biodegradable polymers that are widely used in a variety of medical devices, such as orthopedic screws, plates, etc. Implanted devices designed with RESOMER® resorb without a trace in the body over six months to two years, eliminating the need for secondary surgery to remove the devices.

Evonik plans not only to provide customers with a reliable supply of the material but also to help them find the best way to use the material for their specific design and production requirements. This includes selecting the most suitable RESOMER® product for the application, characterizing the production process (injection molding and extrusion) for successful design and scale-up, as well as manufacturing technical samples for feasibility studies. The aim is to help customers develop and bring their medical devices into production faster. New applied

Interested customers at the opening of the new lab in Shanghai.

technology laboratories for medical devices are planned in other regions. The next planned opening is in Darmstadt, Germany, to serve the European market.

Investment in pipeline specialist AOG

Through its venture capital arm, Evonik has invested in Airborne Oil & Gas (IJmuiden, Netherlands) and now holds a minority interest in the Dutch company. The investment was made jointly with HPE Growth Capital (HPE) and Shell Technology Ventures. Airborne Oil & Gas (AOG) possesses a unique technology for the production of thermoplastic composite

AOG flowlines ready for shipment to a customer.

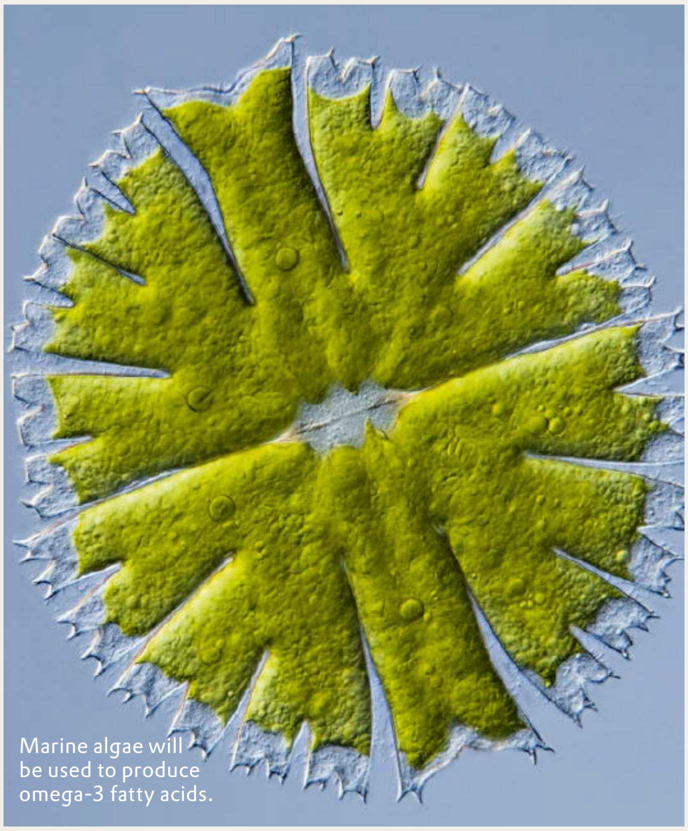
pipes for a variety of offshore oil and gas applications.
The current offshore oil & gas infrastructure consists of either rigid steel pipes or so-called flexibles. The latter consist of multiple layers of steel and polymers. AOG's thermoplastic composite pipes dispense with steel entirely and are therefore not susceptible to corrosion. They have extremely high mechanical stability but are also flexible. As an added advantage they are lightweight and can be fabricated in lengths of up to 10 kilometers, which means that AOG's pipes can be installed relatively simply and cost-effectively. Rigid steel lines are welded together from segments that are 10 to 20 meters long, using highly specialized and costly pipelaying vessels.

A number of operators have qualified AOG's pipes for offshore oil and gas transport lines. A considerable amount of the 150,000 to 200,000 km of globally installed transport lines is over 20 years old and in need of replacement. This is an attractive entry point for AOG. For Evonik, the oil and gas industry is an attractive growth market and an important innovation field. Furthermore, the company is a market leader in polyamide 12, marketed as VESTAMID®, which is well-proven in pipes for oil and gas production and transport.

Award for CoverForm® series application

The Society of Plastic Engineers (SPE) has awarded the Grand Prize in the Electronical/Optical Parts category to the visually appealing Mercedes touchpad, which is equipped with an extremely scratch-resistant surface made with CoverForm®. The automotive suppliers Continental and Daimler are the first users to integrate CoverForm® into mass car production together with Evonik and the machine manufacturer KraussMaffei. The decision to use this technology developed by Evonik and KraussMaffei came about from the requirements for on the touchpad. It must be possible to manufacture the three-dimensional component using injection molding, and the surface of the part must not show any scratches or chemically induced changes, even after intensive use.

