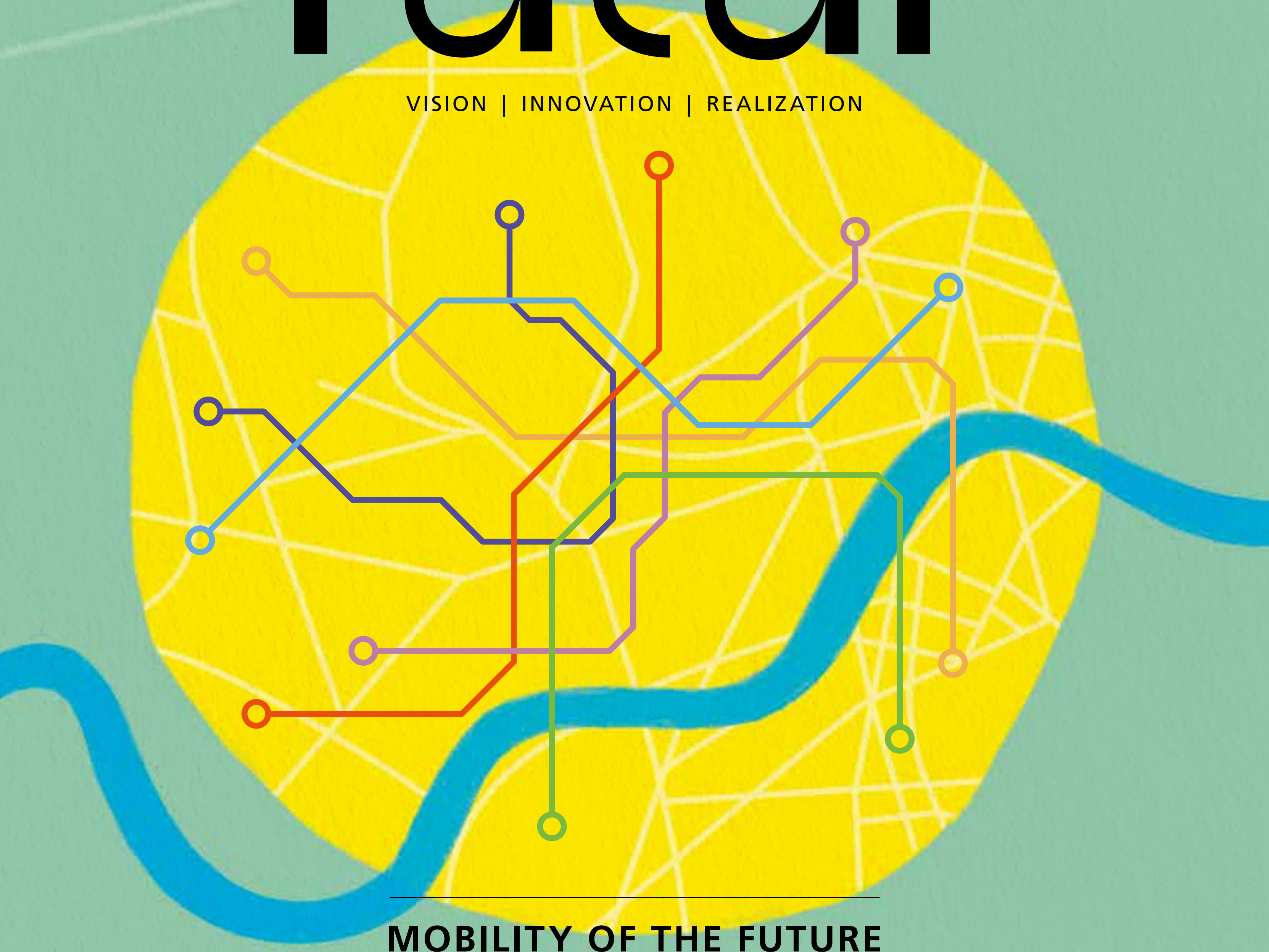
THE MAGAZINE OF THE **PRODUCTION TECHNOLOGY CENTER BERLIN**

futur

VISION | INNOVATION | REALIZATION



MOBILITY OF THE FUTURE

Keeping the Wheels Turning

Current headlines on the automotive industry in Germany are mostly a cause for headaches. Meanwhile, experts at Fraunhofer IPK are paving the way out of the crisis.

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Green on Blue

MAN builds engines for the world's largest freighters – and thus has a decisive influence on the future of shipbuilding. We spoke with leading minds at MAN Energy Solutions about their strategy for sustainable maritime transportation.

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Systems for a Digital Take-off

A passenger flight in 2050: low-emission, quiet, safe, affordable? The aviation industry faces enormous challenges on the journey to a new generation of propulsion systems.

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Fraunhofer IPK

INSTITUTE
PRODUCTION SYSTEMS AND
DESIGN TECHNOLOGY

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INSTITUTE MACHINE TOOLS
AND FACTORY MANAGEMENT
TECHNISCHE UNIVERSITÄT BERLIN

**Car.
Cargo.
Cargo transport.**

↳ page **30**

Production Technology Center (PTZ) Berlin

PROFILE The Production Technology Center (PTZ) Berlin houses two research institutes: the Institute for Machine Tools and Factory Management IWF of the TU Berlin and the Fraunhofer Institute for Production Systems and Design Technology IPK. As production-related research and development partners with a distinctive IT competence, both institutes are in international demand. Their close cooperation in the PTZ puts them in the unique position of being able to completely cover the scientific innovation chain from fundamental research to application-oriented expertise and readiness for use.

We provide comprehensive support to companies along the entire process of value creation: Together with industrial customers and public-sector clients, we develop system solutions, individual technologies and services for the process chain of manufacturing companies – from product development, planning and control of machines and systems, including technologies for parts manufacturing, to comprehensive automation and management of factory operations. We also transfer production engineering solutions to areas of application outside industry, such as traffic and safety.

DEAR READERS,

Technology moves us, in the truest sense of the word. Many of the most significant inventions in human history have been dedicated to mobility – from the invention of the wheel, to the steam engine that pulled the first train 42 kilometers from Stockton to Darlington in 1825, to the many technical innovations that space travel has brought us. However, the mobility of the future is not just a technical issue, it is also a social one. Who has access to which means of transportation and at what price? How can we prevent traffic from contributing to climate change? And how will the changing mobility landscape affect our economic system?

Our research at PTZ Berlin shows that the answers to these questions are close at hand, that the course is already being set here and now. In this issue of FUTUR, we provide an overview of the latest findings in production science on a wide variety of mobility types. Our journey takes us on the road, up in the air, on the rails, and at sea.

