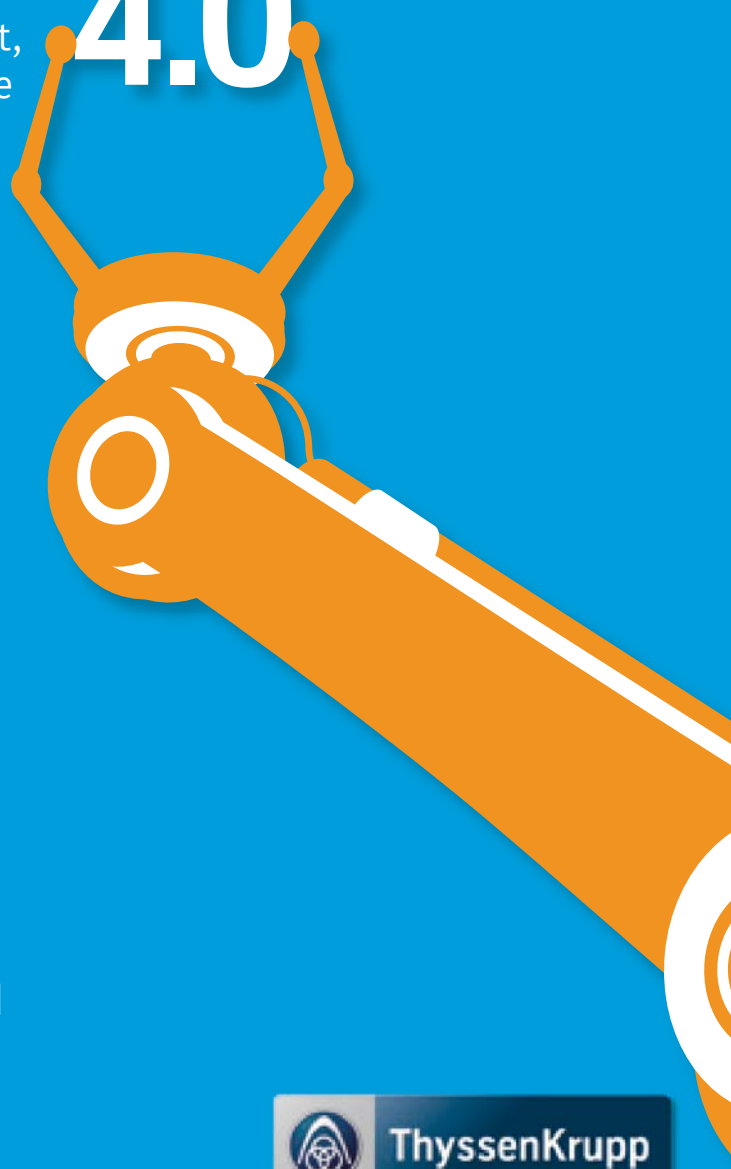




INDUSTRY 4.0

Flexible, efficient,
connected: the future
of manufacturing
starts now



AN ELEVATOR WITHOUT A CABLE

With MULTI, ThyssenKrupp is bringing the technology of the Transrapid train into skyscrapers

MILESTONE IN CHLORINE PRODUCTION

A new process can almost halve energy consumption

A TOWER FOR ALL SEASONS

The flexible TetraFlex concept is ideal for repowering wind farms

German government and industry plan to invest jointly up to **€400 million** in the development of **Industry 4.0**.

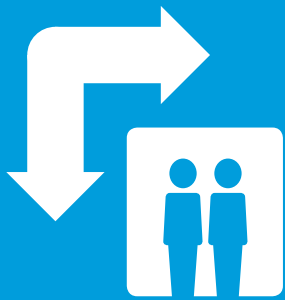
→ MORE ON THIS SUBJECT IN OUR COVER STORY STARTING ON PAGE 8.

RESOURCE EFFICIENCY IN
MANUFACTURING
IS EXPECTED TO RISE BY

30 to 40%

AS A RESULT OF INDUSTRY 4.0.

→ SAYS ACATECH PRESIDENT PROF. DR. HENNING
KAGERMANN IN THE INTERVIEW ON PAGE 16.



THE NEW MULTI
ELEVATOR
TECHNOLOGY FROM
THYSSENKRUPP
ELEVATOR IS
PARTICULARLY WELL
SUITED TO BUILDINGS
BEYOND A HEIGHT
OF 300 METERS, AND
WILL FACILITATE
COMPLETELY NEW
BUILDING CONCEPTS.

→ WE PRESENT THE REVOLUTIONARY
TECHNOLOGY ON PAGE 22.

→ A new civilian
submersible from
ThyssenKrupp Marine
Systems is almost **100
meters** long – much
longer than an A380.

→ WE EXPLAIN HOW IMPORTANT THIS IS FOR OIL EXTRACTION ON PAGE 36.

Thanks to the new oxygen-depolarized
cathode from ThyssenKrupp Electrolysis, chlorine
production will in future use at least

30%
**LESS
ENERGY**

→ WE EXPLAIN HOW THIS IS ACHIEVED ON PAGE 32.

ELECTRIC
STEERING
SYSTEMS FROM
THYSSENKRUPP
PRESTA
REDUCE FUEL
CONSUMPTION
BY UP TO

0.3
LITERS
PER
100
KILOMETERS

Wind power plants
could become up to
200 meters high with
the new TetraFlex towers
from ThyssenKrupp
Steel Europe.

→ WE INTRODUCE THE TEAM BEHIND THIS INNOVATION ON PAGE 48.

→ MORE ON PAGE 38.

Dear readers,

The internet is just a passing fad." This was said by no less a person than Bill Gates. That was in 1993, and the founder of Microsoft, who was otherwise so successful, was very wide of the mark on this occasion: As early as 1994, ten million people across the globe were surfing the internet, and now around three billion have access to that worldwide network.

Today, barely 26 years after the computer scientist Tim Berners-Lee laid the foundations for the World Wide Web, we stand once again on the threshold of a new technological age. This project is called "Industry 4.0," and the debate surrounding it is similar to what we saw in the early days of the internet: To some, Industry 4.0 is no more than a buzzword – a new fad. To others, it is the start of the fourth Industrial Revolution.

At the same time, Industry 4.0 has been clearly defined: it is a new stage in the organization and management of the whole value chain throughout the life cycle of products, including related services. The basis is the availability of all relevant information in real time through the networking of all entities involved in value creation. This generates dynamic, self-organizing value-creation networks, which can be optimized according to various criteria.

We at ThyssenKrupp are certain that Industry 4.0 will triumph in a similar way to the internet. The digital networking of factories and machines, and of customers, suppliers, and producers, is a fundamental transformation. For this reason, we are actively involved not only within our own company – we are also helping to define this concept in Germany. Our country is currently regarded as a pioneer in manufacturing for the future, and has a good chance of gaining a leading position in this field for the long term. However, this requires industry to adapt as swiftly as possible to the new challenges.

Yours,



DR. REINHOLD ACHATZ,
Head of Technology at ThyssenKrupp AG





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ThyssenKrupp is banking on Industry 4.0 and optimizing its manufacturing.

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Megacities: Home to billions of people, and a central challenge of our age.

DIGITAL PLATFORM ON THE MEGATREND OF URBANIZATION

It is estimated that, by the end of this century, 10 to 11 billion people will be living on the Earth – around 70 percent of them in urban areas. Sustainable planning of the megacities of the future is, therefore, a central challenge of our age. For this reason, ThyssenKrupp has used the Smart City Expo in Barcelona to introduce the digital platform Urban-Hub.com, where ideas for all aspects of urbanization are presented, from innovative solutions for local passenger transportation to intelligent buildings and sustainable infrastructure. The range of topics covered is rounded off by reports on pioneers of intelligent urbanization. Urban-Hub.com is available initially in English, German, French, Spanish, and Portuguese, and is also due to be offered in Chinese in the second phase.

Metal parts out of a printer

ThyssenKrupp and the Fraunhofer Institute for Laser Technology (ILT) in Aachen are working together on a project to look into the widescale industrial use of Laser Additive Manufacturing (LAM). In contrast to the widespread 3D printers, which work using synthetic powder, the project partners intend to use steel powder to produce metal parts that are new in function and form. The idea is to fuse the individual powder particles with a laser. “We want to know whether LAM is of interest to ThyssenKrupp. Does it threaten established processes, and which customer requirements can the technology satisfy?” explains Markus Oles, Head of Innovation Strategy and Projects at ThyssenKrupp. As a first step, the project partners are planning a LAM service center, as an offering for companies that do not find it economic to buy a professional 3D printer costing between 600,000 and one million euros. A market and customer-requirements analysis is expected to show whether there is sufficient demand for such a service. The costs and benefits of LAM-produced parts will be put to the test in consultation with customers. A decision will then be taken on how to proceed further.

GERMAN PACKAGING AWARD 2014 FOR STEELCARE

The technology network composed of the companies Lanico, Schuler Pressen, and ThyssenKrupp Rasselstein has won the German Packaging Award in the cosmetics and hygiene articles category. The judging panel of experts from industry, research, teaching, and the trade press granted this award for the innovative “SteelCare” aerosol can, which has outstanding qualities that enable it to protect its contents especially well. The concept brings together specialized technical expertise in the field of presses, superior sealing technology, and thorough knowledge in the area of packaging steel. This prize is considered the most prestigious packaging award in Europe, and it attracted a total of 230 entries from manufacturers and suppliers in 2014.

Prestigious: The coveted German Packaging Award went to the innovative SteelCare can.



Triumphant winners: Toni Eggert and Sascha Benecken celebrate victory in Calgary (Canada).



Decisive milliseconds

**MORE THAN
140
KILOMETERS PER
HOUR – THE SPEED
ACHIEVED BY THE
LUGE DUO IN THEIR
VICTORY IN THE
WORLD CUP AT LAKE
PLACID (USA).**

ThyssenKrupp has made the successful two-seater luge team of Toni Eggert and Sascha Benecken from Thuringia even faster: experts from the camshaft technology center in Liechtenstein in Alex Meier's team not only provided their expertise to improve the material for the runners – they are also giving the luge the benefit of their experience in the development and production of camshafts, and optimizing other metal components in sleds. The deployment of this concentrated engineering knowledge is paying dividends: this season Toni Eggert and Sascha Benecken are moving from one success to the next.

ThyssenKrupp consolidates its IT

Data-processing systems and services that were previously housed in around 700 data rooms and eleven computing centers at ThyssenKrupp were transferred to five global data centers at the end of 2014. The Group is also migrating more than 80,000 computer workstations and 10,000 server systems worldwide to the cloud, from where employees will in future be able to access services and applications – a move that will make it easier to exchange data and documents and to cooperate internationally. The project is being carried out by the Deutsche Telekom subsidiary T-Systems, and is part of ThyssenKrupp's IT harmonization.



On the way to Industry 4.0

Developers at ThyssenKrupp are working on manufacturing for the future – for their own products, and as partners for industry.

TEXT: BURKHARD STRASSMANN

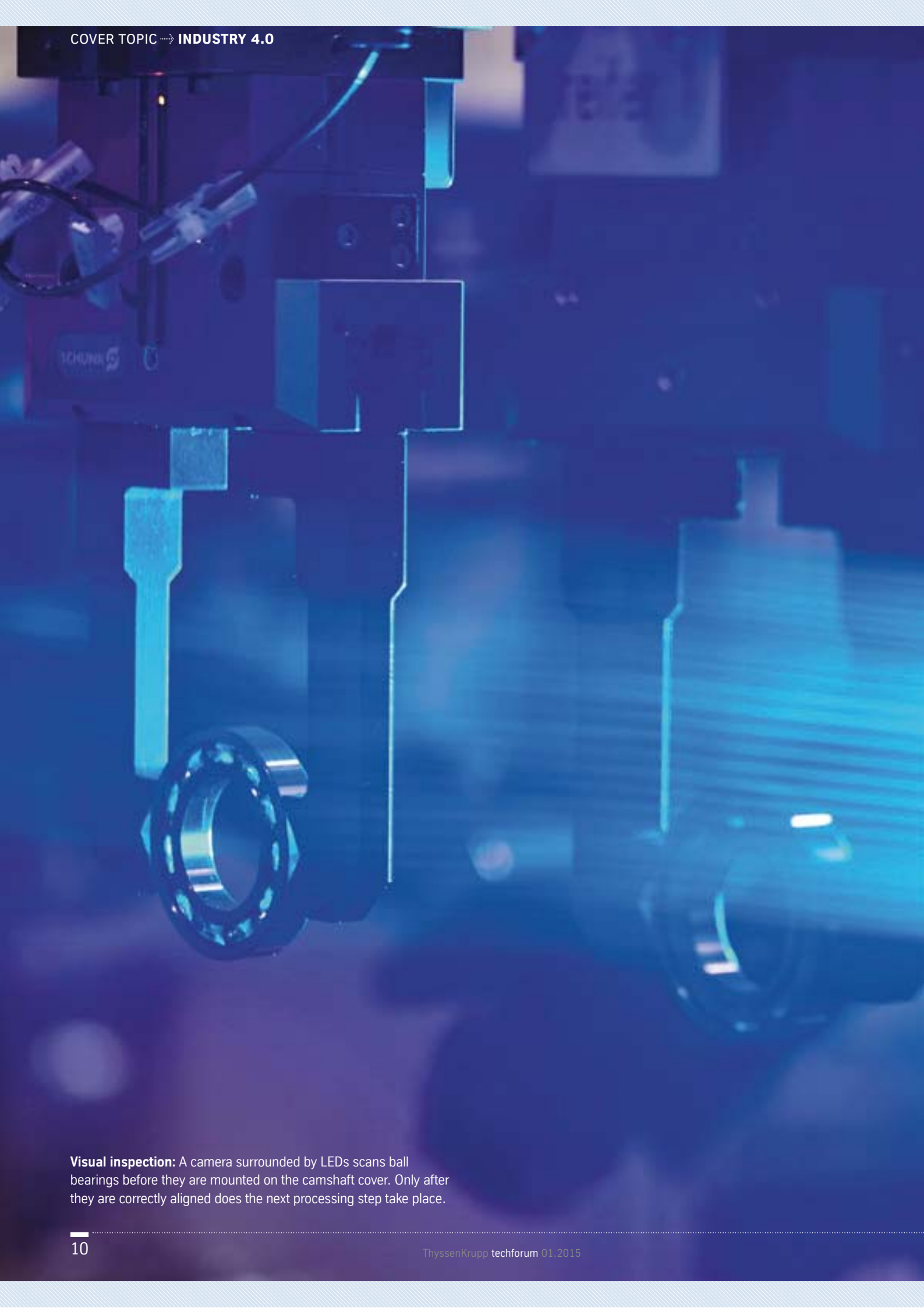
PHOTOS: GÖTZ SCHLESER

Ilsenburg on the edge of the eastern Harz area. A large hangar in an industrial zone. Robots are moving about busily in assembly cells, indicator lamps are flashing red and green, and forklift trucks are on the go between yellow lines. In the middle of all this, a laser pointer is burning coded information onto a camshaft. This looks like an incidental process, but for the product it is a crucial step in its short life – and, for ThyssenKrupp Presta in Ilsenburg, this marking process is symbolic of their vision of manufacturing for the future. Here, this future has already begun.