Continental manufactures the touchpad in Babenhausen for the C-Class, S-Class, V-Class, GLE-Class, GLC-Class and GT-Class in the Mercedes model range and for the Maybach. The company uses the CoverForm® process, in which the part is coated with a highly crosslinked, scratch-resistant acrylate layer during the injection molding process. Surfaces produced in this way are extremely scratch and chemical-resistant. A production volume of more than a million faceplates is expected to be reached as early as 2016.


Marine algae will be used to produce omega-3 fatty acids.

FATTY ACIDS FROM ALGAE

DSM Nutritional Products (Switzerland) and Evonik Nutrition & Care are cooperating on the development of algae-based omega-3 fatty acid products for animal nutrition. The products will be used especially for aquaculture and pet food applications. The aim is to meet the increasing demand for omega-3 fatty acids by harnessing naturally occurring marine algae using sustainable biotechnological processes based on natural non-marine resources.

DSM has expertise in the cultivation of marine organisms and long-established biotechnology capabilities in development and production. Evonik's focus for decades has been on industrial-scale biotechnological production of amino acids in large-volume fermentation processes. Until now, the omega-3 fatty acids used in aquaculture have been obtained exclusively from marine sources such as fish oil. The envisioned algae-based omega-3 fatty acid products will be an alternative to fish oil. This will help keep up with the increasing demand for omega-3 fatty acids in animal nutrition without endangering global fish stocks and will contribute to sustainable aquaculture.

Dr. Peter Nagler receives award

Dr. Peter Nagler, Head of International Innovation at Evonik, received the IAIR Award for Chief Innovation Officer of the Year in the chemistry section in the Europe region at a ceremony in London. The citation for the award highlights his influential role in Evonik's strategy for innovative products and solutions: "Peter Nagler's conviction of the importance of networks, internationalization, and sustainability paved the way for innovative research and investments that have expanded Evonik's business and technologies throughout Europe."

The internationally renowned IAIR (International Alternative Investment Review) Awards are presented annually, by a research institute under the patronage of the European Commission, to companies and individuals for business performance, sustainability, and innovation. Peter Nagler, who holds a doctorate in chemistry, has been head of International Innovation since January 1, 2015. He took on the then newly created post of Chief Innovation Officer in 2011. In early 2015 Dr. Ulrich Küsthardt succeeded him in this position.


Dr. Peter Nagler, Head of International Innovation at Evonik.

Innovation Awards for ROHACELL®

The AVK Federation of Reinforced Plastics presented awards to two Evonik developments containing the PMI structural foam ROHACELL® for sandwich components at the Composites Germany Conference.

The new development "ROHACELL® Triple F—Production-Ready Foam Cores for Sandwich Components" received second prize in the Innovative Products and Applications category. The "PulPress Process for Large-Scale Production of Complex Fiber Composite Parts," for which ROHACELL® is used as a foam core, was awarded third prize by the jury in the Innovative Processes and Systems category.

An innovative manufacturing process, in-mold foaming (IMF), is now enabling the production of complex three-dimensional structural cores for industrial-scale CFK sandwich components. ROHACELL® Triple F can significantly lower the cost per part by reducing waste, manual work, and cycle times, and produce 1,000 to 50,000 complex 3D sandwich structures per year rapidly and efficiently. This is particularly attractive for applications in the automotive segment and aircraft construction, but also for sports articles.

The PulPress process is designed for the highly automated, continuous, and cost-effective series production of fiber-composite profiles with complex part geometries. It innovatively combines the pultrusion and compression methods, as well as the fiber composite materials and the ROHACELL® rigid foam structural core used in the process. The process enables the molding of highly complex parts with narrow component tolerances and outstanding component properties, and is particularly well-suited to the serial production of cars.

Photography: Evonik (3), AOG, Shutterstock

At the beginning of his career Dr. Jens Busse spent a lot of time in control rooms, optimizing processes and training plant personnel.

DR. JENS BUSSE

Open to New Ideas

Dr. Jens Busse studied process engineering and at the beginning of his career worked primarily with simulations and energy optimization for sites. Today, he is constantly on the lookout for attractive start-ups for venture capital that fit well with Evonik's innovation activities. Ever since Busse, who is now 43, joined the Group as a specialist in process technology, he has forged ahead into uncharted territory again and again.