Let's start with the driving force of the German economy, the automotive industry. It is facing one of the most important questions since the founding of the Federal Republic: What type of drive will replace the fossil fuel combustion engine? We address this question not only in our featured article, but also in a constructive debate between experts from industry and research. Even if the automotive industry clarifies where we are headed, the question of how will still remain. What new processes, materials, and technologies will be necessary for cars powered by electric motors with batteries or fuel cells instead of fossil fuel driven engines? Can e-fuels for combustion engines be an interim solution? To enable the transition to a circular economy, our scientists are working on implementing battery and product passports. These will help improve life cycle analyses and traceability.

A major cause for concern when it comes to emissions is currently aviation. With the help of end-to-end digitalization and digital twins, our researchers want to make aircrafts hybrid-electric for a more sustainable future air traffic. Freight transport by rail and ship will also be affected by the transport revolution. We are pleased to have two Fraunhofer alumni present the most significant changes ahead: Dr. Sascha Reinkober reports on how DB InfraGO AG plans to increase the efficiency of the German rail network. And Dr. Johanna Rauchenberger from MAN Energy Solutions, together with her colleague Dietmar Pinkernell, explains in our FUTUR interview why both ammonia and methanol are better suited as ship fuels than hydrogen.

Hoping you, too, will be moved by this issue,

Yours

Eckart Uhlmann

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Will robots soon have the necessary know-how for disassembly …
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… as well as the necessary delicate touch for assembly?
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»Fully electric vehicles will for the most part be our ultimate goal, but not today and not tomorrow.«

Fraunhofer IPK director Prof. Uhlmann's assessment of drive technologies of the future.
↳ More on page 22

»The battery passport is particularly useful at the end of a battery's usage period – in the areas of battery collection, recovery and recycling.«

More on data ecosystems as a basis for battery passports
↳ on page 40

Our alumnus Dr. Sascha Reinkober shares insights from his work at DB InfraGO AG
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SHORTCUTS

IN DETAIL

Find out what is being scanned here
in our article »Auto-Assembly, Auto-mated«
↪ on page 44.

WELL SAID

»We will have a blend of different drive technologies, which we will have to think through and implement from cradle to grave if we want to achieve carbon neutral mobility.«

Kurt Blumenröder, CEO of T-Cell AG, in conversation with Dr. Rüdiger Schwarz, Head of Strategic Communication PtX Projects at EDL Anlagenbau, and Prof. Dr. Dr. Eckart Uhlmann and Prof. Dr. Julian Polte
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THE JOURNEY TOWARDS IMPLEMENTATION

From February 2027, the battery passport containing information on composition, carbon footprint, performance and circularity will be mandatory in the EU. The BatteryPass-Ready project, launched in April 2025, is now moving on to implementation: A test environment will enable SMEs and other industry users to try out battery passports in practice, paving the way for their introduction along the entire value chain. At the same time, guidelines for policymakers and companies will also be developed.

↪ **More information (German only) on BatteryPass-Ready at**
www.ipk.fraunhofer.de/battery-pass-ready

More on the strengths of the battery pass
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NUMBER OF THE ISSUE

41,000 km

is the distance a hydrogen fuel cell car would have to travel to offset the CO_2 emissions generated during its production compared to a gasoline-powered car, based on the current electricity mix – that is once around the world.

↪ **Find out how research can help overcome the challenges of hydrogen drive systems**
on page 12.

FASTER PRODUCT DEVELOPMENT THANKS TO AI

The use of AI models can significantly simplify time-consuming tasks in product development. This also applies to the automotive industry, where engineers often have to take into account numerous design requirements, a wide range of parameters, and limited installation space. In a collaboration between Fraunhofer IPK and BASF Polyurethanes GmbH, a neural network was developed that can predict possible geometries for jounce bumpers that are important for driving comfort.

↪ **More information on this case study at**
s.fhg.de/case-study-basf-en

Driving Research Forward

Hydrogen, batteries or e-fuels – which drive technology will prevail? Research in production science provides industry and politics with crucial insights.

The automotive industry in Germany in 2024

613

billion euros turnover

> 770,000

employees

Sources: Statista, Statistisches Bundesamt

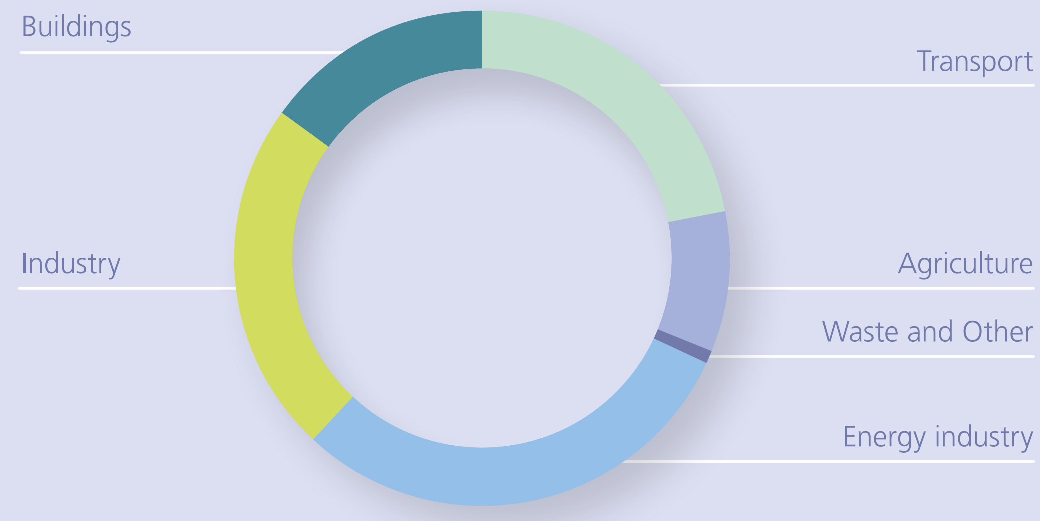
According to the Federal Ministry for Economic Affairs and Climate Action, the domestic automotive industry is »by far the most important industrial sector in Germany«. This is confirmed by data from Statista, according to which the industry has a turnover of around 613 billion euros annually, employing over 770,000 people nation-wide. However, various global, European and national developments are increasingly putting this proverbial engine of the German economy under pressure.