A little earlier, the individual parts of the camshaft – shafts and cams – were still lying in large boxes, which likewise carried a bar code. The coded numbers of the batch had been affixed by the supplier. Before the individual parts were allowed into the first cell, their batch number was stored on an RFID chip on the small mounting trolley. The steel shaft and the intake and exhaust cams then disappeared into a hermetically sealed assembly cell, where they were “married up” – as they say here – by an industrial robot. After that, the cams were positioned immovably on the shaft at the correct angle to, and distance from, each other. Then came the crack testing. →



Experienced team: At this workstation, camshaft modules are greased and sprayed with oil. Two large robots transport the modules, while two smaller units supply the grease and oil.



Visual inspection: A camera surrounded by LEDs scans ball bearings before they are mounted on the camshaft cover. Only after they are correctly aligned does the next processing step take place.

→ “Up to this point, all we know about the camshaft is the batch from which its individual parts originate,” says Manfred Muster, division manager for project handling. It is still a non-entity – but as long as no cracks are found, the camshaft will now receive an identity: It will get a “name” lasered onto its side. From this very moment and for the rest of its life, the camshaft will carry in a Data Matrix code (similar to a QR code) information such as serial number, drawing number, part number, and customer identification. It now has proof of identity, because nothing can happen without a name from this point on: Every camshaft has to be registered individually with the next machine on its journey. “In this way, the machinery knows whether the product has the correct status and is actually allowed to be assembled on this machinery, or whether a prior step in the process has been missed,” Muster says.

Cyber-physical systems fuse things with data networks

In this way, the physical world of things is fused with data networks at Ilsenburg to form a single system, a “cyber-physical system” – and this is exactly how the future of industrial production is intended to look. The prerequisite is that as many elements in the production process as possible should have a name, a history, and a web interface. The goal is the “smart factory,” which is self-controlling, adaptable, and flexible. What flexibility means here, among other things, is the ability to manage small batch sizes. This means a move away from mass production and toward individualized products.

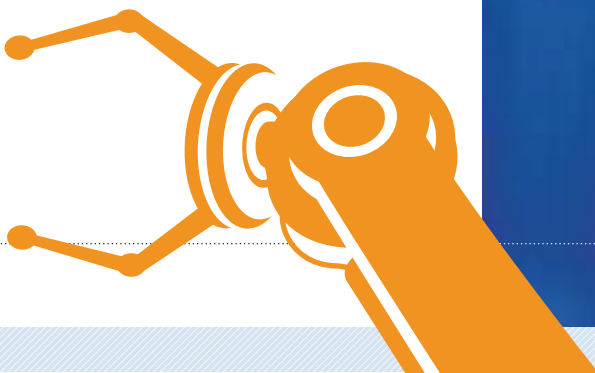
One product that is already made in a very individualized way is the automobile, and pressure to innovate is correspondingly high in that industry: Whereas only 31 percent of companies in mechanical and plant engineering use “intelligent” production facilities, the figure for automotive suppliers is as high as 80 percent, according to a survey conducted by the market research firm Pierre Audoin Consultants in 2013 on behalf of the IT service

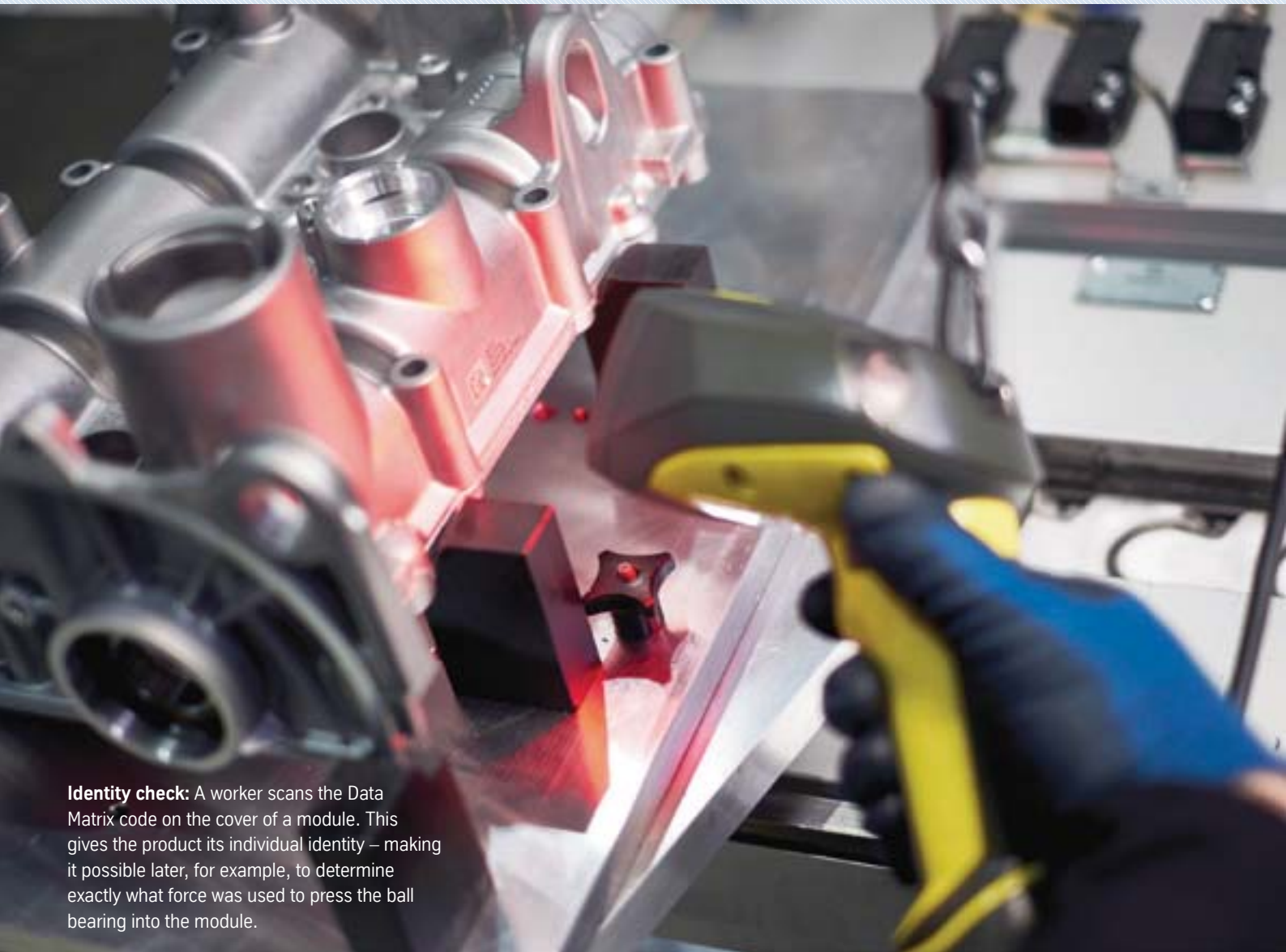
provider Freudenberg IT. “Automotive suppliers already need to be capable of guaranteeing on-demand production for their customers,” it says. This will soon also be the case for many other sectors.

The Ilsenburg plant is already providing a foretaste of this. In some places here, there are five large industrial robots in one cell working at high speed, presenting each other with parts to be cooled, heated, aligned, and pressed. Workers have one main task: to listen in to the automatic processes as they proceed, with bar code or Data Matrix code scanners, RFID readers, and tablets with data-acquisition modules. What they are monitoring here is not individual machines or processes, but the whole system – and a very modern one, too.

Around 650 workers at this plant are engaged in assembling camshafts. Unlike casting or forging, the process of assembling makes it possible to combine a variety of materials and, for example, to use high-strength materials in the cams. This process is cheaper, and it is possible to reduce the weight – but, on the other hand, this way of manufacturing is more complex. One kilometer away, at the new ThyssenKrupp Valvetrain production plant, they produce integral modules with the camshafts already built into the cylinder head cover. Around 150 workers are employed here. The two Ilsenburg plants together turn out around 11.5 million camshafts per year. They are global market leaders.

At both plants, the codes on the modules are checked again and again before the next step in the production process can happen – and then the decision to stop or go is taken immediately. “There are various exclusion criteria: NA, NIO, or ‘No number,’” Muster says. NA means “Not Applicable,” and NIO stands for “Not In Order.” To demonstrate his point, he swaps over an intake →





Identity check: A worker scans the Data Matrix code on the cover of a module. This gives the product its individual identity – making it possible later, for example, to determine exactly what force was used to press the ball bearing into the module.



Clear labeling: The Data Matrix code is reminiscent of the widely used 2D bar codes. The information connected with it is stored on ThyssenKrupp servers and forms a kind of “biography” for the product.



→ and an exhaust cam. By return, the next assembly cell sends the incorrectly sorted module back: “NA!”

Each camshaft has an identity and is linked to the net through an interface. It also possesses a memory. Muster calls the database behind this the “formulation,” and because it is instantly available at all times, it is easier to modify subsequent steps in the process in order, for example, to achieve better manufacturing tolerances. Assembly lines and machines can be influenced by a new “formulation” at any time. This is flexibility as understood in Industry 4.0.

Virtual: robots, machines, and control technology

It has to be acknowledged that assembled camshafts are put together with a manageable number of individual parts. However, one great advantage of Industry 4.0 is that the basic principles can be applied equally to machine elements and to complete production processes with a high degree of complexity. Thanks to rising computer performance levels and the continued development of software tools, this means that even whole factories, complete with machines, systems, and assembly lines, are now planned by computer.

The development of such systems – for example, for volume production of automobile bodies, engines, or transmissions – is complex and requires interdisciplinary cooperation among a variety of engineering disciplines. An additional complication is that, during the planning process and even at the implementation stage, customers intervene again and again with requests for improvements and changes. Here, flexibility is crucial, and this explains why it is a key element in Industry 4.0.

The methods and tools used in digital plant development are brought together in the generic term “digital factory.” One of the tools used here is Virtual Commissioning (VC): The planning of a plant is carried out solely by computer, and it is then commissioned virtually – albeit with operating equipment and control programs for the machines and robots. VC systems have

“We are interested in the whole value chain, from product development to the end of the product’s life cycle. Industry 4.0 applications are of great importance to us, and this is also true when we need, for example, to make sustained improvements to our energy management, the maintenance and repair of equipment, or logistics and service processes.”

DR. KARSTEN KROOS, CHAIRMAN OF THE
MANAGEMENT BOARD OF THE COMPONENTS
TECHNOLOGY BUSINESS AREA
AT THYSSENKRUPP AG



been used increasingly in recent times. “ThyssenKrupp is not merely making use of these systems, but is also developing the methods further,” says Matthias Hartmann, Vice President Product Management at ThyssenKrupp System Engineering (TK SY). This is no surprise, because TK SY is one of the leading companies in the world for production facilities for the automotive industry. The company plans and builds plants worldwide for assembly systems – the assembly of engines and transmissions – and body-in-white (BIW) construction. This ThyssenKrupp subsidiary employs 3,800 people worldwide. Its customers include both the automotive and aerospace industries.

Virtual testing reduces commissioning time

BIW construction can occupy an area the size of several soccer pitches. A few hundred robots are engaged in putting together a complete BIW out of individual sheet metal parts. These are supplemented by, among other things, materials-handling equipment between the individual stations, fixtures to hold the components, and joining technology – such as welding tongs for joining the sheet metal parts together. These complex systems are backed up by extensive control technology.

“All robots, machine islands, and control elements are assembled and tested virtually in a 3D simulation,” Hartmann explains. This reduces development costs and commissioning times, safeguards process and product quality – and, of course, cuts production costs. However, he says, the main argument for virtual, computer-based development is “to turn up at the customer with a virtually validated line and to reduce commissioning time there.”

For assembly systems, Hartmann demonstrates a turbocharger test station. Two years ago, they had the idea not merely of completely developing such a station digitally, but also of displaying it in a virtual reality tool. This means it is possible to make a virtual walk-through of the facility. “This enables us, for example, to identify the best place →

Business processes unconfined

At ThyssenKrupp, the **Hoesch Hohenlimburg hot-rolling mill** in Hagen is a good example of the topic for the future that is Industry 4.0, because its process-related and digital networking extends far beyond the confines of its own company. It has thus put one aspect of Industry 4.0 into effect: integration across business processes for whole value chains – for example, in its close collaboration with the raw-material supplier HKM (Hüttenwerke Krupp Mannesmann) in Duisburg, in which ThyssenKrupp holds a 50-percent stake.

That company works almost exclusively to produce slabs for Hoesch Hohenlimburg (HHO) on a **continuous-casting line**. Booking is carried out directly by HHO. This makes it possible to have the steel blocks cast at short notice according to schedules requested by HHO's customers (such as cold-rollers).

Meanwhile, Hoesch Hohenlimburg's customers can also influence production in Hagen on a "just-in-time" basis. In addition to the direct booking of orders on the HHO system in the form of coordinated, fixed, or variable **material specifications**, and open information on the internal production process, the customer can determine for himself, in 65 percent of orders, when his hot strip is to be rolled.

The advantages for customers are obvious: first, **flexibility in scheduling** their own orders; second, the opportunity to adjust material properties, such as thickness or width, to their requirements until shortly before rolling begins. For HHO's production and logistics staff, this is a challenge that requires the integration of commercial, administrative, and technical data ("from shop floor to top floor").

→ for maintenance access and valve connections, or the ideal position for the console," Hartmann explains. "We can also present our products graphically and in detail to our customers all over the world: a compact 3D projector is all we need."

Despite all the progress, virtual engineering still has a lot of untapped potential. The goal is "seamless engineering" – meaning that virtual development manages completely without data breaches or media disruption. "In computer-based plant design today, there are still a lot of software tools that are not adequately networked and compatible with each other," Hartmann explains. They work with a variety of data formats, and the transfer of data between systems leads to additional effort – which is not just a time issue, but also a potential source of errors.

Uniform data pool without media disruption

Data breaches and media disruption are also risks that need to be reduced in the long term beyond the digital world of plant developers, in the reality of production lines. Here is one example. A facility has been designed virtually in a 3D CAD system, and then there is an extensive data pool that describes the whole system in terms of its technical data, designs, manufacturing processes, and vendor parts. This also includes parts lists detailing every individual component.