When Jens Busse assesses start-ups, he considers a great deal more than just their technological innovation. Other key questions include: What are the market opportunities of this technology? What expertise does the start-up team bring? Could Evonik benefit from collaboration with, or participation in, this company? Busse is a member of the Venture Capital Team, which has been Evonik's corporate venture arm since 2012. The team has €100 million at its disposal for medium-term investments.

"I work on behalf of a variety of business lines to find technologically suitable start-ups that make our products better or expand their function," explains Busse. "This kind of assessment requires technological expertise, although obviously the colleagues I work with closely in the business lines are the ultimate experts."

Busse spends three days each week at the Essen site and two days at the Hanau site—when he is not traveling. His travel destinations frequently include relevant conferences where start-ups are presenting and the sites of the start-ups themselves, for the purpose of getting to know them better. "Our team also takes a look at the people behind the start-up, because the personalities of the founders largely determine the success or failure of a technology." This requires some insight into human nature—something that Busse acquired in earlier positions.

Busse's specialty: Charting new territory

Busse studied mechanical engineering with a concentration on process engineering at Ruhr University Bochum, where he earned his doctorate in process synthesis. In 2001, he began his career in the process engineering unit of the former Degussa AG. There he was part of a team that developed training simulations for various plants. These kinds of simulations are now used to train today's plant operators just like flight simulators are used to train pilots. But back then, it was new territory. "It was classic project management," says Busse. "We also had to do a lot of work to sell people on this new tool."

In another team he focused on demonstrating the potential for energy savings at chemical sites and plants. "Ultimately, our goal was to identify best practices that we could then transfer to other sites," says Busse. "We functioned as ambassadors." In this position, Busse worked closely with the company's processes and sites and got to know many colleagues who are now valuable contacts. In addition to the training simulation and energy optimization, he was part of a team that managed internal training sessions for improving the marketing of products and services for process engineering. "You could say that was my first foray into marketing," he says. In 2009, Busse moved from process engineering to Creavis, Evonik's strategic innovation unit. He worked there as head of the Development Line Energy Generation in the newly started Science-to-Business Center Eco^2, which focused on energy efficiency and climate protection. His team conducted research on heat recovery, hydrogen technology, and membranes. "I was responsible for a variety of projects, had to apply for public funding, and managed large consortia with as many as ten internal and external partners," says Busse. The disciplinary responsibility was new. He credits intensive training and "excellent senior managers, who taught me a great deal" for helping him in this step in his development.

Busse has been part of the Venture Capital Team since early 2015. While his work at Creavis focused on developing technologies to the point where they could be transferred to the business units, his efforts are now directed at helping start-ups that have a new product enter the marketplace. Busse says, "It's exciting for me, because it's the next step on the way from R&D to commercial success."

While it all seems like such a straight path in hindsight, it was anything but that. "There's no question that I wanted to develop my skills further and do something different," says Busse. "But I couldn't have predicted that my path would lead to Creavis and now the Venture Capital Team." After spending a number of years in a certain position, he simply kept his eyes and ears open to the options the Group offered. And because of its size, Evonik offers a lot of options—even when it comes to switching to completely new subject areas, as in Busse's case. "The fact that my 'visibility' in the Group increased over time because of my work certainly facilitated such a fundamental change," he says. ■

Further information on Evonik Venture Capital: **venturing.evonik.com**

"I got to know many colleagues during my work at Process Technology. I'm still benefiting from this network today."

Dr. Jens Busse

Evonik Venture Capital: On the trail of new technologies

Evonik intends to invest a total of €100 million in young technology companies and specialized venture capital funds over the medium term. Investment in innovative ideas and solutions is oriented to the megatrends that are most important to the company—health, nutrition, resource efficiency, and globalization. The key regions are Europe, the United States, and Asia.

The team from Evonik Venture Capital consists of eight investment professionals with relevant experience in the venture capital sector, as well as employees who have worked a number of years in technical and operational positions at Evonik and know the company extremely well. They are located in Hanau (Germany), Essen (Germany), Parsippany (New Jersey, USA), and Woodlands (Texas, USA).

To date, the team has evaluated the business plans of more than 1,500 start-ups. Evonik currently holds an interest in seven start-ups and three funds.

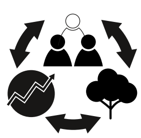
Photography: Dirk Bannert/Evonik

Nominated for the Evonik Innovation Award 2015

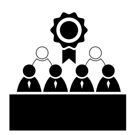
REWARDING CREATIVITY

Recognition is an important driver of creativity. This is why work on new ideas is particularly well rewarded at Evonik. Once a year, the specialty chemicals company confers its own Innovation Award for outstanding research success and the creative minds behind it. There are three teams in the finals for the Innovation Award 2015 in each of the two categories New Products/System Solutions and New Processes. Their projects are presented on the following pages. The nomination is intended to underscore that second and third place are just as reflective of great achievements as first place.