Take tighter regulatory conditions, for example: The European Green Deal aims to make Europe the first climate-neutral continent by 2050. On the way there, net greenhouse gas emissions must be reduced by more than half by 2030 compared to 1990. The European Climate Law creates a legally binding framework for EU climate neutrality by 2050, while the German Climate Protection Act sets binding targets for reducing greenhouse gas emissions in Germany. By 2040, 88 percent of emissions are supposed to be avoided compared to 1990.

In 2023, the transport sector was responsible for over a fifth of the greenhouse gases (GHG) emitted in Germany, making it an important lever for reducing emissions. Politics, legislation and society have therefore taken the initiative to dictate conditions for the transformation of the automotive industry.

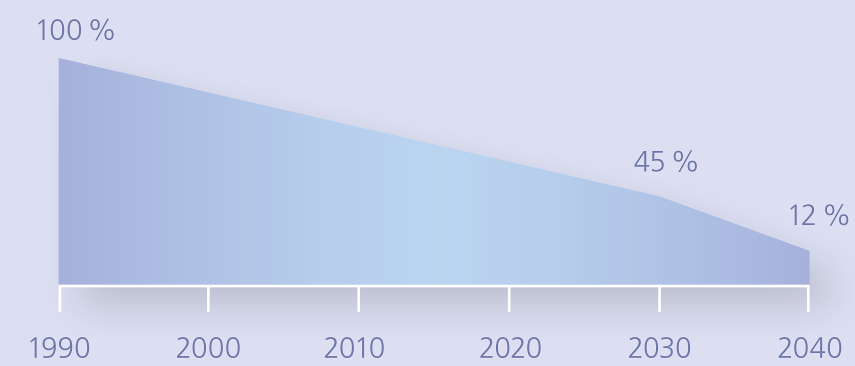
One thing is clear: The classic gasoline engine will soon have served its purpose. Which drive technology will prevail in its place, however, is less certain. Battery-powered electric vehicles tend to attract the most media attention and, given the resources currently available, are the most sensible technology right now. Science and research, however, are already discussing the further development and integration of hydrogen technologies. Which scenarios and perspectives are on the table, and what do they mean for the automotive and supplier industries in Germany?

The role of transport for greenhouse gas emissions in Germany



Source: Umweltbundesamt

Planned reduction of greenhouse gas emissions in Germany



Sources: European Green Deal, German Climate Protection Act

THE MARKET REACTS

German companies such as BMW and Volkswagen are pursuing a range of different strategies. BMW, in collaboration with Toyota, plans to launch the first hydrogen car into mass production by 2028, while Volkswagen is aiming for 70 percent electric cars by 2030. These trends show that manufacturers are clearly focusing on developing sustainable alternative concepts in order to meet regulatory and societal demands. All of them are grappling with the question of how to scientifically substantiate the various approaches. In other words: Which technologies should they focus on? The various drive technologies have different degrees of efficiency, which is crucial for reducing carbon emissions.

Among the alternative drive technologies, battery electric vehicles (BEV) have the highest overall efficiency. Their production, however, causes significant carbon emissions, mainly due to the use of materials such as cobalt or rare earths. Producing a conventional combustion-powered vehicle currently emits 39 percent less CO_2 than would be the case for a BEV.

However, if we consider the entire life cycle of a vehicle, operation plays a greater role than production across all drive types. For e-fuels, hydrogen and BEV, emissions are determined by the electricity mix. Currently, about 55 percent of Germany's electricity comes from renewable sources. The remaining 45 percent come from predominantly non-renewable sources which results in significant carbon emissions due to their low efficiency, especially in the case of hydrogen-powered vehicles. Even with completely climate-neutral electricity generation, a car with a hydrogen fuel cell drive would still have to travel a total of 41,000 kilometers to offset the carbon emissions created during its production, compared to a gasoline-powered car – that is equivalent to driving around the entire planet. Direct hydrogen combustion can offer a good alternative here, even if its efficiency is slightly lower.

THE HYDROGEN DILEMMA

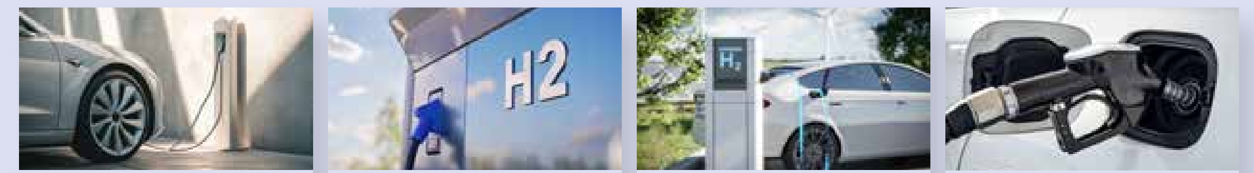
Hydrogen offers several advantages over conventional fuels such as gasoline or diesel, but it also presents challenges:

- Relative to its mass, hydrogen has three times the energy content of gasoline. However, due to its lower density, its energy content per volume is only one-third. Larger tanks are therefore required for the same range when hydrogen is stored in gas tanks.
- Hydrogen has a very wide ignition range, which allows for good partial load efficiency, but also makes it dangerous to handle.
- The ignition energy is significantly lower than for other gasoline fuels. This makes hydrogen very sensitive to unwanted pre-ignition.
- The lack of lubrication provided by the fuel is another disadvantage compared to hydrocarbon-based fuels.

Even with completely climate-neutral electricity generation, a car with a hydrogen fuel cell drive would have to travel a total of 41,000 km to offset the CO_2 emissions from its production compared to a gasoline-powered car – that is once around the world.

How environmentally friendly are different drive technologies really?

The graph shows the CO_2 emissions from the production and operation of vehicles with different drive types in grams per kilometer. The efficiency (in the case of BEV and hydrogen from electrical energy, in the case of petrol from the chemical energy of the petrol) is calculated up to the drive power in the vehicle.