But what is the installer in the assembly shop going to use for guidance? The answer: plans printed on paper. The effect of such a media disruption is that any design modification will need first to be communicated in a time-consuming manner and with a lot of process stages. Also, every time it is printed out on paper, there is the risk that it will no longer be the most up-to-date version. "This will create redundant data, which may also contradict each other," Hartmann says, describing the problem. The solution is known by Industry 4.0 experts as the "Single Point of Truth," meaning a single data pool that is always available. In Hartmann's words, "we are looking

here for ways of bringing workers in the assembly shop more closely into the world of digital planning." A start has already been made: for example, assembly hall workers already work with tablet PCs, which they use to call up directly the latest planning data for their piece of machinery.

Combining with commercial data

In the future, it is also planned to combine design and process data with commercial information. This would enable sales staff to use their computers to access production data and, conversely, give assembly planners a quick overview of the state of the order books. Hoesch Hohenlimburg, a Group company in the Steel Europe business area, illustrates how this can work in practice. This rolling mill is a specialist provider of hot-rolled steel strip in the Lennetal area. Together with IBM and in collaboration with Siemens, the plant has implemented an Industry 4.0 solution that integrates commercial, administrative, and technical data, and thus facilitates business processes that pull value chains together (see also the box on this project). At Hoesch Hohenlimburg's medium-wide strip mill, coils are rolled from slabs. IBM uses its "Integration Bus" to combine data from production (such as pickling, balances, measuring stations, and laboratories) with the superordinate manufacturing execution and enterprise resource planning system, without any need for intermediate data pools. "The Integration Bus speaks many languages and can semantically connect data from a variety of sources and process levels," says Ulrich Schneppe, head of IT at Hoesch Hohenlimburg.

The collaboration between IBM and Siemens in the Hohenlimburg project has now made it possible to read the Simatic S7 programmable logic controllers directly and to integrate that information instantly into overlapping business processes without intermediate storage. "In this way, we are coming ever closer to the 'Highlander principle of data': there can be only one truth," Schneppe smiles.





Checkpoint: The Ilsenburg plant produces 25 different types of cam. Here, a laser scanner is looking at an indentation in the product to check whether the right type is on the transport plate for the next processing step.



Connected: Nothing happens at the Ilsenburg plant without IT. All production facilities are part of the network, ensuring a smooth, efficient manufacturing process.

RECORDED BY: CHRISTIAN BUCK
PHOTOS: GÖTZ SCHLESER



Copernican revolution in industry

The manufacturing of the future is highly customized, self-organizing, and resource-saving. In an interview acatech President Prof. Dr. Henning Kagermann explains where Germany stands and why Industry 4.0 is important for our prosperity.

techforum: Why is Industry 4.0 such an important topic?

Henning Kagermann: Because it allows companies to produce individualized products for the price of a mass produced item, opening up a new dimension of industrial manufacturing to them. It also provides a high degree of flexibility, thus increasing their ability to withstand shocks in volatile global markets. Finally, we can shift more production back to our high-wage country once again, because in Industry 4.0 knowledge and ability count. The environment benefits from Industry 4.0 as well: according to estimates, resource efficiency in manufacturing could rise by 30 to 40 percent.

techforum: How can that be achieved?

Kagermann: First, through the further merging of the real and virtual world by means of cyber-physical systems. As a result, every object will have a digital model in future with which we can do many things in virtual space. For instance, much better simulations of products and production processes will be possible, meaning that less energy and resources have to be expended in trial runs. Also new is the increasing connectedness within manufacturing and along value chains. This leads to a higher degree of automation, improved manufacturing quality, faster innovation cycles, and lower consumption of resources. Since all physical objects can be interconnected via the internet, we can, for example, make just-in-time logistics even better and prevent machine failures through predictive maintenance. Both prevent idle periods in production, thus saving resources.

techforum: The manufacturing of the future needs to be decentralized and to run autonomously. How realistic is this scenario?

Kagermann: That is the logical consequence of the Industry 4.0 approach, because increasing networking and centralized production control are not compatible – such a system would be too rigid and inflexible. In future, therefore, the conventional control pyramids are set to dissolve: The intelligence will



“We should be a leading market for Industry 4.0”

migrate to small units such as tool carriers or vehicles that interact autonomously. In this respect Industry 4.0 is similar to a Copernican revolution. The self-organization of manufacturing is the only way to implement Industry 4.0.

techforum: Are established providers of central control systems facing the threat of sliding into insignificance?

Kagermann: I do not believe that, because these companies have gathered a great deal of know-how and practical experience in recent decades, and they have a precise understanding of the processes in manufacturing. It is conceivable, however, that new providers will pick out and occupy lucrative parts of the value chain. I have experienced that with SAP in ERP systems: Salesforce has occupied a small and very attractive segment in customer relationship management and left the less attractive parts to others. This can also happen with Industry 4.0, aided by the fact that we can now interlink various basic services

via software-defined architectures. That makes it easier for new providers to pick out the prime cuts.

techforum: How strong is Germany in the key technologies for Industry 4.0?

Kagermann: We are world leaders in some of them. Our companies are very strong in embedded software that controls machines or cars. We also know a lot about company software that is hugely important for the vertical integration of data. Then there is our vast expertise in semantic technologies for machine-to-machine communication and in the real-time analysis of large volumes of data. What we lack a little is major suppliers of internet technologies and cloud computing as well as a feel for the B2C market – yet that is especially important, because Industry 4.0 also makes individual products possible. What is more, customers will demand isolated products and services less, opting rather to put together individual packages from products and services: smart services. For example, car ownership is becoming less important for young people – they combine car-sharing and other modes of transport as needed in order to travel conveniently from A to B. Much will depend on these intelligent services and business models. Only those who intelligently interlink smart services and Industry 4.0 can expect to be successful.

techforum: Other countries are also focusing on the manufacturing of the future. Can only one country win this race?

Kagermann: No, several bases will be established. It is our task in Germany to remain at the cutting edge of development and to implement the technology successfully. We should be a leading market for Industry 4.0 – otherwise we will quickly drop down the ranking of the most competitive nations. And we should remain a leading supplier of state-of-the-art production technologies. Our prosperity and full employment in the future therefore depend on Industry 4.0. Not being successful is simply not an option. ←

World Wide Race

Other nations are also working on manufacturing for the future. An overview of the activities in Europe, Asia, and the USA.

TEXT: CHRISTIAN BUCK

Germany is not the only place where companies and researchers are wondering about the future of industry. “Everywhere in the world policymakers and businesses are facing the same issues,” reports Professor Jürgen Jasperneite of the Institute of Industrial Information Technology at the Ostwestfalen-Lippe University of Applied Sciences and of the Fraunhofer Application Center for Industrial Automation in Lemgo. “The focus is on increasing digitization and its impact on production processes and industries.” It therefore comes as no surprise that governments and companies elsewhere have launched research programs along similar lines.

Everyone is agreed on the objective: the manufacturing of the future should be efficient, environmentally friendly, and highly customizable – these are also the central goals of the German Industry 4.0 project. Individual countries have different starting positions, however, which have an impact on the main focuses of their research programs. Whereas Germany is traditionally seen as the “world’s supplier” and therefore relies heavily on its extensive know-how from individual industries, the USA has the reputation of the “world’s networker” and places a stronger emphasis on the IT aspects of the topic. This is also illustrated by the name and the member companies of the Industrial Internet Consortium, which is the US counterpart of the Industry 4.0 initiative in Germany.

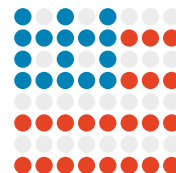
Internet of things as the platform

Experts believe that the individual initiatives will apply similar basic technologies – such as the internet of things as the platform for the networking of sensors, products, and systems. It is very likely that many countries will make a contribution to the production of the future. To this end, basic standards need to be defined so as to enable machines to communicate with one another, for instance. “We want to be the leading market and leading supplier of the production technology of the future,” stresses Professor Wolfgang Wahlster, CEO of the German Center for Artificial Intelligence, with sites in Saarbrücken, Kaiserslautern, Bremen, and Berlin. “Other countries are also set to benefit, because Industry 4.0 allows them to raise their production to a new level.” ◀

USA

Industrial Internet Consortium

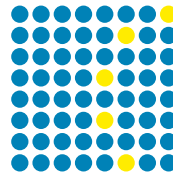
The Industrial Internet Consortium (IIC) was established in the USA in March 2014. It comprises more than 100 companies, including General Electric, IBM, Intel, AT&T, and Cisco, all working on technologies for the production of the future – with German heavyweights such as Siemens and Bosch among them, too. Since many IT specialists are involved in the IIC, one of the focal points is on the internet of things and the interlinking of the factories of the future. The IIC’s vision is largely consistent with the goals of Industry 4.0: to make production more efficient and to optimize value chains. In addition, the companies are striving for higher machine availability and the cost-effective manufacture of customized products.



Europe

Initiatives at EU and national level

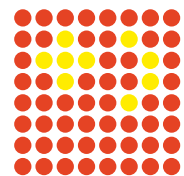
Alongside Germany's Industry 4.0 project the EU and individual countries across the continent have set up their own activities aimed at preparing for the production of the future. At European level, Industry 4.0: Powering Europe, a German-led high-impact initiative, has been launched at the ICT Labs of the European Institute of Innovation & Technology (EIT). Its aim is to bring about a rollout of cyber-physical platforms across European smart factories. There is also the Factories of the Future public-private partnership aimed at supporting mainly small and mid-size companies in their efforts to stay successful in global markets in the future. Individual countries are also active: Finland intends to spend some €100 million on its Industrial Internet program by 2019, while Austria plans to inject around €250 million into its vision of Industry 4.0. France, the UK, and the Netherlands have likewise launched their own initiatives.



Asia

Core technology catch-up

The Chinese government is seeking to develop intelligent production systems on the basis of ubiquitous information and communication systems under its Advanced Manufacturing Technology Roadmap, which extends as far as 2050 and defines milestones for the years 2020 and 2030. It is the country's aim in core production technologies – such as in the automotive industry – to be less dependent on imports. This is also reflected in the current five-year plan, which designates advanced manufacturing equipment as a field of especially high priority. The activities of other countries such as Japan or South Korea are less well known. The many visits by delegations to Germany demonstrate, however, that there is huge interest in this topic in those countries as well.



Industrial work



to become more attractive

All levels will be affected by the changes that Industry 4.0 will bring in the working world. For the industrial sociologist Hartmut Hirsch-Kreinsen this will open up new opportunities for employees.

TEXT: PROF. DR. HARTMUT HIRSCH-KREINSEN ILLUSTRATION: BIANCA CLASSEN

Industry 4.0 will have significant implications for the working world that will affect all direct and indirect value-adding activities in industrial enterprises. This means production employees at the operational level, as well as the junior and middle managers of manufacturing processes together with technical experts.

New demands on the man-machine interface

Man-machine interaction will be one of the central challenges. The main issue here is the extent to which employees are still able to control the system and to assume responsibility for its opera-

tion. The reason for this is their growing distance from the complex sequences in the production process – as a result of which operating personnel may no longer be able to assess correctly the status of their systems and may make the wrong decisions if they intervene in the automated process. Research refers in this context to the “ironies of automation”: Automated processes produce, owing to their routine nature, situations that are difficult to manage in the event of malfunctions. The man-machine interface must therefore ensure that a sufficient number of qualified employees are able to perform their supervisory tasks effectively.

The operational level requires new qualifications

A further central challenge is the organization of tasks and job structures at the operational level. I assume that many jobs requiring low qualifications and involving simple, repetitive tasks will be replaced by intelligent systems – such as in logistics, in machine operation, and in data acquisition and input. At the same time, skilled workers could face the prospect of deskilling: It is possible that tasks such as machine operation and various control and supervisory functions will be automated. This also applies to scheduling decisions in production logistics, because the

systems can request the goods required themselves to a large degree.

At the same time, we are also expecting upskilling and job enrichment elsewhere. The reasons for this are the increased complexity of manufacturing as well as the decentralization of decision-making, control, and coordination functions – the employees affected increasingly have to plan and coordinate processes on their own, calling for a broader understanding of the whole production process, logistics, and delivery conditions, for example. In addition to this overview knowledge, social skills are required, because the integration of once separate operating units creates a growing need for interaction with different groups of people.

Consequences for indirect areas and management levels

It is expected that Industry 4.0 will provide impetus for decentralization and the dismantling of hierarchies within what are often factories with an already relatively flat organizational structure: there are some signs that owing to the decentralized self-organization of systems and flexible organization of work at the operational level a proportion of the planning and control duties are delegated “downward” – tasks for which technical experts and production managers are currently responsible.

In addition, a range of tasks in indirect areas could be automated and thus simplified or even replaced altogether. Depending on the system configuration, these can be planning and control tasks, maintenance and service activities, as well as quality assurance duties.

Finally, increased complexity should result in expanded and new planning tasks for these areas. There are some indications, for example, that troubleshooting tasks will gain in importance greatly. Moreover, previously separate tasks and skills – such as IT and production expertise – could well merge at the planning and management level.

This evidence shows that planning and management areas will be affected by Industry 4.0 in the long term just as much as the operational level. What is more, I assume that this change and a reorganization of management levels

are an indispensable prerequisite for mastering the new technologies.

New forms of work organization

These findings show that a fully automated humanless factory is not a realistic prospect for both technological and economic reasons. At the same time, there is no discernible magic formula for optimally organizing the work on smart production systems. I am therefore taking a broad range of diverging patterns of work organization as a basis.

One extreme is the “polarized organization”: It has, on the one hand, a small number of simple tasks with little or no room for maneuver – particularly for standardized supervisory and control duties. On the other hand, there is an expanded or even newly formed group of highly qualified experts and technical specialists whose qualifications are well

above the previous skilled labor level. They are responsible not only for tasks such as overcoming faults, but also for aspects of production management.

The other extreme is an approach to work organization that can be described as “work swarming” and is characterized by loose networking among highly qualified employees of equal ranking: there are no longer any defined tasks for individual employees – rather, the workforce acts depending on the problems to be solved in a self-organizing, highly flexible, and situation-specific manner. This pattern of work organization utilizes informal social processes of communication and cooperation, as well as the process know-how of employees.

In the long term hybrid forms and interim solutions will probably come together from these two extremes. They show that in the introduction of Industry 4.0 companies not only have organizational and personnel policy options but also, depending on the specific operating situation, can combine with them very different social and economic effects. ←

“The humanless factory is not a realistic prospect”

PROF. DR. HARTMUT HIRSCH-KREINSEN

Prof. Dr. Hartmut Hirsch-Kreinsen is Chair of Economic and Industrial Sociology at the Technical University of Dortmund.