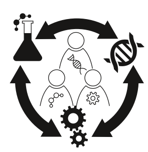
The award: motivating
Winning the Innovation Award means having done outstanding work. The winning team in each of the two categories can also look forward to a cash prize of €30,000.



The standards: sustainable
The six finalists are selected on the basis of the criteria of economic importance, environmental advantages, and societal benefit. The team that accumulates enough points with its project in all criteria has an opportunity to reach the final round.

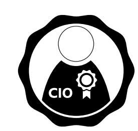


The jury: demanding
The members of the audience select the winners of the Innovation Award during Evonik's traditional Christmas Colloquium. The audience is made up of about 200 members of the Group's senior management, as well as researchers from all segments.



The teams: interdisciplinary
Innovation occurs at the interfaces between traditional disciplines such as chemistry, biology, and engineering. Accordingly, most of the teams that make it to the finals are interdisciplinary.

The finals: conclusive
During the final round, each of the nominated teams has ten minutes to present its project. The members of the audience then evaluate not only the scientific depth but the quality of the presentation, because a new development is only innovative if it is successful on the market. And that includes good marketing and a professional sales approach.



The CIO Award: surprising
The Chief Innovation Officer (CIO) Award acknowledges an individual achievement. Last year, it went to the molecular biologist Dr. Mechthild Rieping, who received the award and the €5,000 prize money for her inventiveness. Rieping has been responsible for more Evonik patents than anyone else, based on a Group-wide comparison.

New Products/System Solutions

Linerless labels: TEGO® RC silicones for innovative labeling systems

Typical application for linerless labels: food packaging.

Currently, up to 40 percent of the weight of a standard, self-adhesive label consists of a liner that winds up in the garbage as soon as the label is peeled off. Thanks to the patented TEGO® RC technology, this liner is no longer necessary. A team from the Interface & Performance Business Line has been nominated for the Evonik Innovation Award 2015 for this development.

Labels are sophisticated systems. A conventional label laminate consists of a liner, the adhesive, and the actual label. A fourth layer, a silicone release coating, is invisible yet crucial to the label's function. This layer ensures that the label can be removed from the liner rapidly and without leaving residue. Systems without liners are far more sustainable. These save not only 40 percent of the weight and the associated material costs but also conserve resources. In Europe alone, up to 300,000 metric tons of paper and plastic liner waste are discarded every year.

When used as a separating layer, TEGO® RC silicones make linerless self-adhesive products a reality. RC stands for "radiation cured." Instead of heat, UV radiation is used to crosslink and cure these silicones—which takes only a fraction of a second. Compared to labeling systems with thermally cured silicones, this method reduces energy consumption and is gentler on the label. This is why TEGO® RC silicones can be used for heat-sensitive liners such as BoPP films. During production, linerless labels are printed first, and afterwards coated with silicones.

Applied to the top of the printing, newly developed TEGO® RC silicones ensure optimal adhesion and release effect with respect to the adhesive layer. This way, the labels can be rolled up like an adhesive tape without sticking to each other and are reliably dispensed, whether manually or automatically.

In cooperation with machine manufacturers, Evonik has shown that UV siliconizing can be easily integrated into modern, fully automated plants for the production of labels. Typical applications are linerless thermal-printed labels, wrap-around labels, and microperforated decorative labels. End applications range from food packaging and labels for transport and logistics to consumer goods. ■

Dr. Stefan Stadtmüller,
spokesperson of the nominated TEGO® RC silicones team

New Products/System Solutions

Gas separation with fibers: Hollow-fiber membranes for harvesting nitrogen

SEPURAN® N_2 for energy and cost-efficient nitrogen extraction.

The new SEPURAN® N_2 hollow-fiber membranes represent an unprecedented cost and energy-efficient tool for harvesting nitrogen. This has been well-received on the market: Evonik is currently expanding its capacities in response to increasing demand. In order to acknowledge this new development, the team of experts from the High Performance Polymers Business Line has been nominated for the 2015 Evonik Innovation Award.

With sales volumes of US$10 billion, the nitrogen market is the second-largest gas market in the world after oxygen. The gas protects chemical storage facilities and server farms from fires and explosions. In the food industry nitrogen extends the shelf life of cheese and fruit, and in liquid form it is used as a coolant for freezing blood and tissue samples.