	Battery powered electric vehicle	Hydrogen fuel cell	Direct hydrogen combustion	Combustion engine with e-fuels / gasoline: E-fuels	Combustion engine with e-fuels / gasoline: Gasoline
Production[1]	70	84	59	43	43
Use[1,2]	82	155	343	557	175
Degree of efficiency	72 %	31 %	23 %	16	30 %

[1] Taking into account the German electricity mix as of 2023, total mileage of 150,000 km
[2] Share would be eliminated with 100 % carbon neutral electricity generation
Data sources: ADAC, Electricity Maps, E.ON Energy Research Center, EPRS, Hydrogen Energy, IGEMBB, KBA, Öko-Institut, ORF, Statista, TÜV NORD, Umweltbundesamt

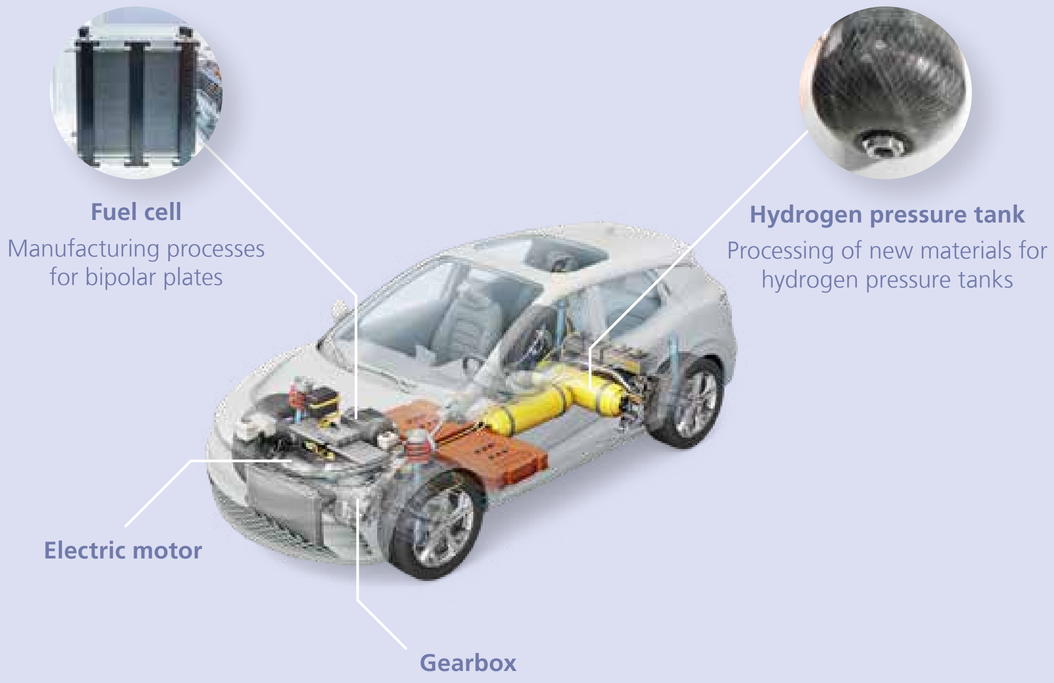
Hydrogen in all its shapes and forms

		CO_2 emissions per MJ H_2[1]	
Color	**Production**	**Current energy system[2]**	**Future energy system[3]**
Grey hydrogen	Steam reforming using steam from fossil fuels such as natural gas, coal and oil	134 g	54 g
Blue hydrogen	Like grey hydrogen, but the CO_2 produced is stored underground (CCS technology)	103 g	16 g
Turquoise hydrogen	From methane using high-temperature processing (pyrolysis)	108 g	17 g
Green hydrogen	By water electrolysis	13 g	0 g

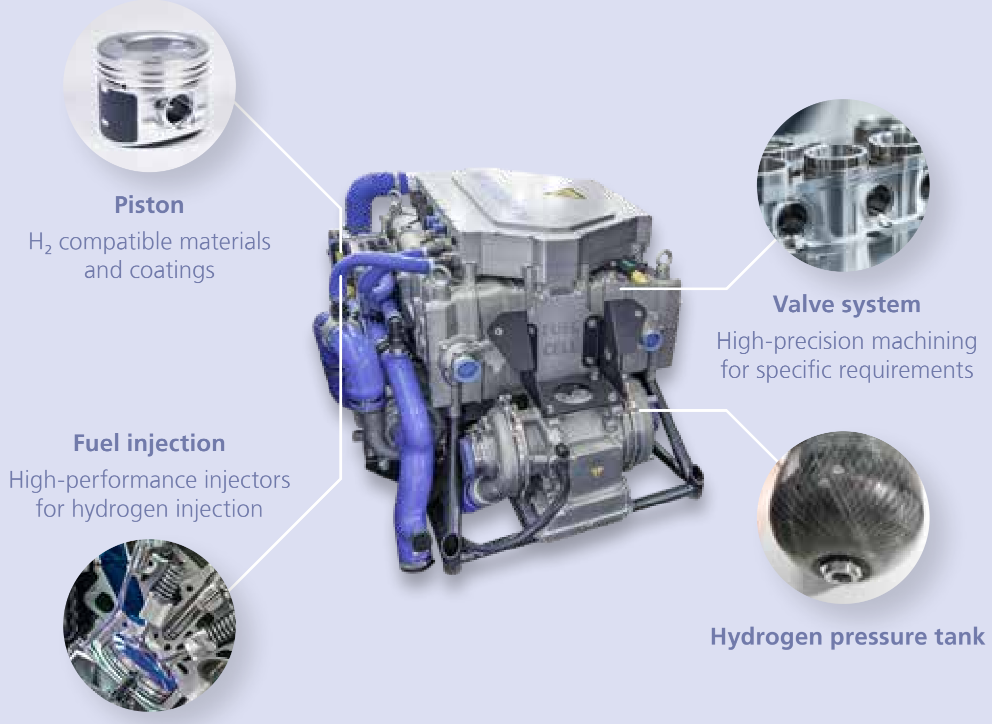
[1] Emissions are given in g CO_2 e per MJ H_2 or »grams of CO_2 equivalent per megajoule of hydrogen«
[2] with the electricity mix of the current general supply
[3] with electricity from renewable sources

Source: Umweltbundesamt

Select RnD potentials of fuel cells



Select RnD potentials of direct hydrogen combustion



These challenges require scientific solutions: Researchers in production and materials science have identified several promising areas to improve fuel cell electric vehicles (FCEV) and are working on implementing them.

Producing hydrogen tanks from carbon fiber-reinforced plastics (CFRP) offers great potential, as these provide high strength combined with low weight. CFRP tanks enable a weight reduction of up to 72 percent compared to metallic tanks. However, they cause high carbon emissions during production – around 2,210 kg CO_2e for 350 bar tanks and 2,670 kg CO_2e for 700 bar tanks. Advances in fuel tank production are therefore crucial to making hydrogen fuel cells competitive as a low-emission mobility solution.

The fuel cell itself consists of up to 200 individual components, centered around the bipolar plates through which the hydrogen is channeled. Instead of milling them individually, these plates are increasingly being manufactured in series through forming processes using metallic materials such as stainless steel, titanium or aluminum, which reduces their production costs and improves durability. Optimized channel structures within the bipolar plates can improve gas flow and increase the efficiency of the fuel cell. When chemical energy is directly converted into electrical energy without thermal losses, degrees of efficiency of up to 60 percent are possible. This makes the fuel cell an efficient and environmentally friendly drive solution.