The Holy Grail

ThyssenKrupp is ushering in a revolution with its innovative **MULTI** elevator concept: cabs move without a cable and can even go sideways. This opens up completely new possibilities for architects.

TEXT: CHRISTIAN BUCK



Closed circuit:

MULTI combines the elevator with the paternoster principle for the first time. The cabs can also move horizontally and connect neighboring skyscrapers to each other.



25

PERCENT
more usable
area and living
space in build-
ings – this can
be achieved
with MULTI.

For more than 160 years, it was all very simple: an elevator is a cab that is pulled up or lowered down by a cable in a shaft. There had been no fundamental change to this principle since its invention in 1853, until ThyssenKrupp publicly presented a revolutionary new concept in November 2014: MULTI. The Group intends to use this not merely to optimize passenger transportation in skyscrapers, but also to open up completely new possibilities for architects. In the future, they will be able to erect even higher buildings, because MULTI will enable their residents to be transported many hundred meters up and back down in a manner that will both be faster and save more space.

The most striking difference between conventional elevators and MULTI is this: the ThyssenKrupp innovation manages entirely without something that was thought to be indispensable – a cable. “Instead, we use a linear motor, as in the magnetic levitation train Transrapid,” explains Dr. Friedrich Löser, Head of the ThyssenKrupp TechCenter Control Technology in Munich. “The cab is driven by moving magnetic fields, and rollers in rails ensure stable movement. In other words, the elevator runs in a very similar way to a train.” Although there is no longer a cable, there is no danger to passengers even in the event of a power failure: MULTI stores enough energy to enable each cab to reach the next level safely. The braking system will also work perfectly in that situation, because it will engage automatically without electricity.

Any number of cabs in a shaft

The new drive concept opens up completely new possibilities for passenger transportation: with no need for a cable, any number of cabs will in future be able to share one elevator shaft, which means a marked increase in flexibility and transportation capacity. ThyssenKrupp took a first step in this direction as early as 2003. This was when the Group presented the TWIN system, which had two cabs moving independently of each other in the same shaft – albeit still driven by a cable. This alone reduced the amount of space required by up to 30 percent, while at the same time increasing transportation capacity.

“The vertical and horizontal movements of MULTI with several cabs per shaft are a turning point in the history of elevator systems.”

ANDREAS SCHIERENBECK, CHAIRMAN OF THE EXECUTIVE BOARD,
THYSSENKRUPP ELEVATOR AG



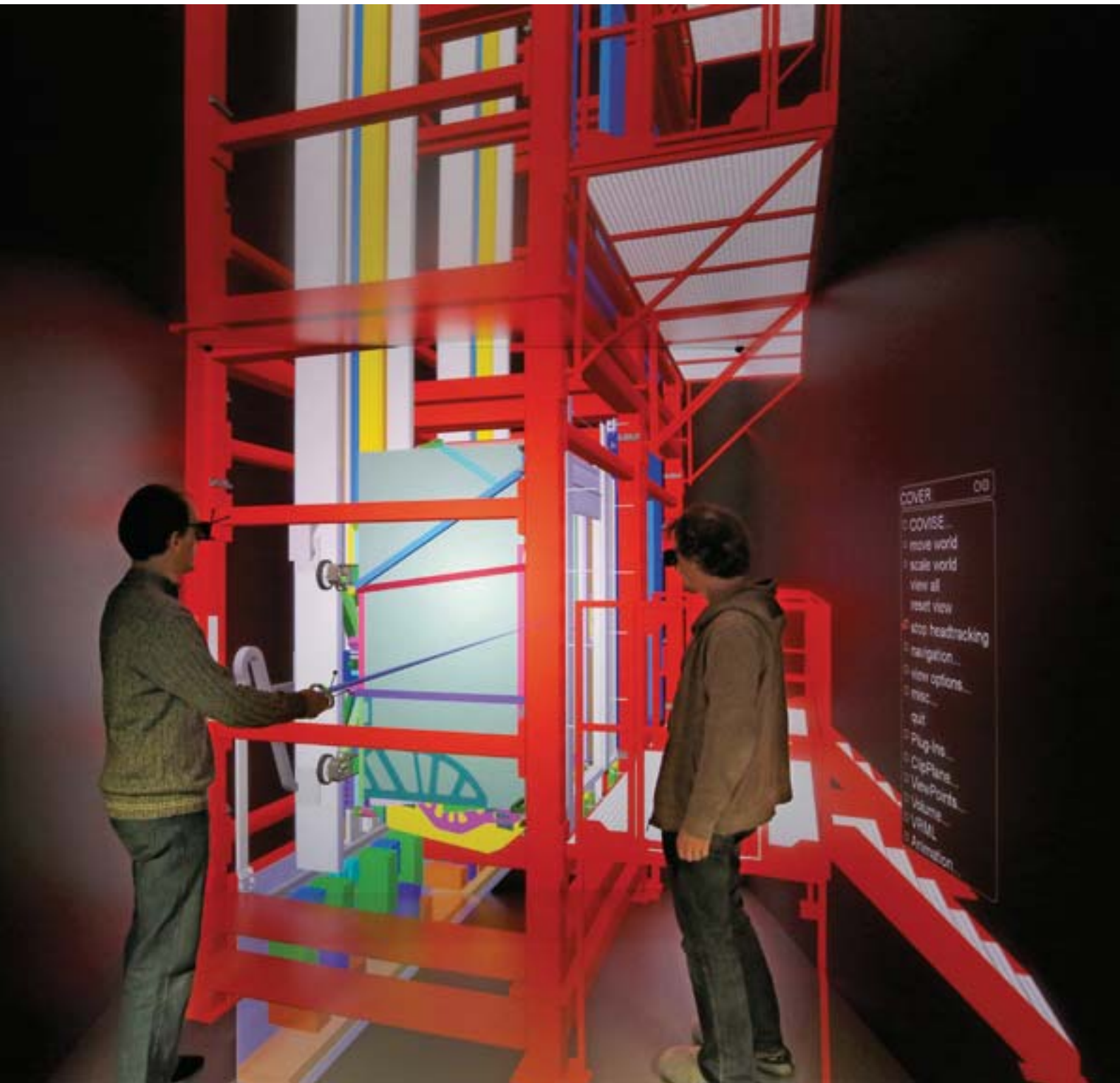
MULTI goes a key step further, because this system combines the elevator with the paternoster principle: several cabs use one shaft for their ascent, and then descend in a parallel shaft. This is where another unique feature of MULTI comes in: the linear drive enables the cabs to move not just vertically, but also horizontally – in principle, MULTI is a miniature local transportation system, one that does not extend along one level, but is aligned vertically upwards. In theory, this could even enable neighboring skyscrapers to be connected to each other.

“MULTI provides a closed circuit where many cabs are on the move at the same time, which allows many more passengers to be carried within the same space requirements,” explains Markus Jetter, Head of Research for ThyssenKrupp Elevator in Pliezhausen near Stuttgart. “In addition, the system is able to adapt transportation capacity to current needs: when demand is low, some of the cabs are simply parked – like trains in a siding. For maintenance work, too, technicians can withdraw individual cabs from circulation without needing to interrupt operations.” With the help of artificial intelligence, the system learns to respond better and better to a particular situation, and to optimize operations in line with prescribed criteria – such as short waiting times or minimum energy consumption. Collisions cannot happen, because the system always knows where the individual cabs are located.

Lightweight construction cuts energy use

As with Transrapid, the power that moves the cabs is fed into electromagnetic rails, which in this case run along the walls of the elevator shaft (see also the box on linear motors). The other systems in the cabs – such as lighting, ventilation, and electronics – obtain their power by contactless means on the transformer principle, like an electric toothbrush in a bathroom. To reduce consumption to a minimum, the engineers use lightweight construction. “We want to limit the cab weight to 800 kilograms,” Jetter says. “The door, for example, will weigh only around 50 kilograms, because it is made of carbon. For the walls and ceilings, we are using a mix of aluminum, carbon, and fiber-reinforced plastics.” The elevator specialists are collaborating on this with the experts at the ThyssenKrupp TechCenter Carbon Composites in Dresden.

In addition to lightweight construction, intelligent energy management is important for the efficient running of MULTI: on their descent, the cabs feed energy back into the system, where it is either used immediately for ascending elevators or stored temporarily – for example, in batteries, supercapacitors, or flywheels. Finally, flexible operation itself contributes to saving energy: whereas traditional elevators work at only about →



Elevator from light: At the University of Stuttgart's 3D visualization center, engineers can make virtual journeys on MULTI, simulate assembly processes, and present the new system to customers.



Transrapid in the elevator shaft

They may look completely different on the outside, but MULTI and the Transrapid are driven by the same technology, because the movement of both is provided by a linear drive. The basic principle is this: rails ("long stators") equipped with copper coils cast in resin are integrated into the walls of the shafts. Variable-frequency alternating currents flow through these coils, creating a moving magnetic field.

The MULTI cabs are fitted with permanent magnets, on which the magnetic field exerts a force – this either lifts them up or, on their descent, causes them to brake. Their speed depends on the frequency of the magnetic field: the higher this is, the faster the cab moves. Electronic frequency converters in the shafts determine the speed, and ensure that passengers are speeded up and slowed down gently.



Despite all the parallels, however, there is one fundamental difference: whereas a Transrapid carrying several hundred passengers requires output of around 20 to 50 megawatts for its journey at up to 500 km/h, a MULTI cab can manage with only 50 to 100 kilowatts.

→ ten percent of capacity, the MULTI cab, with its capacity of eight people, scores substantially higher in simulations.

MULTI makes optimum use not only of energy, but also of the limited space in skyscrapers: the new drive technology means that, in the future, transport capacity will no longer decline in accordance with the building's height. Also, the mass of the cables – which would snap under their own weight beyond a certain height – will no longer be an issue here. Finally, building and cable vibrations will no longer be a factor, either: especially in high shafts, there is a risk of resonances, which could cause the cables to strike the walls and cause damage there. "In windy Chicago, elevators often have to be closed down or reduced in speed during storms," Jetter reports. "However, MULTI will have no problems running even in such conditions." Furthermore, MULTI requires smaller shafts than conventional solutions: instead of a footprint of nine square meters, as in a double-deck elevator, the figure for MULTI is only six square meters.

Ideal for buildings higher than 300 meters

All this will enable architects in the future to erect even higher buildings. Technically, this has long been possible, but it has been prevented by the limited scope of traditional elevators. The need for such super-high skyscrapers is great: 2.5 billion more people are expected to be living in cities by 2050, and high-rise buildings are the most economic and environmentally friendly solution for offering them a place to live. This is because they facilitate intelligent energy management, and contribute to ensuring that even the megacities of the future will still have enough green areas. The trend toward higher and higher buildings has already become evident in recent years: whereas in 2000 the average height of the 50 tallest buildings in the world was 315 meters, in 2013 that had already risen to 390 meters – an increase of around 25 percent.

"MULTI is ideal for buildings beyond a height of 300 meters, and can run in shafts with a length of 600 meters and more," Jetter explains. "In a traditional elevator system, there would be only a single cab on the move in each shaft – that is roughly the same as only ever having one ICE train running on the high-speed rail line between Munich and Stuttgart." Admittedly, MULTI is not quite as fast as Germany's express trains: It carries its passengers at a speed of five meters per second – studies on high-speed elevators have shown that anything beyond that will cause many people to feel discomfort, because of the noticeable difference in pressure. On the other hand, it offers many more connections than an ICE: the ThyssenKrupp experts intend that MULTI will offer access to a cab at intervals of 15 to 30 seconds, which will make a transfer stop approximately every 50 meters – the floors in between are then

50

PERCENT
less weight
compared with
a standard
cab: MULTI
consistently
uses lightweight
construction.

reached by using conventional elevators. "After all, an ICE does not stop at every small station, either," Jetter comments. "Local trains are there to cover the journeys in between."

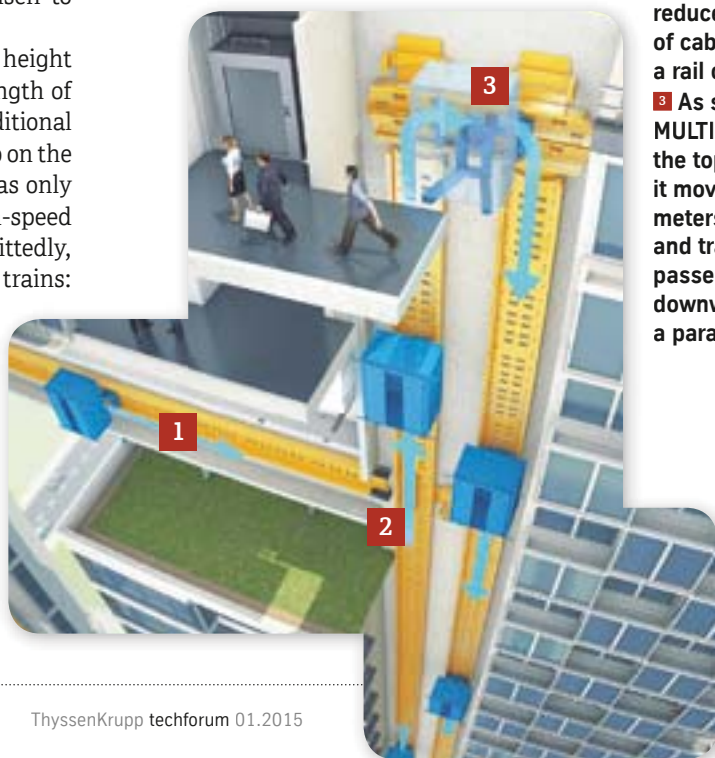
As well as the experts from ThyssenKrupp Elevator and their colleagues at the TechCenters in Munich and Dresden, the University of Stuttgart was involved in the development of MULTI. The engineers used the university's visualization center to make virtual journeys on the system, to simulate assembly processes, and to persuade customers of the merits of their new concept, among other things. MULTI still exists only on computers and in the form of working prototypes of various critical components, but as early as mid-2015 there is due to be a scale model of a complete system with several cabs in a double shaft. Then, starting in 2016, the system will be examined and certified in practice in three 100-meter-high shafts in the new test tower in Rottweil. "Even now, we are already registering a huge level of interest," says Jetter. "Every day, we receive enquiries from potential customers, who also give us fascinating ideas as we go along." Many of those could also become reality within a few years, thanks to the flexible MULTI system.