Nitrogen is extracted from the air, which consists of 78 percent nitrogen and nearly 21 percent oxygen. Made of polyimide that has been spun into hollow fibers, SEPURAN® N_2 hollow-fiber membranes represent a particularly efficient way of separating the two gases. The manufacturing process yields 0.5 mm-thick hollow-fiber membranes, which are then bundled, embedded in a special resin, and finally embedded in a stainless steel module. As compressed air is fed along the bore side of the hollow fibers, oxygen molecules—which are more mobile—preferentially diffuse through the membrane, leaving nitrogen to accumulate on the feed side.

The purity of the nitrogen can be controlled by adjusting the amount of air fed into the fibers. The smaller the initial amount of air, the higher the purity of the nitrogen. Nitrogen with a purity of 95 to 98 percent is adequate for many applications, and this is exactly the process regime that reveals the economical superiority of the technology. The investment costs and energy consumption of SEPURAN® N_2 technology are lower than those of the classic technique (fractionating air at low temperatures).

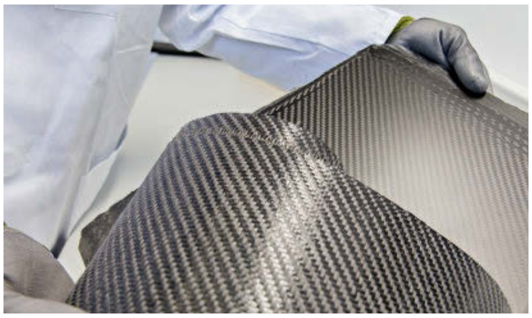
The new technology is piggybacking onto the success of SEPURAN® Green, an Evonik product that has established itself on the biogas upgrading market. SEPURAN® now stands for customized membrane technology for the processing of industrial gases such as hydrogen and helium. With this system solution, Evonik covers the entire value chain—from monomer and polymer synthesis to production of the hollow fibers and ultimately of entire modules. ■

Dr. Goetz Baumgarten,
spokesperson of the nominated SEPURAN® N_2 team

Photography: Evonik Illustration: C3 Visual Lab

New Products/System Solutions

The best form of lightweight construction: Fiber-reinforced plastics



Pre-impregnated carbon fibers based on VESTANAT® PP.

High strength, high rigidity, low weight: Fiber-reinforced plastics offer enormous potential in lightweight construction. With VESTANAT® PP, a new matrix system for pre-impregnated carbon fibers ("prepregs"), these plastics are now easier to produce. For this system, the developers from the Crosslinkers Business Line have been nominated for the 2015 Evonik Innovation Award.

Fiber-reinforced plastics are key to lightweight construction. Extremely strong glass or carbon fibers embedded in a polymer matrix are responsible for their unique mechanical properties. But their potential is still not fully realized, because manufacturing components from these composites is complex and time-consuming.

With resin transfer molding (RTM), for example, the dry fibers are placed in the form, impregnated with resin, and the composite is produced with the help of a curing agent, pressure, and temperature. However, even in commercial production in the automotive industry, RTM can only produce components in batches.

Prepregs make production easier, because in this continuous method the fibers are already pre-impregnated with resin and curing agent, so all that is needed to cure them in the mold is a high temperature. However, the prepregs in current use, which are predominantly based on epoxy resins, can be stored for only short periods at –20 °C; otherwise they cure prematurely. In VESTANAT® PP, Evonik has developed a polyurethane (PU) matrix system that offers a new route for the automated production of components from composite materials.

By virtue of a chemical trick, the PU matrix cannot crosslink below 140 °C and therefore remains stable when stored at room temperatures. Because it softens beginning at 80 °C, it is easy to mold the prepregs into the shape of the desired component before the curing process. Other advantages are the fast curing and good mechanical properties, which allow the same component properties with less material than other matrix systems.

VESTANAT® PP combines ease of handling with the potential for continuous production. Evonik is currently holding discussions with several leading car manufacturers who want to use VESTANAT® PP in the production processes of their future models. ■

Dr. Guido Streukens,
spokesperson of the nominated VESTANAT® PP team

New Processes

For a clear consumer conscience: New surfactant based on certified palm kernel oil

Sustainable: Oil from palm kernels.

Evonik's new surfactant TEGO® Betain P 50 C stands out for its superior sustainability profile and improved application properties. RSPO-certified palm kernel oil is used in it instead of coconut oil. For the development of the production process, the global team from the Personal Care Business Line, the Production & Engineering department of the Nutrition & Care segment, and Procurement has been nominated for the 2015 Evonik Innovation Award.

For more than 50 years, cocamidopropyl betaine (CAPB) has been one of the most successful surface-active substances on the market for personal care products such as liquid soaps, shower products, and shampoos. The products and processes have been optimized many times through improvements such as increasing the content of the active ingredient and eliminating preservatives. But the basic formula has remained the same: A hardened coconut oil or a hardened coconut fatty acid is reacted and forms CAPB.