WHY TAKE A DETOUR WHEN YOU CAN GO STRAIGHT?

Direct hydrogen combustion is a promising transitional technology that can be more easily integrated into existing combustion engines. This makes it less disruptive than other alternative drive technologies, as existing engines can continue to be used with moderate adjustments.

Since the hydrogen flames burn right up to the cylinder walls, the ceramic coatings of the pistons are crucial to minimize thermal stress and wear. Because hydrogen mainly burns to water vapor, this type of combustion results in CO_2-free exhaust gases and lower emissions of nitrogen oxides (NOx).

Fuel is injected by specially developed injectors, while the valve system must ensure optimal sealing and maximum efficiency through highly precise manufacturing of the valve seats. Additional measures such as a leaner mixture and cooled exhaust gas recirculation at high pressure are required to further reduce NOx emissions.

There is still a lot of research to be done in the area of direct hydrogen combustion – but overall, it represents a practical solution to ease the transition to zero-emission drives and make use of existing infrastructure. Today, research scientists at Fraunhofer IPK are exploring new technologies to meet tomorrow's challenges of using hydrogen as an energy source. In doing so, they not only consider new components that are immediately necessary, but also the implications along the entire life cycle of a vehicle. ◆

72 %

of weight can be saved by using CFRP instead of metal tanks.

200

individual components can be part of a fuel cell.

60 %

is their degree of efficiency.

Sources: CIKONI GmbH, TÜV Nord

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Keeping the Wheels Turning

Current headlines on the automotive industry in Germany are mostly a cause for headaches. Meanwhile, experts at Fraunhofer IPK are paving the way out of the crisis.

The German automotive industry is struggling, and the whole country is feeling it. From Stuttgart to Wolfsburg, employees of automotive manufacturers and suppliers alike are worrying about their jobs, while development and design engineers are looking for opportunities in other industries. The reasons for this crisis are complex. The powertrain transformation is progressing more slowly in Germany than in other countries. In the premium segment, where German vehicle manufacturers have so far been leading international markets, strong competition is emerging abroad. This is putting pressure on the export rate, as are punitive tariffs on car imports. This is problematic for an industry that sells three quarters of its products abroad.

Falling sales figures have a massive impact on the capacity utilization of production plants in Germany. High wages and non-wage labor costs as well as high energy costs make plants uneconomical if they only produce at around two-thirds of their capacity – not an uncommon rate at the moment. It is no wonder that the German Bundestag is also concerned about the industry's difficulties. Experts of the Committee on Economic Affairs recently spoke more than worriedly about the situation of German automobile manufacturers and suppliers. In a hearing in mid-November 2024, the President of the German Association of the Automotive Industry (VDA), Hildegard Müller, spoke of an »extremely urgent situation« in the automotive business.

BOOSTING THE TRANSFORMATION

A few figures underscore the urgency. The industry is the country's strongest in terms of revenue. According to a recent study, 25 percent of industrial jobs in eastern Germany are directly or indirectly dependent on the automotive industry. All the more reason to comprehensively reform the industry and put it on a firm footing for the future. The conditions for this are better than the current situation might suggest. Digitalization is revolutionizing product development and production processes by integrating automated manufacturing, data analysis and artificial intelligence to increase efficiency and flexibility. Mobility concepts and customer needs are also changing: Vehicle companies are now producing a variety of new small and micro vehicles with electric motors alongside cars – from electric scooters and e-bikes to e-mopeds. And all of this in individualized variants, sometimes with a batch size of 1. This also changes the product portfolios and production principles of supplier companies.

At the same time, Robert Drewnicki from the Transformation Network for the Vehicle and Supply Industry in the Berlin-Brandenburg Region (ReTraNetz-BB) pointed out to the Committee on Economic Affairs that more than twice as much research and development funding was flowing into automotive jobs in eastern Germany as into other workplaces. This is a solid basis for reinventing the industry, making it faster, more agile, more creative and more efficient.

The conditions for reforming the German automotive industry and putting it on a firm footing for the future are better than the current situation might suggest.

Where a manufacturing industry needs to be transformed, Fraunhofer takes a leading role, setting pace and direction. Fraunhofer IPK experts are actively involved in the ReTraNetz-BB project and keep their fingers on the pulse of local industry. »Companies are identifying development needs in various areas,« reports Prof. Julian Polte, head of the Production Systems division. »They are calling for answers to the energy crisis, because it is killing margins. But digital, AI-supported assistance systems are also a big topic, as are ecosystems for current and potential value chains, which may look very different from what the industry is used to.«

Polte calls on companies that want to successfully shape their transformation to get in touch with him and his team. A real-world laboratory at the institute was inaugurated in November 2024 to support the automotive and supplier industry in the

Berlin-Brandenburg region in its transformation to more environmentally friendly and efficient vehicle production. It is also intended to become an important basis for future research projects as well as for university teaching and the training and continuing education of specialists.

AGENTS PROVIDE INSIGHTS

The topics that the institute is addressing through ReTraNetz-BB and other research projects related to the automotive industry are diverse. They start with a look at the »big picture« in production. »When it comes to making manufacturing more efficient, transparency is the right starting point,« concludes Nikolaos Koutrakis, who heads ReTraNetz-BB activities at Fraunhofer IPK. One promising approach in this context is the creation of a near-real-time status map of resources and processes. It provides a clear overview of the current production status and optimizes communication between the various actors on the shop floor.

A prerequisite for a holistic view of the situation is the digital representation of machines and processes. A Fraunhofer IPK solution maps every entity in production – production machines, materials, inventories, even people – as agents. The agents can communicate with each other and make decisions. They use simulation to identify conflicting goals and potential problems and to initiate suitable countermeasures early on. »When used in a production environment, the agents can take over control and monitoring of components and enable flexible planning and reorganization of tasks in real time,« summarizes Koutrakis. Automated decision-making takes less than a minute, enabling a rapid response to changes in the production process. This makes production more agile and can improve capacity utilization.

DIGITAL ASSISTANTS SUPPORT SHOP FLOOR STAFF

In addition, agents enable highly efficient support for employees on the shop floor. By providing complex information in real time and optimizing the interaction between people and machines, digital assistance systems address a variety of challenges in operational manufacturing. They help to make workflows more efficient and support employees in carrying out processes. They reduce the time spent searching for relevant data and instructions and help to fulfill documentation requirements. They increase safety and quality in production by supporting error-free execution of tasks. And they do so independently of language skills and the level of experience of employees, which makes it easier to integrate untrained or non-German-speaking staff.