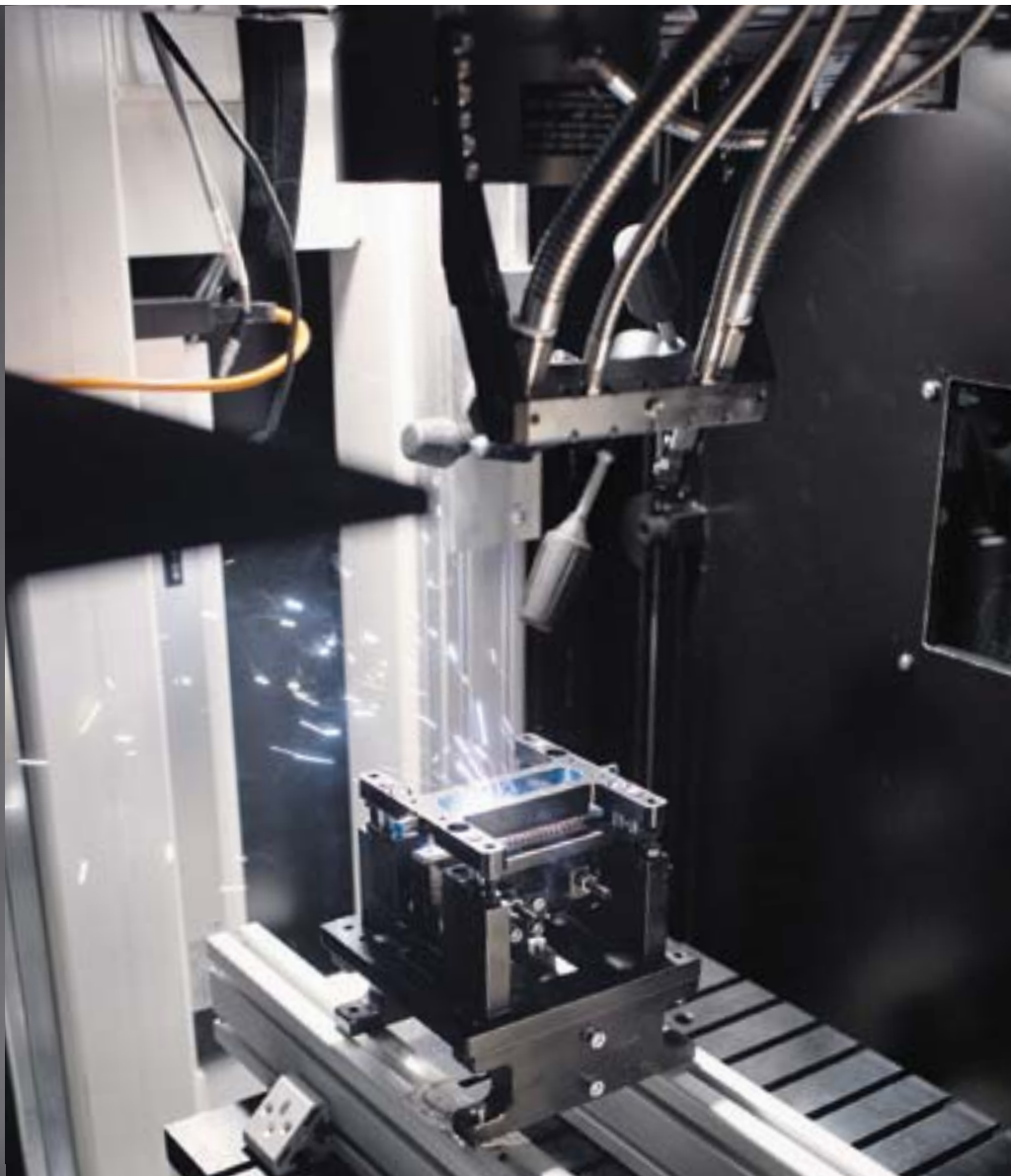
A transportation system for skyscrapers

MULTI can be likened to a rail network that stands vertically: **1** Thanks to the new drive technology, the cab can, if needed, move horizontally and connect neighboring buildings. **2** Transportation capacity can be adjusted according to current demand. If there are only a few

passengers, MULTI reduces the number of cabs – just like a rail operator.

3 As soon as the MULTI cab reaches the top of a shaft, it moves a few meters sideways and transports passengers downwards in a parallel shaft.





Precision tool:

A laser welding plant developed by ThyssenKrupp Systems Engineering connects two battery cells together – with the utmost accuracy and minimum energy consumption.

Battery plant technology

For a long period there has been no significant battery production in Germany. In the age of electric mobility that could be set to change: ThyssenKrupp is optimizing battery production and registering interest from German car manufacturers.

TEXT: CONSTANTIN GILLIES



It is hard to tell from the two-story industrial premises next to the freeway that this is where the future of the car is being worked on. But what is going on behind the unassuming façade could point the way forward, because this building in Pleissa near Chemnitz houses the development center of ThyssenKrupp System Engineering (TK SY). At this technology center some 20 experts are dealing with a product that for a long time aroused little interest in Germany: batteries. The engineers are developing equipment on which batteries for electric cars can be manufactured. “The aim is to rebuild technological expertise,” explains Dr. Matthias Hartmann, Vice President Technology & Innovation at TK SY. “And we can make a key contribution to that.”

Cell production in Germany

This is urgently necessary, because the German automotive industry needs new batteries or else risks losing out in the electric car segment. This very warning was given by the National Platform for Electric Mobility (NPE): in its report of December 2014 it called for “the foundations for establishing competitive cell manufacture in Germany” to be laid. Cells are the basic components of batteries, and the schedule for domestic production is to be put in place as soon as this year.

The battery forms the heart of any electric vehicle and makes up a third of its cost. However, German manufacturers have to purchase these key components abroad, because there are no notable manufacturers left in the country. For the global auto champion this is an unsustainable situation, the NPE believes. Mixed signals are coming from the industry: Daimler recently announced that it would soon be halting the activities of its battery subsidiary

Li-Tec. At the same time, the CEO of US electric vehicle manufacturer Tesla spoke of establishing a production plant in Germany.

Battery manufacture is a complex process. This can be seen from the array of equipment that fills the development center, including calender machines whose high-precision rollers compress coatings on electrode film. A few meters further on laser welding technology is being developed in order to connect together thin conductor film and cell contacts. At the end of the machine welded connections are checked and cells formed, meaning they are charged for the first time and discharged again. To ensure that no problems arise during film coating, the production facility is located in a dry room where air humidity is no higher than two percent.

“The crucial challenges are productivity and quality,” stresses innovation expert Hartmann. High-precision work is required – and at high volumes. For example, with the electric poles consisting of lithium oxide (plus) and graphite (minus): the two substances are applied in extremely thin layers to other metals such as aluminum. A layer of lithium oxide measures between 60 and 120 micrometers, for instance, and is thus about as thick as a human hair. It must be absolutely even so that the battery can reach its full capacity later on.

Once the battery poles are ready, the films are built up one above the other in flat casings and surrounded by a liquid electrolyte, and then the cell is complete. However, one cell is far too little to provide enough energy for a car’s drive system. Therefore, the next step typically involves combining ten cells into a module. Ten of these modules then ultimately form the battery: a power pack delivering 300 volts. ➔



Under pressure: A calender machine compresses the battery electrodes – a key step in the production of a battery system.



TIMELINE

1888

Maschinenfabrik A. Flocken in Coburg builds what is probably the world's first electric car.

1905

Siemens-Schuckertwerke in Berlin builds the "Elektrische Viktoria" electric car.

1971

The battery-powered Lunar Roving Vehicle operates on the moon for the first time.



1972

For the Olympics BMW builds an e-car that accompanies the marathon.



1996

General Motors launches the EV1 electric car.

2008

Newcomer Tesla Motors from the USA begins serial production of its Roadster model.



2014

Volkswagen launches the all-electric e-Golf in Europe.

2014

BMW brings onto the market the i8 plug-in-hybrid consisting largely of CFRP.



→ Yet automation is only the first step. The second innovative achievement is to ensure that the quality is always perfect in spite of the large production runs. To guarantee this the engineers have, for example, developed new laser welding techniques and testing methods using thermography (thermal images), among other things.

Battery production was once a key industry

If battery manufacture were finally to progress in Germany, strictly speaking this would simply be a revival – because electric mobility enjoys a long tradition in this country. It was way back in 1899 that Ferdinand Porsche built a hybrid vehicle with four-wheel drive, and at the 1972 Olympics an electric car developed by BMW accompanied the runners in the marathon. At 60 kilometers, its range was only just higher than that of the athletes – this was as much as the half dozen car batteries under the hood could deliver. They were supplied by Varta, the most well-known battery producer in Germany at that time. Together with such companies as Sonnenschein, Hagen, Batterie and Deta, Varta formed a genuine key industry.

In the 1990s, the sector moved overseas, mainly to Asia. In the years that followed it was from here that the innovations in electricity storage devices came. The lithium-ion battery, for example, was first built into a portable video camera by Sony in 1991; nowadays everyday life is unimaginable without this technology. The lithium-ion battery also features in electric cars, at least in Tesla models, each containing some 6,000 battery cells that are also to be found in virtually the same form in laptops. Experts estimate that this energy storage device alone costs US\$30,000.

Why are batteries actually so expensive? Head of the technology center Dr. Michael Roscher explains: “Because everything contained in the cell is expensive.” The raw materials alone are highly sought-after: cobalt or lithium, for instance, are rare metals and correspondingly costly. Also involved are materials that are expensive to manufacture, such as the separator – a thin film made of plastic between the plus and minus pole, which prevents short-circuits in the cell.

BMW is already using equipment developed by ThyssenKrupp

Is it even worth establishing such an expensive production operation in Germany? One argument in its favor is that battery production is now highly automated. The assembly process is no longer touched by human hand, with employees being required only for quality control and maintenance. High German labor costs are therefore hardly an issue. In addition, the car manufacturers could benefit hugely if they were to produce the batteries virtually on their own doorstep. It currently takes about eight weeks to transport them from overseas by container ship.

Some interest has already been shown in the center's production technology: BMW, for example, is using equipment developed by ThyssenKrupp in the manufacture of the i3 electric speedster. It combines large-size cells first into modules and then into whole battery packs that are tested automatically at the end. Yet this is just the start. The ideal solution would be to handle the whole production process – including the cells – on one line, from the starting material lithium to the ready-to-install battery. It would not take that long to achieve a “Made in Germany” battery: “Production could be established in two years,” estimates Hartmann.

Energy turnaround in chlorine production

TEXT: KLAUS JOPP ILLUSTRATION: BIANCA CLASSEN



Pilot plant: The new process underwent extensive testing at Bayer MaterialScience in Uerdingen. Its use could save Germany alone the power consumed by a city the size of Cologne.

Through the use of oxygen-depolarized cathodes in chlor-alkali electrolysis energy consumption falls by up to 45 percent. The first production plant is scheduled to go into operation in China in 2015.



Chlorine is one of the most important raw materials in the chemical industry: some 70 percent of its products are synthesized using reaction methods, in which the pungent gas or its compounds are involved directly or indirectly – giving rise to such polymers as polyvinyl chloride (PVC), polyurethane, and polycarbonate, but also to pesticides, drugs, and chemicals for producing clean drinking water, as well as to high-purity silicon for photovoltaic and electronic applications. Chlorine owes this paramount importance to its high reactivity: it has the ability to combine with many different substances.

There is correspondingly high demand for chlorine around the globe and especially in chemicals production in Germany: worldwide demand comes to 70 to 80 million metric tons per year, of which some 4.3 million tons are produced in Germany. Around 95 percent of the chlorine required globally is currently produced through chlor-alkali electrolysis from common salt (sodium chloride, NaCl). For electrolysis the producers primarily use the membrane process, whereas the diaphragm

method and the particularly energy-intensive mercury process (also called the amalgam process) play a lesser role.

The comparatively low energy consumption of the membrane method is the crucial reason for its clear dominance: The process requires 2,400 kilowatt-hours (kWh) per ECU – the electrochemical unit stands for the production of one metric ton of chlorine, 1.1 tons of caustic soda and 0.028 tons of hydrogen. The rival methods are well above these levels: The diaphragm process requires 2,600 kWh per ECU, and the mercury process as much as 3,400 kWh per ECU. Whichever method is used, chlorine production of one of the most energy-intensive chemical processes in existence.

All European chlorine producers have therefore pledged to phase out the outdated mercury process by 2017. There is now a further weighty argument in favor of this step and the preferred use of the membrane process: ThyssenKrupp Electrolysis GmbH, UHDENORA, and Bayer MaterialScience have jointly succeeded in replacing the conventional hydrogen-producing electrodes in traditional chlor-alkali electrolysis with oxygen-depolarized cathodes (ODCs). This reduces energy consumption considerably.

Efficient electrolysis

The new process is divided into three steps: first, an aqueous salt solution is pumped into the electrolytic cell. It contains chloride ions, which are oxidized at the positively charged electrode and thus form chlorine gas, which escapes from the cell. The chloride ions also contained in the salt pass through the membrane which separates the two electrolytic cells from each other. At the negatively charged electrode – the ODC – hydroxide ions are formed from oxygen (which comes from an air separator) and water molecules and combine with the sodium ions to form caustic soda. The starting materials of a salt solution and water thus give rise with the help of energy and oxygen to the desired products of chlorine and caustic soda. →