Because coconut oil is becoming more widely used in the food industry and its production is subject to strong weather-related fluctuations, the Personal Care Business Line has now developed a new process for producing a betaine based on RSPO-certified palm kernel oil. "This respects the sustainability ethic of our customers and end users and offers us greater supply security," says Ralf Klein, the global business director of Base Products at Personal Care.

TEGO® Betain P 50 C can be produced with existing production facilities, so no additional investment is required. Moreover, a key problem of current betaine production was solved during process development, and that enabled a significant reduction of production time for the product. The next step is to transfer the process to the production of existing betaine products.

Following production tests in China, the first commercial batches of TEGO® Betain P 50 C have now been manufactured in Germany. Additional production sites are earmarked for Indonesia and the United States, with another facility planned for Brazil in 2016. A number of customers from the cosmetics industry are currently conducting their own laboratory tests with samples of the product. Initial revenues from the new surfactant have already been generated. ■

Ralf Klein,
spokesperson of the nominated TEGO® Betain P 50 C team

New Processes

A simpler pathway to methionine Process optimization by a new precursor

Evonik's latest methionine complex in Singapore.

A team from the Animal Nutrition Business Line and Technology & Infrastructure has shown that major process improvements are possible even for a well-established product like methionine. The process is now simpler and intrinsically safer, because it eliminates liquefied hydrocyanic acid. For this achievement the team has been nominated for the Evonik 2015 Innovation Award.

Evonik has been producing the amino acid methionine for animal nutrition for nearly 50 years and is a technology and market leader in the field. A major objective of the researchers in the Animal Nutrition Business Line is to maintain this technological lead by continual process optimization. Their latest success was incorporated into Evonik's new methionine complex in Singapore in October 2014: Instead of hydrocyanic acid, the plant uses MMP-CN (methylmercaptopropionaldehyde cyanohydrin) as an intermediate. This makes the process more stable and safer.

Three intermediates, methylmercaptan, acrolein, and hydrocyanic acid, are essential to the production of methionine, and Evonik itself produces all three in its fully back-integrated plants. In the first step, methylmercaptan and acrolein react to give MMP, which is then converted to methionine using hydrocyanic acid. Hydrocyanic acid has a low boiling point (25°C) and must be liquefied by cooling. Additional cooling is required for safe storage and handling. This is where the researchers stepped in. In Singapore hydrocyanic acid is not liquefied and stored; instead, it is directly absorbed from the vapor phase into a solution, where it reacts directly with MMP to give the new, far less critical intermediate MMP-CN.

The process was rapidly developed, tested in a pilot plant in Hanau, and finally integrated into the Singapore plant. Consequently, it will be an essential component of future methionine complexes. This success was possible because Evonik pooled its skills for the purpose, combining expertise from methionine production, process engineering, analytics, and pilot-plant operation. ■

Martin Steurenthaler, spokesperson of the nominated methionine team

New Processes

Lightweight construction made easier: Mass production of complex sandwich components

A mass-produced component made from ROHACELL® Triple F.

A new foaming process now offers a simple way of producing ROHACELL® Triple F structural foam in complicated shapes. Thanks to this process, Evonik has cleared an important obstacle on the road to mass producing sandwich components in complex shapes for the automotive industry. The first vehicles with ROHACELL® Triple F components were presented at this year's IAA, an accomplishment that earned the team of developers from the High Performance Polymers Business Line a nomination for the 2015 Evonik Innovation Award.

Right now, the primary method of making sandwich cores for fiber composite components is by producing blocks that are then cut into the desired shape in an additional step (CNC milling, for instance). However, the considerable amount of manual labor involved, as well as the relatively large volumes of waste, make large-scale production cost-prohibitive.

This is where Evonik stepped in, developing a new in-mold foaming (IMF) process for its rigid ROHACELL® Triple F polymethacrylimide (PMI) foam. The process, which makes creating complex geometries considerably easier, involves foaming granulated PMI into the desired mold for the finished foam core, thus saving material and process steps. Embedded metal components such as threaded inserts can be integrated during the foaming process. These foamed PMI cores can be used for manufacturing complex 3D components in commercial quantities, and their considerable rigidity and temperature resistance make them suitable for subsequent processing using high-pressure or wet-pressing techniques.