Image:
Whether setting up a system or starting processing operations, smart assistance systems provide step-by-step guidance.

A real-world laboratory at the institute was inaugurated in November 2024 to support the automotive and supplier industry in the Berlin-Brandenburg region in its transformation to more environmentally friendly and efficient vehicle production.

»Language may sound like a trivial issue, but it's a key challenge in production,« reports Koutrakis. In the Berlin-Brandenburg region, up to nine different languages may be spoken on the shop floor of automotive suppliers. This is not only an enormous hurdle for communication at work, but also for the transfer of knowledge between employees.

Digital assistants offer enormous potential in this area. An example: An employee from abroad has to carry out and document a maintenance process on a system. Using a mobile device, she requests information in her native language about certain aspects of the last maintenance process carried out on the system. The digital assistant finds the information in the stored documentation and returns it in the employee's native language. She then performs the maintenance and documents it in her native language. The assistant translates the documentation into German and stores it centrally.

And that is by no means the end of the story. Taken to the extreme, the digital assistant would automatically generate the documentation while guiding the specialist through the maintenance process – also observing a consistent style and wording. Overall, digital assistance systems can massively reduce activities that do not add value, such as information searches and documentation, which significantly increases efficiency. They also make it possible to flexibly transfer people between industries with little training effort, thus allowing a company to respond to demand and capacity utilization.

MONITORING FOR MORE EFFICIENT ENERGY USE

The fact that energy monitoring is highly relevant for automotive companies is not surprising. Energy prices in Germany are among the highest worldwide – a significant drag on the profitability of Germany as an industrial center. This is a good reason to closely monitor the power consumption of an industrial plant. And not the only one: The Corporate Sustainability Reporting Directive (CSRD) requires industry to verify the energy consumption of components, which is causing a great deal of additional work for the already burdened automotive industry. To meet this requirement, numerous individual consumers and production steps in the process chain must be taken into account.

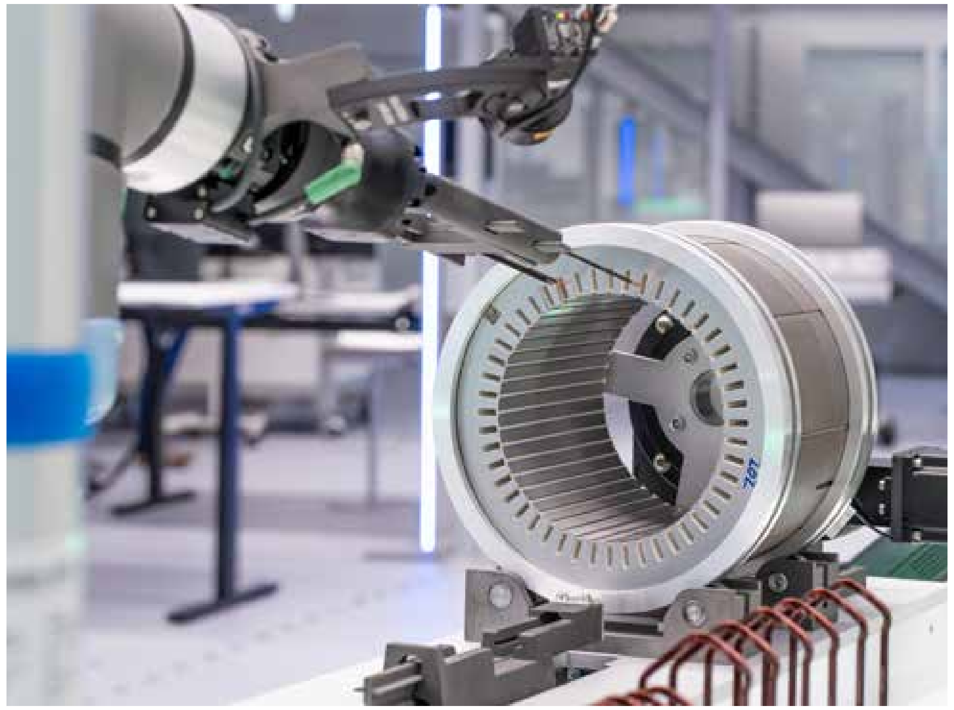
One effective solution is to equip both old and new manufacturing facilities with an energy measurement system that precisely records the energy consumption of individual components. This makes it possible to perform a detailed analysis of energy consumption, which not only helps companies meet legal requirements but also take targeted measures to optimize energy consumption – across the entire process chain and selectively at the component, procedure, and process level.

DIGITALLY SUPPORTED EQUIPMENT MANUFACTURING

Speaking of components: Not every device produced in a manufacturing plant is intended to be sold. Production equipment is purchased or manufactured for internal use. These items are used in industrial manufacturing – they range in shape and size from wrenches and injection molds to clamping devices, and even entire machines.

For certain production equipment, it is cheaper to manufacture them in-house than to buy them or even keep them in stock. In-house production is particularly worthwhile for parts that are rarely but then unexpectedly needed or that cannot be easily repurchased. In the automotive industry, customized assembly fixtures make a decisive contribution to process reliability and repeatability. The ability to customize these operating resources quickly and cost-effectively is particularly important, for example, when changing models, for vehicle-specific geometries, or for ergonomically adapted handling solutions.

Digitally integrated production equipment manufacturing greatly simplifies the manufacturing process as it enables fast and flexible production of spare parts without the need for traditional technical drawings. By using digital models and scans of existing components, the required components can be manufactured directly using 3D printing. This significantly reduces downtime in production. In addition, a continuous digital process chain allows existing components to be quickly adapted and optimized. As a result, companies can maintain their operating resources efficiently and save resources. This increases responsiveness and flexibility, and thus the resilience of production.



1

Images:
1
Inserting hairpins into a stator with the help of a cobot
2
Cleaning environmentally friendly, precise, and residue-free with carbon dioxide

FLEXIBLE HELPERS: COBOTS

When it comes to supporting manufacturing specialists, cooperative robots, or cobots for short, can also make an important contribution. An example application can be seen in the ReTraNetz real-world laboratory, where a cobot is used to demonstrate how hairpins are inserted into a stator. Cobots differ from traditional industrial robots in their compact design, ease of programming and, in particular, their safe interaction with humans. They are equipped with highly sensitive sensors that anticipate and prevent collisions. This makes it possible for them to work in close proximity to humans without protective cages or barriers, which saves space in production facilities and enables flexible integration into existing processes. In addition, they can be easily transported and used in ever-changing locations within a production facility. Cobots have an intrinsic advantage that is essential for these applications: They are programmable intuitively. Thanks to user-friendly interfaces and adaptive control systems, they can be programmed for new tasks in a very short time.