INFO

1. How chlorine gas is formed

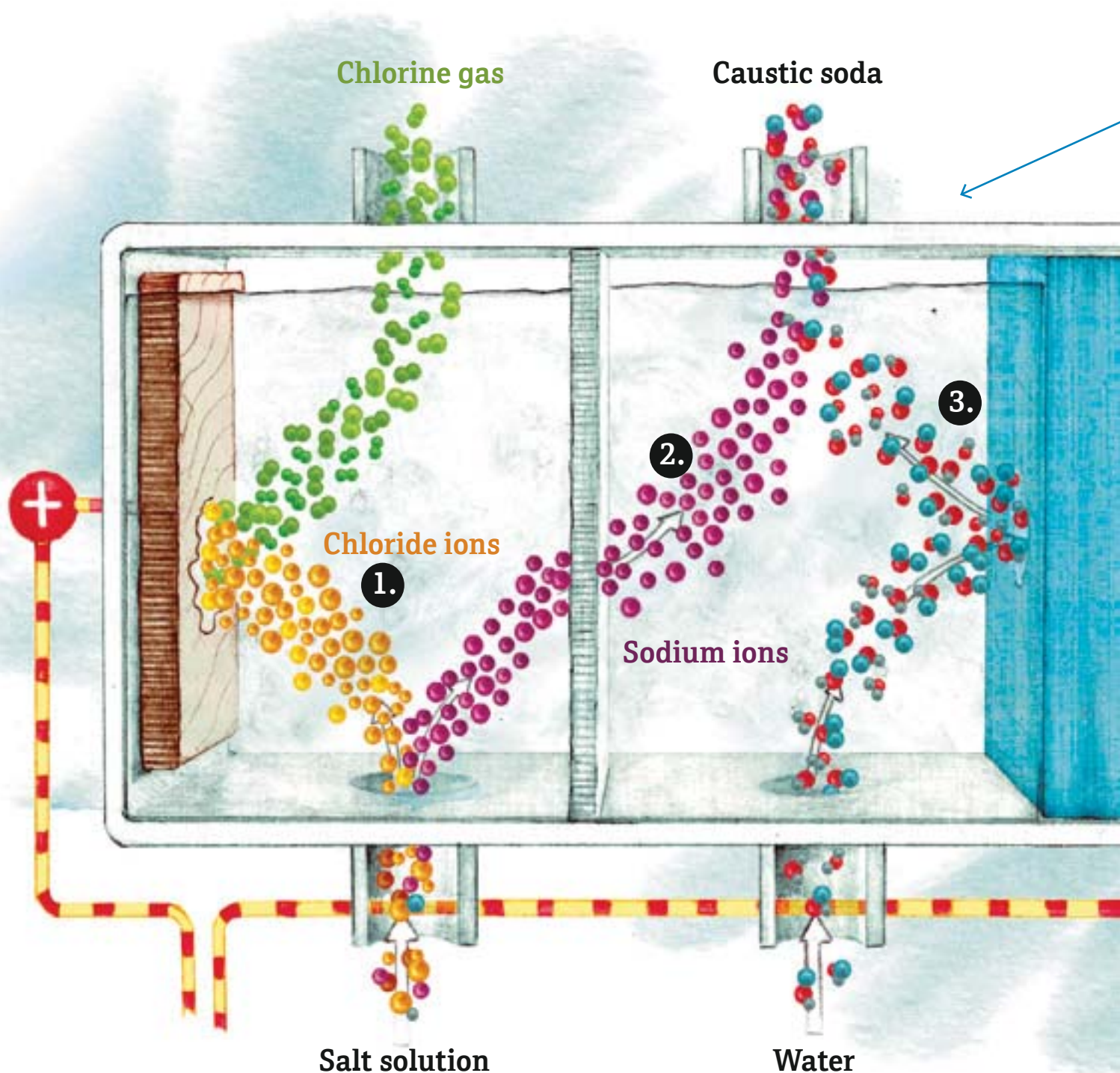
Table salt dissolves in water into chloride and sodium ions. In the electrolytic cell the negatively charged chloride ions gravitate toward the anode, combine in pairs to form chlorine, and escape as gas. The sought-after raw material has been produced.

2. How caustic soda is formed

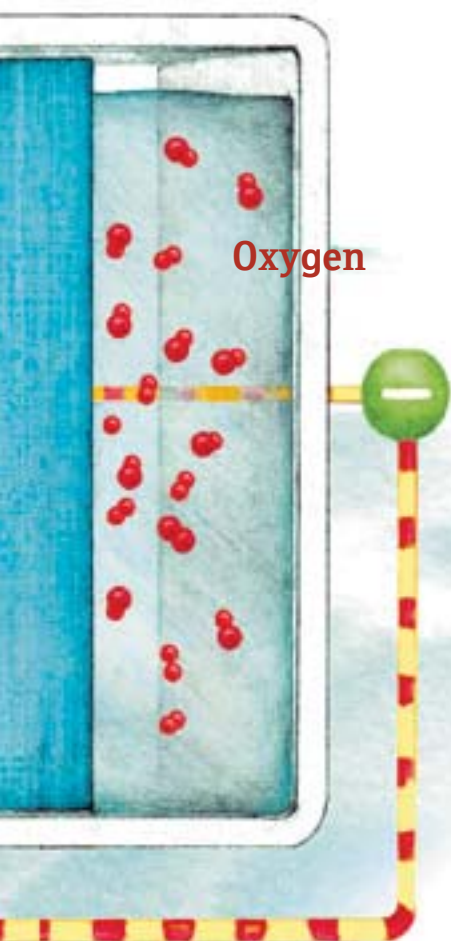
The positively charged sodium ions flow through the membrane into the right-hand part and combine there with the hydroxide ions to produce caustic soda (sodium hydroxide). Caustic soda is another key raw material in the chemical industry.

3. How hydroxide ions are formed

Water flows into the right-hand part of the cell and forms together with oxygen at the oxygen-depolarized cathode negatively charged hydroxide ions, each consisting of a hydrogen and an oxygen atom. They then combine with the sodium ions.



Oxygen-depolarized cathode



Milestone in chlorine production

Compared with standard solutions to date, the ODC process saves at least 30 percent of energy because the chlorine-developing electrode is combined with an oxygen-depolarized cathode. The theoretical difference in the electrode potentials comes to just 0.13 V, whereas the practical voltage of the cell given the technical current density of four kiloamperes per square meter (kA/m^2) is about two volts. With the electrolysis methods used to date, however, the difference between the standard potentials of the hydrogen and chlorine electrode is substantially higher (1.36 V), resulting in a cell voltage of three volts, and it is this difference of one-third that gives rise to lower energy consumption in the new process. "Thus, following the membrane process a further milestone has been achieved in chlorine production," notes Professor Angelika Heinzl from the Institute for Energy and Environmental Process Engineering of the University of Duisburg-Essen.

Oxygen-depolarized cathodes have been known for some time from their use in fuel cell technology. However, they cannot be used readily in chlor-alkali electrolytic cells because they would not be stable under the prevailing physical and chemical conditions. Moreover, cell sizes and ODCs whose area is smaller than 0.05 square meters are used in fuel cells as a rule.

For chlor-alkali electrolysis the researchers had to find a cell design and matching ODC that facilitate the three-phase reaction within the 0.2-millimeter-thick cathode layer on an electrode area of around three square meters. Especially owing to the large ODC area, numerous parameters, such as pore diameter, electrocatalytic activity, gastightness, and wettability with caustic soda, had to be adjusted to the particular chemical conditions and the special pressure conditions in chlor-alkali electrolytic cells. The whole development effort was carried out by ThyssenKrupp Electrolysis, UHDENORA, and Bayer MaterialScience in cooperation with other industrial and university partners within the "klimazwei" project, which is sponsored by the German Federal Ministry of Education and Research (BMBF) and devoted to research for climate protection and protection from climate impacts.

→ The conversion of existing membrane plants to ODC technology would enable a 30-percent reduction in energy consumption – the potential global saving is up to 35 million megawatt-hours (MWh) per year or 2.2 million MWh per year in Germany alone. Compared with the diaphragm method, energy consumption could fall by as much as 45 percent, equivalent to 39 million MWh per year globally or 0.9 million MWh per year in Germany. The greatest potential reduction of 50 percent is offered by the mercury method: global savings in this case would add up to 17 million MWh per year or 0.5 million MWh per year in Germany. In Germany alone one percent of total electricity consumption could be saved if the ODC technology were used nationwide – that is equivalent to the power consumed by a major city the size of Cologne.

However, plants and equipment based on the diaphragm and mercury methods would have to be converted – entailing significant costs. "Nevertheless the project partners sought to develop an ODC solution that enables modification even for existing energy-intensive technologies, but which can also serve as an alternative for current chlor-alkali projects," explains Dr. Ulf-Steffen Bäumer, Research Director at ThyssenKrupp Electrolysis.

From May 2011, the ODC technology underwent testing on an industrial scale in a pilot plant at Bayer MaterialScience's Krefeld-Uerdingen site with an annual production capacity of 20,000 metric tons of chlorine. This, the world's first, commercial electrolyzer with ODC technology, operated so successfully that the technology was approved for marketing in June 2013. Market studies show a great application potential: Experts from the companies involved expect the volume to rise from 100 kilotons (kt) per annum (2013) to 2,200 kt per annum in 2022. "The first facility has now been sold by UHDENORA to the BEFAR Group in China," notes Bäumer with satisfaction. "It is expected to go into operation in the first half of 2015 and in the final development stage it should deliver 100,000 metric tons of chlorine per year." ←

Huge reservoirs of oil and gas are lying dormant beneath layers of ice in the Arctic. However, it would be dangerous to try to recover them with present-day technology. Developers from the “Marine Civil Engineering” project area have, therefore, worked with the Norwegian oil and gas company Statoil on a concept study to design a multipurpose submersible that can help extract these reserves safely, efficiently, and in an environmentally friendly manner.

Exploration under the ice

TEXT: LENA BULCZAK

ILLUSTRATION: NIKO WILKESMANN

Comfort

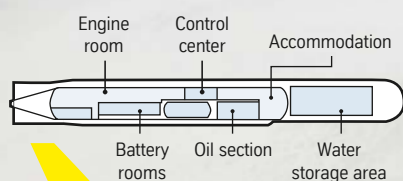
The 19-member crew live under water, but otherwise the submersible is similar to a cruise ship. The two-layer system means practically every member has his own double cabin. There is a common room for watching television, plus an on-board fitness area complete with sauna.

Accommodation

Fitness area

Technical specifications

Length:	99.7 m
Width:	10 m
Height:	9.5 m
Draught (surfaced):	7.7 m
Operating speed (surfaced):	10.5 kn
Operating speed (submerged):	6.5 kn
Ship volume:	7,000 t
Diving depth:	150 m
Operating depth:	1,500 m
Oil-combating capability:	2,800 m ³
Payload:	289 t
Dynamic positioning system:	8 thrusters
Crew:	19



Size comparison: Airbus A380

Underwater robot

Seismic sensors

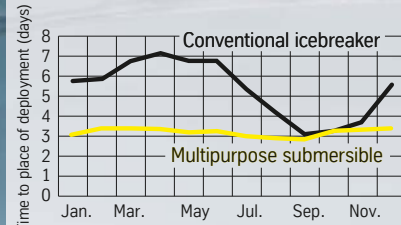
Deep-sea cartography

The submersible makes examinations of the seabed possible even where the oceans are covered by ice, and without the need to break up the ice layer. Its deep-sea robots, sonars, and up to 250 seismic sensors enable reservoirs to be measured in 4D. In this way, it is possible to detect where oil deposits are, or where reservoir rock formations are in danger of collapsing. This makes deep-sea oil extraction not only safer, but also more efficient.



All-weather capability

Whether in ice or rough seas, the multipurpose submersible can be used throughout the year, in all weather conditions. Also, whereas a conventional icebreaker needs about seven days to cover the 780 nautical miles from Norway to north Greenland in April, the submersible is at the scene after just three days – because, below 60 meters, neither waves nor ice can bother it.

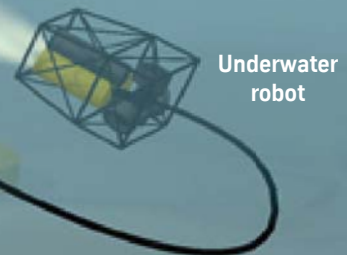


Cargo hold

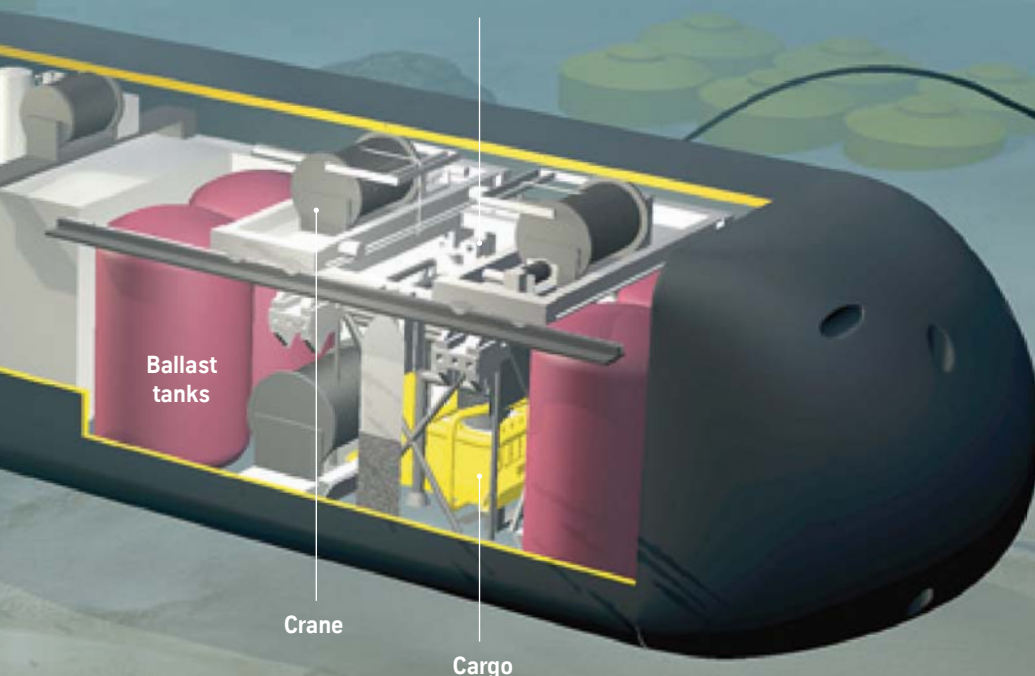
For the first time, thanks to flexible cargo hold systems, a submersible can transport loads as big as a two-family house and weighing up to 289 metric tons. The water-flushed cargo hold alone can take 145 tons, and larger loads can be attached to the outside. Ballast tanks provide the necessary buoyancy, with which the submersible balances itself while floating.

Environmental protection

The submersible can also be used to fight oil spills effectively. It has no problem with poisonous or flammable gases, which cause weeks of delays in clearing up leaks from a ship. Sensors detect leaks on the spot, which are then repaired by diving robots with special equipment. The OCTO oil-combating tool sucks up leaking oil under the ice like a vacuum cleaner.



Underwater robot



Deployment areas

Potential deployment areas are all oil and gas fields that it has previously not been technically possible to explore safely because of rough or ice-covered seas. However, the submersible's technology also opens up new sources of knowledge for marine biologists.



Installation and maintenance

The safe extraction and processing of oil at low depths requires a whole factory on the seabed, consisting of gas compressors, separators with coolers, cables, a power supply, and a wide range of control elements. The dynamic positioning system balances the submersible at a diving depth of 150 meters so precisely that the crew can place and maintain the equipment to the exact millimeter even at a depth of 1,500 meters – either with the crane or with one of the two unmanned diving robots.

Closer to the wind

ThyssenKrupp has developed an innovative concept for wind power towers: “TetraFlex” reduces costs over their entire service life and is ideal for repowering existing plants.

TEXT: PETER HAHNE

ILLUSTRATION: JONAS SCHENK



16th century

WINDMILLS may perhaps have been invented in the Orient, but HOLLAND'S are the most famous.

19th century

The WESTERN-STYLE WIND-MILL is ubiquitous in all movies about the Wild West. It was used for pumping and energy generation.