Doing so allows manufacturers to create composite components with lightweight foam cores quickly and efficiently. The automotive industry then uses these in bodies, chassis, and add-ons. The ROHACELL® Triple F cores are foamed in situ by LiteCon Advanced Composite Products GmbH, a joint venture established in 2013 by Evonik Industries and SECAR Technology. LiteCon manufactures the finished components as well, and production of the first series is already underway. ■

Dr. Kay Bernhard, spokesperson of the nominated ROHACELL® Triple F team

Photography: Evonik (7), Shutterstock

Prof. Renée Schroeder, 62, is a biochemist and a professor at the Department of Biochemistry at Max F. Perutz Laboratories, a joint venture of the University of Vienna and the Medical University of Vienna.

Prof. Schroeder is an expert in the field of RNA biology and a recipient of the renowned Wittgenstein Award. She is a prominent advocate of measures to ensure a wider acceptance of science.

Her most recent book is *Von Menschen, Zellen und Waschmaschinen. Anstiftung zur Rettung der Welt* (Of People, Cells, and Washing Machines: An Incitement to Save the World) (Residenz-Verlag 2014).

WHAT I HOPE FOR FROM SCIENCE

Renée Schroeder

AN OPEN MIND

There is nothing that says that simply being new makes something valuable. Just because something is new doesn't mean it is good or even better. Established things are tried, tested, and familiar. Evolution, on the other hand, requires constant new impetus and new things to try out. My hope is for science and innovation to make the world better and to ensure that it develops further. The most important thing above all is freedom, and freedom begins in the mind. Ideologies restrict this freedom—they are prisons of the mind.

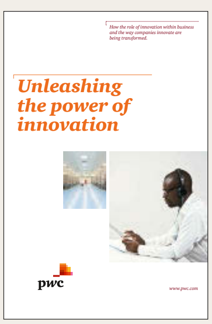
Education is therefore the most important prerequisite for a free mind. And so my wish is for everyone to have education, specifically education in the sense of freedom of thought. On the basis of the realization that our level of knowledge is low but that we are capable of expanding it, I define education as training our abilities: to be unbiased, to ask critical questions, and to be creative. No question is off-limits. Everything can be and should be questioned. This is not easy, of course. But, as we all know, taking the easy way is not what drives evolution.

PATHS TO GREATER INNOVATION

Useful information on culture and markets

Innovation is a key matter

The question of how companies can further increase their innovative capabilities is addressed in the Innovation Report by PricewaterhouseCoopers. According to the results of a survey of 246 CEOs worldwide, innovation has become a function of senior management. The report concludes that the way a company is managed and the company's culture are the most important ingredients for innovation success—this includes room for creativity, a willingness to work together, and the readiness to challenge the status quo. The key to greater innovation, said one CEO, speaking for many others, is in creating an organizational culture that encourages and strengthens innovation at all levels.



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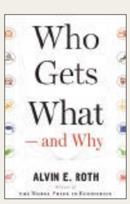
Who gets what and why?

US economist Alvin Roth, who received the Nobel Prize in Economics in 2012, has written a book that the *Washington Post* has described as recommended reading for "all innovation junkies." Between the market economy and legislative frameworks, Roth looks for the key factors that shape today's markets, the "matchmaking" between consumers and offerings. Roth, a game theorist, cites college admissions and the market in organ transplants as examples of the fact that the days when price determined everything are long over.



Alvin Roth, *Who Gets What—and Why:* *The New Economics of Matchmaking and Market Design,* Eamon Dolan/Houghton Mifflin Harcourt, New York 2015

What inhibits innovation ?

A new study commissioned by the German chemical industry association VCI and conducted by IW Consult and Santiago Advisors provides answers to this question. Nearly 200 companies from Germany's third-largest industry participated. The results show that internal and external hurdles impede research and development to the same degree. First, we must remove unnecessary bureaucracy and simplify complex regulations. Second, further promotion of the culture of innovation within the company must be a priority. One of the recommendations of the study's authors is a stronger focus on disruptive innovation and new business models. Companies should venture into more partnerships and participate in attractive start-ups.

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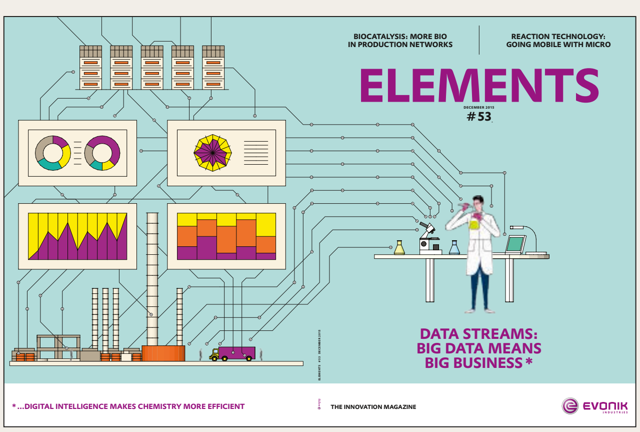

Photography: Ingo Pertramer

THE COVER #53

From the creativity of the researcher in the laboratory to operation of a large-scale plant: Digital technologies generate enormous amounts of data from experiments, process development, production monitoring, material flows, sales, logistics, and marketing. Big Data analysis turns this data into a valuable raw material for the optimization of processes.