Both advantages – mobility and programmability – make cobots ideal tools for supporting dynamic, variant-rich manufacturing as highly flexible production systems. In direct interaction with employees on the shop floor, they combine the strengths of both partners by uniting the flexibility and problem-solving ability of humans with the precision and resilience of machines. Working with cobots reduces repetitive or physically demanding tasks and allows employees to concentrate on challenging tasks. At the same time, people remain at the center of the production process.

DRY AND RESIDUE-FREE CLEANING

In the cleaning industry, the regulatory framework for companies is becoming increasingly restrictive. With its Zero Pollution Action Plan, the European Commission has set the goal of reducing air, water, and soil pollution by 2050 to levels that are no longer harmful to our health and natural ecosystems. Poisonous substances as well as substances that are harmful to nature and water will be gradually banned along the way. This directly affects cleaning, where alternatives to harmful chemicals must be found.

Cleaning with carbon dioxide (CO_2) is a promising approach. Unlike most conventional cleaning methods, CO_2 blasting leaves no residue on the object being cleaned. The blasting medium sublimates immediately upon contact with the surface – with no need to dispose of any cleaning agent residues or purify contaminated water. There is also no need for subsequent drying of the cleaned object, which is often energy-intensive. This saves a lot of time and energy. The CO_2 used is a waste product obtained from other industrial processes and therefore has a neutral carbon footprint.

In the automotive industry, the process enables comprehensive and gentle cleaning prior to important process steps such as surface finishing by painting. It is also ideal for cleaning highly sensitive components. The risk of damage from aggressive chemicals and subsequent mechanical or energy-intensive drying processes is minimized, while the technical cleanliness required for subsequent processes is guaranteed. This makes vehicle production a clean affair. ◆

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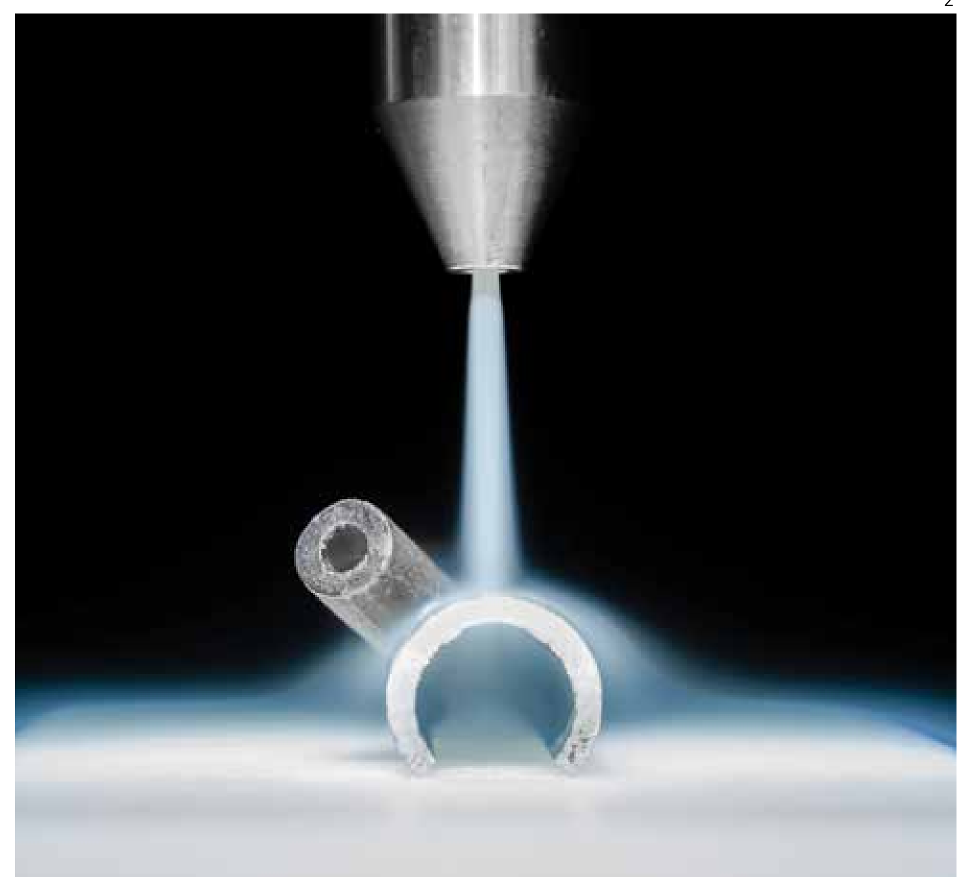

More information
www.ipk.fraunhofer.de/retranetz-en

The research and development project ReTraNetz-BB is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Finding the Right Blend

The mobility of the future is already being powered by a variety of drive technologies. Each one has its own strengths and weaknesses. Kurt Blumenröder, CEO of T-Cell AG, Dr. Rüdiger Schwarz, Head of Strategic Communication PtX Projects at EDL Anlagenbau, and Prof. Dr. Dr. Eckart Uhlmann and Prof. Dr. Julian Polte from Fraunhofer IPK discuss which technology will ultimately win the race.

Prof. Dr. Dr. Eckart Uhlmann
is Director of Fraunhofer IPK and university professor for Machine Tools and Manufacturing Technology at TU Berlin. He has been working with automotive manufacturers at the interface between research and industry for decades and has been instrumental in coining the term »digitally integrated production«.

Dr. Rüdiger Schwarz
is Head of Strategic Communication PtX Projects at EDL Anlagenbau. EDL is an innovative service provider for the process industry, particularly in refinery, chemical and petrochemical industry and gas technology. The company offers engineering and plant construction services, from concept development to the commissioning of turnkey plants.

Prof. Dr. Julian Polte
heads the Production Systems division at Fraunhofer IPK and is a university professor for Machine Tools and Technologies for Additive Manufacturing of Precise Metallic Components at TU Berlin. Together with the researchers in his teams, he works closely with the automotive industry on various projects.