20th century

WIND POWER becomes an important energy source. Wind farms with the familiar round steel towers go up all over the world.



The expansion of wind power is progressing rapidly: in the first half of 2014 alone, Germany saw 650 new onshore plants with a total capacity of 1,700 megawatts connected to the grid, plus 30 new offshore plants near the coast with a capacity of

108 megawatts. The Federal Ministry for Economic Affairs and Energy puts the planned annual increase in capacity at 2,400 to 2,600 megawatts, equivalent to around 1,000 new plants and an investment volume of more than €1 billion each year. "The wind power sector remains a growth market with many attractive opportunities for the use of steel products," says Adrian Paton, who is responsible for steel concepts in renewable energies at ThyssenKrupp Steel Europe.

In addition to the sheer number of plants, the size of the turbines and the height of the towers are also rising, because the further the rotor blades extend into the sky, the bigger the return: At great heights, the wind is not only stronger but also more constant. This means a significant increase in the number of full-load hours and the electricity yield: Newer plants are entering the three-megawatt class, whereas the 24,000 or so wind turbines currently installed deliver an average of less than 1.5 megawatts. As a rule of thumb, each additional meter in height – with otherwise the same technology – adds one percent to the yield.

Higher yield, lower costs

Every meter in height also matters in "repowering," where old plants with a low capacity are replaced by new technology with a higher yield. This is urgently needed: In many places, according to a study by the German Wind Energy Association, the yield of old plants connected to the grid up to 2006 leaves much to be desired. An evaluation of the annual results of 175 wind farms reveals that only one-third of all the plants operated at a profit. A further one-third earned profits that were much too small even to cover their financing costs. ➔

"It is no longer economically viable to operate plants that are even higher using traditional tower technology."

PROF. HOLGER LANGE, UNIVERSITY OF APPLIED SCIENCES BREMERHAVEN

21st century

To boost yields and reduce costs, wind farm operators turn to innovative tower technologies such as **TETRAFLEX.**

→ It is no wonder, therefore, that repowering already accounted for one-quarter of the total market in 2013. Experts are also expecting that share to rise to around one-third in the coming years. According to a study by HSH Nordbank, industry insiders estimate that repowering could lead to a doubling of capacity and a trebling of electricity yields in Germany, with a simultaneous halving of the number of plants.

Higher towers with bigger turbines, all at low cost: This is the wind power industry's formula for reducing the price of renewable electricity further in the future and boosting its returns. This is why Paton and his project team have been working for two years, under the project name "TetraFlex," on an innovative concept for wind power towers made of steel that can extend 120 to 200 meters into the sky – at present, the familiar round steel towers have a maximum height of 120 meters. "It is not economically viable to operate plants that are even higher using traditional tower technology, because the exorbitant increases in construction, logistics, and maintenance costs would cancel out the additional yield," says Professor Holger Lange, who specializes in the structure of wind power plants at the University of Applied Sciences Bremerhaven.

Proven technologies from the oil and gas industry

The focus of TetraFlex, therefore, is on achieving a significant reduction in the costs of production, transportation, and the construction and eventual dismantling of the towers, because these account for around one-quarter of the total costs of a wind power plant. "The aim of TetraFlex is to reduce costs by comparison with rival solutions," Paton explains. "To do this, we have developed new design approaches and alternative production processes, which are already well established in other sectors." This is an ambitious project, because higher towers, bigger turbines and longer rotor blades place heavy demands on the structure of wind power plants.

TetraFlex uses spirally welded tubes – which have been used for many years in the oil and gas industry and have now been toughened and certified to meet the requirements of the wind power sector – as well as innovative node concepts for joining the tubes together. The wind tower concept has many advantages over alternative solutions: the weight – and, therefore, the material input – is lower, because the shape and structure of the tower allow for a stress-optimized construction method. The top part consists of a round tower, while the bottom part is made of a four-legged lattice structure.

Advantages in production, transportation, assembly, and recycling

"Different tower concepts require a greater wall thickness and, thus, more material to achieve the necessary stability," Paton explains. "In addition, the amount of offcuts resulting from the continuous production of spirally welded tubes from coils is lower than in other manufacturing methods." Furthermore,



120 meters

PRESENT-DAY WIND FARMS
Limited height and high costs
reduce yield. This makes repowering
increasingly important.

tubes made from steel coils can be made at a very high processing speed, and the production process enables the tube lengths to be adjusted simply and flexibly. Finally, fewer components are required than in a high lattice tower, because lattice towers are made up of many small L-profiles and bolts, whereas TetraFlex uses a small number of large tubes. All this saves costs, because the production of individual wind power towers can be standardized for different heights.

TetraFlex also has advantages over other types of structure with regard to transportation. TetraFlex towers have a considerable weight advantage over hybrid towers made of concrete and steel: they weigh only about one-third as much as those hybrid structures, which have to be delivered to their operating site in several expensive special transport operations. TetraFlex also saves money in the process of assembly at the operating site, because this new variety of tower needs up to 90 percent fewer threaded joints than alternative structures – for example, the longitudinally oriented steel structure. This speeds up the assembly process and reduces the costs of cranes and personnel. Moreover, the deep foundations made of concrete are much smaller than the massive foundations of rival hybrid towers, which require a substantially greater volume of concrete.

These new-style towers also save money at the end of their life: whereas on a TetraFlex tower the individual assemblies can be simply dismantled at

the threaded joints and then completely recycled, the individual concrete segments of concrete and hybrid towers have to be shredded and are then suitable for use only as a low-value product, at most, such as fill material in road construction.

In the future, it is intended to use TetraFlex towers mainly in low-wind areas on land, so as to boost the energy yield in such locations. The concept development has now been concluded, and potential cooperation partners from the wind power industry are making positive noises. “Customers can understand that TetraFlex will be economically viable,” Paton reports. The planned next step is to build a prototype in collaboration with them. “We aim to assemble and test the first tower in 2016,” Paton says. ThyssenKrupp Steel Europe intends to use this project to lengthen the company’s value chain.

**“The aim
of TetraFlex is to
reduce costs by
comparison with
rival solutions.”**

ADRIAN PATON,
THYSSENKRUPP STEEL EUROPE



157 meters

COLOGNE CATHEDRAL

The towers of this architectural masterpiece can just about compete with wind turbines.



150 to 200 meters

THYSSENKRUPP'S TETRAFLEX

High flexibility and low costs: the new tower concept improves returns from wind power plants.



324 meters

EIFFEL TOWER, PARIS

The landmark of the French capital will surpass even the highest wind towers for some time to come.

Alloys from the computer

A new era in materials science has begun in Bochum. More than 80 researchers at the Ruhr University are developing simulation methods that will make it possible to devise new materials on the computer in future.

TEXT: HANS SCHÜRMANN
PHOTOS: NATALIE BOTHUR

This is what materials research looks like in the 21st century: In the three-story building on the campus of the Ruhr University Bochum you will not find complicated apparatus or vast laboratories, where scientists in white coats mix together new materials from known ingredients and then examine their properties. Instead, the researchers sit in front of computer screens, program software, analyze charts, and discuss the results of their calculations and simulations.

The Interdisciplinary Center for Advanced Materials Simulation (ICAMS) in Bochum is one of the first institutes in Germany that deals exclusively with the development of simulation models for research on materials. The scientists aim to use these models in the future to predict the properties and behavior of new materials, thereby eliminating the need for extensive and costly experiments. Their chemical and physical models start by describing the bonds at the atomic level – thus providing information on a material's behavior. "On the basis of these theories we develop simulation models with which we can calculate the properties of materials," explains Professor Ralf Drautz, the ICAMS Director.

That sounds simple, but is in fact highly complex. When calculating the material's properties the scientists have to take a large number of variables into account. This is not possible using standard computers from the electronics market. For that reason, the Bochum researchers need a mainframe

Laboratory researcher:
Instead of mixing together new materials in a white coat, Prof. Ralf Drautz relies on a mainframe computer with 4,500 processor cores.





A portrait of Dr. Thomas Pretorius, a man with shoulder-length light brown hair and glasses, wearing a dark suit, white shirt, and patterned tie. He is standing in front of a server rack with green lights.

“Only with atomic calculations will we succeed in understanding the key effects of complex materials.”

DR. THOMAS PRETORIUS

User: Dr. Thomas Pretorius of ThyssenKrupp is convinced that the development of materials will benefit greatly from simulation methods.

→ computer for their work, similar to that used by meteorologists to forecast the weather or by car developers for their crash tests. Through parallel computing these mainframes are able to process vast quantities of data rapidly. The ICAMS cluster computer “Vulcan” consists of a network of 4,500 processor cores that are all interlinked via a high-speed network. “The mainframe computer is our most important tool,” says Drautz. “Without it we would not even be able to perform our calculations in the first place.”

The Bochum-based Interdisciplinary Center for Advanced Materials Simulation has been in existence since 2008 and was the brainwave of the Ruhr Initiative Group, the Max Planck Institute for Iron Research and the Materials Innovation incentive program run by ThyssenKrupp. During the launch phase the center was subsidized under a five-year start-up scheme amounting to €24.2 million – by an industrial consortium consisting of ThyssenKrupp, Salzgitter Mannesmann Forschung, Robert Bosch, Bayer MaterialScience, Bayer Technology Services, Benteler, and the federal state of North Rhine-Westphalia. In 2013 ICAMS became an institute of the Ruhr

University Bochum and apart from federal state resources is financed from external funding provided by industry and the public sector.

Bridge building

Computer-aided simulation methods are already widely used in many fields of technology. However, it is not possible as yet to predict with sufficient accuracy such key material characteristics as strength, toughness, or corrosion resistance, for which a lengthy and costly series of tests is still required. “We will change that,” says Drautz.

The special feature of the Bochum institute is not only interdisciplinary collaboration between engineers, physicists, chemists, computer scientists, and mathematicians – the concentration of scientific knowledge is also unique: Professor Drautz and his two colleagues, Professor Ingo Steinbach and Professor Alexander Hartmaier, simultaneously cover with their professorial chairs three

areas of materials science. In their work the Bochum researchers focus on what is known as “scale-bridging” – building a bridge from the atomic via the mesoscopic to the macroscopic level. “Engineers record material properties in the millimeter to meter range,” explains Drautz. “However, they originate at the atomic level: they are determined by the bonds between atoms, which are approximately one-tenth of a nanometer apart from one another.”

The ICAMS scientists can draw conclusions through their calculations based on microcosmic conditions about the macroscopic behavior of materials. Through this holistic approach they intend to bring about a paradigm shift in the development of new materials and in the understanding of material properties. “We want to help companies such as ThyssenKrupp Steel Europe that are engaged in developing high-strength steels, for example, to be able to see already on their computer which phases are forming and how they can change them,” notes Drautz, explaining the benefits of the new technology.

That the development of materials is set to benefit greatly from the simulation methods is something Dr. Thomas Pretorius is convinced of. He heads the Materials Modeling and Simulation team at ThyssenKrupp Steel Europe and has acted as the contact person for ICAMS since its creation. Pretorius arranges joint research projects and communicates the research findings within the Group. “The atomic calculations may be a great challenge – but only with them will we succeed in understanding the key effects of complex materials so as to utilize these findings in the macro world,” explains Pretorius.

Professor Steinbach’s working group has developed the open-source software OpenPhase for this purpose. The program calculates complex processes in microstructure formation during the phase change and presents the results as charts: the scientists can observe on the screen the growth of crystal grains in the form of colored network structures and recognize individual phases as well as microstructural defects. Professor Hartmaier’s department uses this calculated microstructure to predict through further simulations the mechanical behavior of materials.

Faster programs

In a cooperation project with ICAMS the team led by Pretorius at ThyssenKrupp Steel Europe is currently examining how effective OpenPhase is in answering practical questions. A PhD student from his team is working on the software and reporting back to the Bochum researchers on how easy the program is to operate – the aim being to develop it further so that it is suitable for practical application. There are already commercial programs that perform in a similar way, says the ThyssenKrupp Steel Europe team leader, adding that the big advantage versus the tools available to date, however, is that the program code can be altered. “The software can therefore be adapted to our needs,” explains Pretorius. “This is important, for instance, if parameters that are crucial to a current question were not predicted by the developers.”

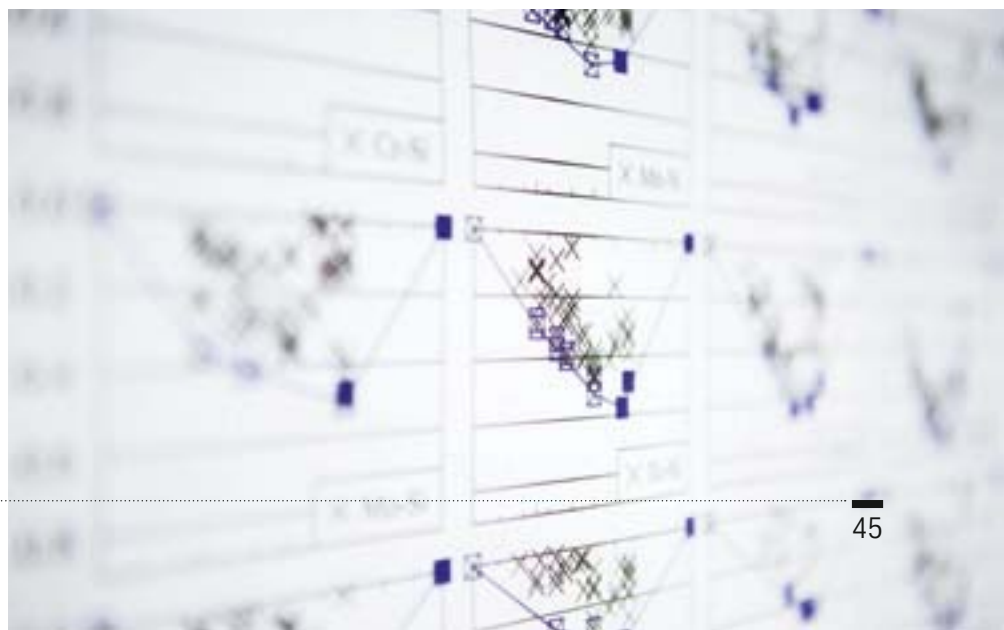
Apart from the evaluation of simulation models the ICAMS researchers are grappling with ways of reducing computing times. “We first transformed theories into computing models in order

to simulate processes,” reports Drautz, adding, “The calculations then showed that they had become too complex, especially for alloys made of several different components.” Many companies do not have their own mainframe computer – and where they are available, the usage times in computer centers are often restricted: The departments are allowed to use only a certain number of processors for a specific time, such as six or twelve hours. “To ensure that our software can be used in industry in the future, we are now working on enhancing the efficiency of the programs and on simplifying the models without reducing their information value,” says Drautz.