Masthead

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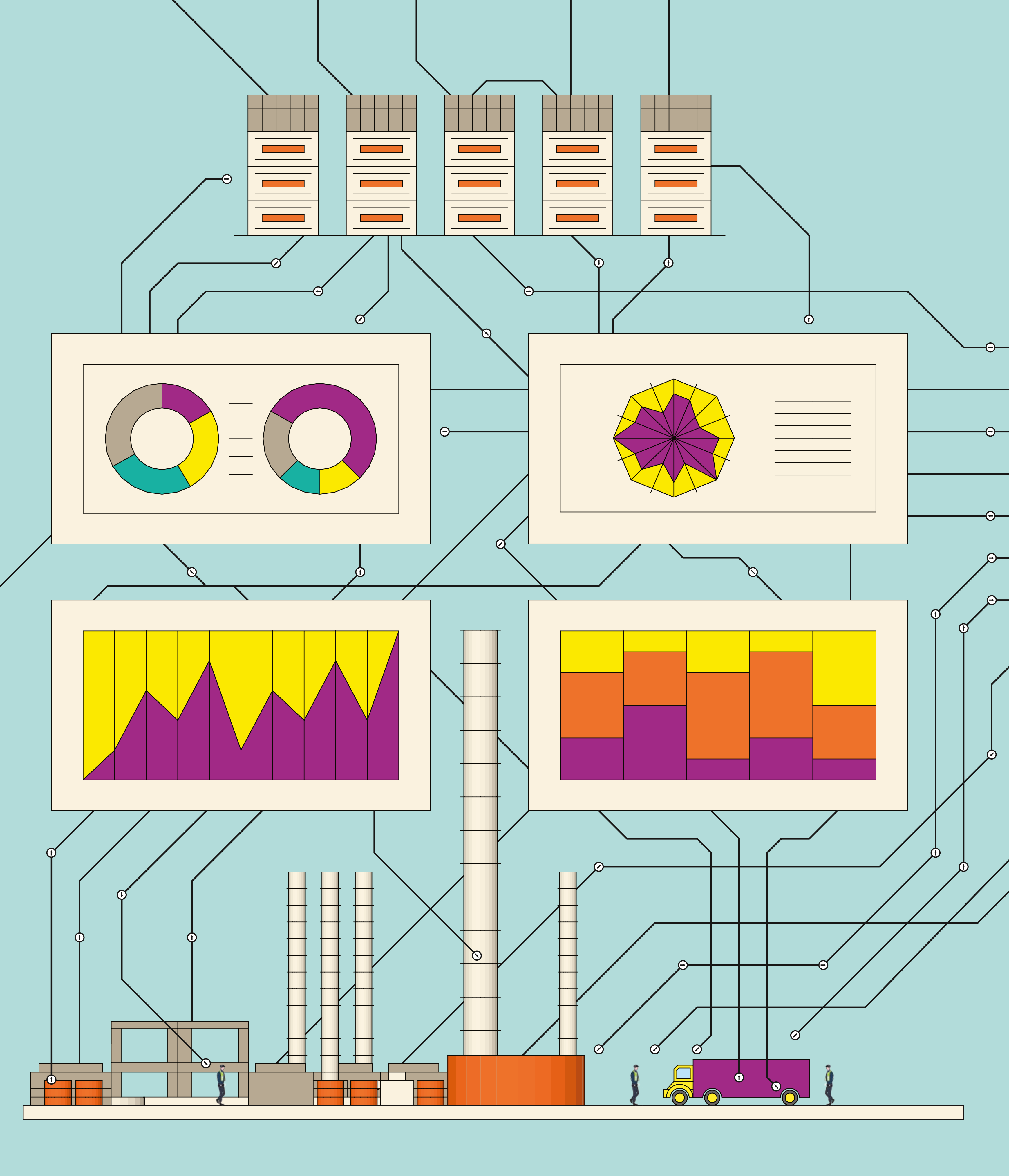

*** ...DIGITAL INTELLIGENCE MAKES CHEMISTRY MORE EFFICIENT**