During the early stages the researchers mainly focused on developing simulation models. “These must now prove their worth in practice,” says Drautz. In order to examine the real-world operability of multiscale simulation, ICAMS is conducting a project in cooperation with ThyssenKrupp Steel Europe and a major German automotive supplier that is focusing on calculating the microstructural development of tempering steel and the development of that steel’s properties. First and foremost, the properties of martensitic structures – which are extremely hard and strong lattice structures in steel – and how they change through thermal treatment are simulated. The researchers start with atomic calculations and work up to the macro level gradually. The high-strength steels developed in this way are required, for example, in the construction of lighter cars and in the manufacture of crash- and strength-related components.

Atoms seeking partners

With their computer models the ICAMS researchers calculate the energy of formation between two atoms (blue lines). The lower it is, the stronger the bond – which in turn allows conclusions to be drawn about the properties of new materials, such as their strength or their thermal conductivity.





Scope for innovations

More quickly and more cost-effectively from the idea to the product: that is the aim of the Invention Center on the campus of RWTH Aachen University, where the architecture plays a key role.

It is intended to be a cradle of new ideas: the Invention Center on the campus of RWTH Aachen University. Various professorial chairs in business management and engineering science plan to work there, together with companies, on how to bring innovations to the market more quickly while taking account of the market's needs even in the early stages of development. Alongside the RWTH and Fraunhofer researchers some 25 companies are already taking part in the project, and by mid-2015 that figure is set to rise to over 50. Along with Daimler, Johnson Controls, 3M, and Hilti, ThyssenKrupp is one of the Invention Center's premium partners and has high hopes for the new institution: "The Invention Center aims to reduce lead times by 75 percent and development costs by 90 percent," says Dirk Bartels, head of Processes, Tools and Standards.

Not only is the Invention Center's interdisciplinary approach expected to contribute to this, but also the architecture of this unique project nationwide: When at the end of 2015 the center has moved into its premises in the new production technology cluster on the RWTH Aachen campus, the researchers and engineers will have at their disposal a 1,000-square-meter venue that actually depicts the innovation process in its architecture. By following a course through several rooms they pass through all the phases of the development process. For creative sessions there will

TEXT: CHRISTIAN BUCK



be an ideas-generating room, for example, depicting the great megatrends of our time, where engineers and designers can develop and visualize their innovations. In another room they can deal with the specific concept and discuss how and with which technologies it can best be achieved. How other industries tackle similar challenges will also be represented there – an invitation to observe and draw inspiration. Further rooms are devoted to construction and design and to the development of business models. “With every room the idea takes increasing shape,” explains Toni Drescher, who heads the Invention Center. “We are very flexible: The number of rooms and their topics can be adapted to each individual project. The focus is on speed and efficiency: more quickly and more cost-effectively from the idea to the product.”

Market outlook and business models always in mind

“The architecture reflects a new understanding of the development process,” says Professor Frank Piller, who is Chair of Technology and Innovation Management at RWTH Aachen University. “We rely from the outset on interdisciplinary collaboration in which the market outlook and promising business models are always taken into account as well.” Possible topics are the development of complex products such as machine tools, packaging plants, or marine propulsion systems.

The partners can propose their own projects at the annual meeting in September and, as in a casino, place chips on their favorites – a new form of allocating financial resources. In addition to the Invention Center’s partners, the institution is also open to other interested parties who can lease space at the center from time to time and, if they wish, receive assistance with their work from the institution’s staff. The initiators expect a typical development process to take between three and six weeks to pass through the innovations course – after which there should be an initial prototype. If need be, experts from RWTH Aachen University or Fraunhofer institutes can support the projects through proposed technical solutions or feasibility studies within the laboratories and workshops, for instance. The partners involved are expected to share the intellectual property rights relating to the results from joint projects by, for example, jointly utilizing the rights related to the basic developments and protecting only the applications on an individual basis.

RWTH Aachen University is ThyssenKrupp’s biggest collaborating partner among German universities. Worldwide the Group’s business areas work with other higher education institutions such as Georgia Tech in Atlanta, USA, the University of Northampton in the UK, and Universidad de Oviedo in Spain, as well as in China with Tsinghua University in Beijing and Tongji University in Shanghai. ←

The Invention Center’s initiators (from left): Prof. Dr. Günther Schuh, Prof. Dr. Daniel Wentzel, Prof. Dr. Frank Piller, Prof. Dr. Malte Brettel, Dipl.-Ing. Markus Wellensiek, Toni Drescher, and Christian Gülpen.

Software for steering

Engineers from ThyssenKrupp Presta are developing one of the most advanced steering systems in the world at the center of excellence for electric and electronic systems in Budapest.

TEXT: CHRISTIAN BUCK

If asked to name the most important centers of international automobile development, most drivers would probably think of locations such as Stuttgart, Munich, Wolfsburg, or Detroit. There are probably very few who would mention Budapest. Yet the 11th district of the Hungarian capital is home to the creation of one of the most advanced steering systems in the world, which will make a substantial contribution to driver safety and the driving experience in many BMW or Daimler products. Here, very close to Budapest University, ThyssenKrupp Presta has its center of excellence for electric and electronic systems, where around 300 engineers are developing hardware and software for the intelligent steering systems of the future. It is the biggest development center for software and electronics in the whole ThyssenKrupp Group.

Drivers have long been accustomed to comfortable power steering, which enables vehicles today to be controlled almost effortlessly. In the past 60 years or so, this has been provided mainly by hydraulic systems, which support the driver by means of an oil circuit. The future, however, belongs to electric steer-

ing systems (Electric Power Steering, EPS), where an electric motor delivers the necessary power to the front wheels. "Around 80 percent of all new vehicles will be equipped with EPS by 2018," reports László Naszádos, Department Manager E/E Hardware at the Budapest center of excellence, who has been a member of the team since 2003. "This will enable us to reduce fuel consumption by up to 0.3 liters per 100 kilometers, because the electric motor needs energy only when the driver makes a steering movement. By contrast, the hydraulic pump is constantly in use, even when it is not actually needed." In addition, the electric motor is more environmentally friendly, because it requires no oil at all. Finally, EPS is also more reliable, and can be combined more easily with new comfort functions such as parking assistants.

Precision work for all customers
In Budapest, the engineers develop all the components for intelligent

Teamwork: Around 300 engineers in Hungary are developing hardware and software for the steering systems of the future.





Mastermind:
László Naszádos is
Department Manager E/E
Hardware and a member
of the Budapest team
since 2003.



steering systems, build EPS prototypes, simulate and test their functions, and meticulously adapt their solutions to the specific requirements of their customers, because every marque defines itself to a considerable extent by its models' steering behavior. One major focus here is on software development, because it is only the engineers' sophisticated programs that can provide the system with the necessary intelligence. "A computer registers the driver's steering movements and calculates the extent to which the motor will need to support him," Naszádos explains. "At the same time, the software also takes account of other variables, such as speed, crosswinds, and information from other computer systems in the vehicle." As a result, the vehicle responds to the driver's actions in different ways, depending on the situation at the time: for example, by reacting less sensitively to steering movements at high speed on a freeway than to those made in parking outside a supermarket.

The steering system's computer devotes around half its time to overseeing the system's safety. "To do this, our algorithm contains various diagnostic functions, which



monitor the correct and safe operation of all functions," Naszádos says. "It was developed here in Budapest, and is one of ThyssenKrupp Presta's central innovations, because this is what really makes the electromechanical steering system possible in the first place. It is one of the most important selling points in our customers' eyes." It is also, clearly, a persuasive one: the solutions from Budapest are now to be found in more than a million vehicles worldwide. However, the developers in Hungary are, of course, not resting on their laurels: As their next big challenge, they are working on autonomous driving, where a vehicle can move through traffic with the help of sensors such as radar systems and video cameras, with no driver intervention at all – and, naturally, reliably controlled by an intelligent steering system from Budapest.



My unique automobile

Chameleon paint and leg propulsion: columnist Peter Glaser dreams of his tailor-made automobile from just-in-time manufacturing.

The year is 2030, and I am looking forward to getting my new car. Today is the big day: the factory is going to come round to deliver it to me.

Cars used to be made on assembly lines in huge plants – but now, the production process has become so individualized that only single items are made. The old automobile plants have, therefore, turned themselves into swarms of small, mobile super-workshops, which each tailor-make just one vehicle. Since they themselves became mobile, the interconnected workshops also perform transportation tasks such as the procurement of parts and the delivery of the finished vehicle. Economists call this “just-in-time manufacturing.”

I want to wear something appropriate for this important occasion. First, though, I have a lengthy discussion with my favorite jacket, which is in a bad mood – all everyday objects now have a well-developed technical inner life. This means that even textiles are highly networked, and endowed with their own intelligence. Items of clothing can now sometimes be smarter than the people who wear them.

Before the autonomous factory arrives, I have a chat by video link with the operational staff. Factory workers now proudly call themselves “manufacturers,” and see themselves as the modern descendants of the master craftsmen of old. They receive crucial assistance here from the robots that support them in their work.

The mechanical helpers are able to reconfigure themselves at great speed. Now, the robot has just assumed human form, as is customary for presenting products to customers. “Can you see Mr. Eigenstein?” he asks me with a grin, pointing behind him to the empty space in front of a cavity wall. I know that this is where my new car is, and grin back.

The top half of Mr. Eigenstein suddenly appears, as if from nowhere. He is the chief designer and assembly supervisor, all in one, and has just been testing the chameleon paintwork. When this effect is switched off,

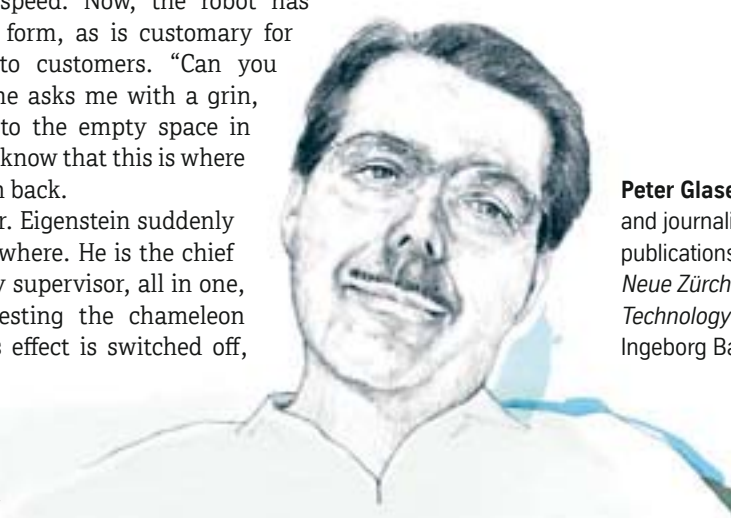
the vehicle has a fixed color. When it is switched on, the car body assumes the patterns and colors of its surroundings. You become virtually invisible. As this would be too dangerous on the public highways, the chameleon paintwork can be activated only for off-road driving. This is precisely what I have ordered: the ultimate all-terrain vehicle.

I am moved, and express my gratitude to the two vehicle construction workers. The robot makes a dismissive gesture, and clanks: “It was nothing.” Mr. Eigenstein looks at his robotic colleague through a narrowed eye. “He does not have to eat or sleep, and he does not need to shave,” he says, admiringly. “But still, working with him is not always easy.” No wonder: engineers have established that robots have to be given a certain amount of self-will, or else they cannot develop the highest forms of artificial intelligence. They need human moods to achieve maximum performance.

“Pay no attention to him!” the robot growls, pushing Mr. Eigenstein away with one of his gripping arms. The pair start arguing, and I can see the robot rolling his eyes in annoyance and groaning, “Oh, for goodness’ sake!” My jacket indicates that it, too, would like to say something on this subject – but I switch it to silent, although I know this will get me into trouble later.

Fortunately, the factory stops outside my front door at this point, and I am admitted to the workshop space. My new vehicle is now visible before me – with mounted legs, as I requested. These biomechanical mobility aids look like small feet, and a dozen of them take the place of one tire. This is true precision work: the legs were developed especially for me.

In the simulations during the ordering process, the vehicle always reminded me of a millipede. As the legs are much more flexible than traditional tires, they are brilliantly suited for off-road driving. I decide to put this to the test immediately: I leave the man and the robot to continue their discussion, and waddle off with my new vehicle.



Peter Glaser is an author and journalist. He writes for publications including the *Neue Zürcher Zeitung* and *Technology Review*. He won the Ingeborg Bachmann Prize in 2002.



Comprehensive introduction

Why is Industry 4.0 important for Germany? In which areas does the greatest need for action lie? And what will meaningful use cases for Industry 4.0 look like? These implementation recommendations from the Science and Industry Research Union and the German National Academy of Science and Engineering offer a comprehensive introduction to all aspects of this topic.

IMPLEMENTATION RECOMMENDATIONS FOR THE INDUSTRY 4.0 FUTURE PROJECT

<http://tinyurl.com/techforum5>



Investment in the billions

In the coming five years, more than half of German industrial companies' investment in capital equipment will go into Industry 4.0 solutions, according to a TNS Emnid survey of 235 German industrial companies. This is equivalent to annual investment of around €40 billion between now and 2020. How Industry 4.0 is transforming companies, and the impact that this process will have on value chains, is described in the study, "Industry 4.0: Opportunities and challenges of the industrial internet," by PwC and Strategy&.

INDUSTRY 4.0: OPPORTUNITIES AND CHALLENGES OF THE INDUSTRIAL INTERNET

<http://tinyurl.com/techforum6>



British angle

In Britain, too, experts are thinking about the future of manufacturing. They have developed their vision of the factories and the industry of the future in an extensive report for the British government. It offers an interesting addition to the German discussion of the key issue for the future that is Industry 4.0.

THE FUTURE OF MANUFACTURING

<http://tinyurl.com/techforum3>



American perspective

The USA is the world leader in network technologies, so it is no wonder that experts there lay great emphasis on the industrial use of the internet in the discussion about the future of production. The potential resulting from the combination of the internet of things and big data analyses is examined in a joint study by General Electric and the Accenture management consultancy.

INDUSTRIAL INTERNET INSIGHTS REPORT

<http://tinyurl.com/techforum4>

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“More efficiency and better solutions – this is what I expect from the ‘Single Point of Truth’: All parties will access clear product and process data from a single source.”

For **Dr. Matthias Hartmann**, dealing with Industry 4.0 offers him, time and again, opportunities to scrutinize existing products and processes. What fascinates the Vice President Technology & Innovation at ThyssenKrupp SystemEngineering here is that, thanks to the increase in computing power, things are possible today that engineers of the past could only dream of – for example, that a technician in a factory workshop can use a tablet PC to directly access planning data from an assembly plant. **Page 8.**