Kurt Blumenröder
is CEO of T-Cell AG. The company was founded in 2022 as a start-up by experienced scientists, international managers and experts from the energy sector. T-Cell is an innovative fuel cell technology that facilitates an efficient and sustainable energy supply.

| futur | **Each one of you is working on researching new drive technologies. Which drive types do you think will prevail and why?**
/ UHLMANN / We are working hard on answering this question, particularly with regard to the energy efficiency and climate neutrality of automotive vehicles. Electric mobility has been promoted quite vigorously in Germany in recent years, but without sufficiently considering the necessary infrastructure. The automotive industry was essentially presented with a gift in the form of subsidies for many electric technologies, even those that are not necessarily helpful and, at best, constitute transitional technologies. Hybrid vehicles, for example, consume a lot of resources and make vehicles heavier without being able to run entirely on electricity.

In order to assess the efficiency and environmental compatibility of the various drive technologies, we need to look at their degree of efficiency and CO_2 emissions. We have done that for battery-powered electric vehicles (BEVs), fuel cell vehicles (FCEVs), direct hydrogen combustion engines, and combustion engines running on e-fuels and gasoline. Our analyses show that battery-powered electric vehicles have the highest degree of efficiency, followed by fuel cell vehicles. Hydrogen direct combustion and e-fuels, on the other hand, would rather be seen as alternative technologies.

/ SCHWARZ / How was this calculated?

/ UHLMANN / We started with a mid-range passenger car and calculated its CO_2 emissions both during operation and production. The emissions during production reflect the entire life cycle of a passenger car with an assumed total mileage of 150,000 km. We calculated the emissions during operation based on the electricity required to produce the fuel, taking into account the current electricity mix in Germany. In our analysis of e-fuels, we assumed that 100 percent pure e-fuels would be used – although they are currently only allowed to be added to aviation fuel in minimal quantities.

/ SCHWARZ / That varies. There are currently ten internationally approved production paths for producing SAF, sustainable aviation fuels, and the admixture ratios range from five to 50 percent. This is however more of a political than a technical issue, as a 50 percent admixture ratio has been possible for decades using Fischer-Tropsch synthesis. Between 50 and 100 percent, it's a question of the right sealing materials and mechanisms in existing airplanes. New airplanes that are being produced today can already fly with 100 percent e-fuels. But an aircraft has an average service life of 30 years. This means that fuels with a lower admixture ratio will still be needed for existing airplanes for another 30 years.

But you already mentioned the infrastructure: How much electricity do we actually have available? We as EDL have been in the application process for an Important Project of Common European Interest (IPCEI) for four years, called »LHyVE – Leipzig Hydrogen Value Chain for Europe.« Here, together with VNG AG, ONTRAS Gastransport GmbH, and Stadtwerke Leipzig, we want to realize the entire value chain for the production, storage, transport, distribution, and end use of green hydrogen in the Leipzig region and integrate it through the infrastructure with European projects, cities, and municipalities. More specifically, we plan to produce 50,000 tons of e-fuels and 15,000 tons of green hydrogen per year. If we want to achieve climate neutrality in mobility and logistics, we need green hydrogen. But according to your calculations, it is not green anymore.

/ UHLMANN / That is true, fuel cell vehicles or direct hydrogen combustion engines still cause rather high emissions when operated with today's electricity mix, because hydrogen has to be produced. Can we significantly improve the way we produce it compared to today? If, instead of selling surplus electricity from wind turbines to neighboring countries at a cost, we use it to produce hydrogen with electrolyzers, then perhaps we can.

/ SCHWARZ / It is an illusion to believe that surplus electricity can be fed into electrolyzers. I can explain this to you with a simple calculation: Firstly, as hardly anyone knows, all wind turbine operators receive 95 percent of the remuneration even when their wind turbines are not running. Secondly, the EU requires compliance with a series of complex electricity procurement criteria for the operation of electrolyzers for the production of green hydrogen, which ultimately reduce the operating hours of electrolyzers in Germany to less than 3,000 to 4,500 operating hours per year. However, electrolyzers can in principle run for a good 8,400 hours per year, making them easier to amortize. As a result, the green hydrogen produced in this way is between three and four times more expensive. Nobody currently reimburses you the difference.

/ UHLMANN / Exactly, but that is a political or regulatory problem.

/ SCHWARZ / But this narrative of »surplus electricity« has found its way deep into politics, the federal ministries and administration. If you ignore economics, then processes simply do not take place in industry. Then certain technologies are not supported.

/ BLUMENRÖDER / I agree with you that politics is neglecting power generation and infrastructure. In order to evaluate technologies, we need a perspective that is also comparable in its premises so that it can be used for policy recommendations. Then we would not have this divided approach between technical solutions with their efficiency on the one hand and the political approach of promoting certain technologies on the other. Engineers need to look at the physics. I can only recommend that. Any other approach would be wrong.

/ UHLMANN / Let us look at the technical facts, then: We have to live with the electricity mix we have today. Switching to 100 percent renewable energies immediately is unrealistic. That also means that we would have higher operating costs for both fuel cells and direct hydrogen combustion due to the necessary hydrogen production. The manufacturing costs for the vehicles are similar to those for gas-powered cars, even though some different materials are required. I therefore see fuel cell vehicles and direct hydrogen combustion engines as an intermediate solution.

In my view, e-fuels are another alternative technology, but they are currently expensive to produce as they incur high energy costs and can emit large amounts of CO_2. I also do not believe that the current production of e-fuels is sufficient to meet demand, particularly in aviation.

This means: Fully electric vehicles will for the most part be our ultimate goal, but not today and not tomorrow. We have to get there step by step. This becomes clear when you calculate how much electricity we would need if all 45,000,000 vehicles currently on the road in Germany were electric. We have an energy requirement of 100 terawatts in our country. One sixth of that would be needed to power all vehicles with electricity. We simply cannot manage that. That is why we need intermediate technologies.

/ SCHWARZ / We need the intermediate technologies for yet another reason, and that brings us to aviation. Nobody throws away a functioning airplane – you have to factor in its remaining service life. The same applies to the billions of cars currently in use around the world, all of which have a remaining service life that must be taken into account.

/ BLUMENRÖDER / Perhaps it would help to focus our discussion on the practical applications, because without applications, there is no benefit. Battery-powered electric drives are well suited for use in road traffic, especially in passenger cars and commercial vehicles. This covers 80 to 90 percent of all applications – provided that the necessary infrastructure for charging and, of course, renewable power generation are in place. Considering hydrogen fuel cells, hydrogen as an energy carrier is particularly useful in areas where batteries are not ideal due to their weight and charging times. The handling of hydrogen, especially its storage, is very energy-intensive and safety-relevant.

/ UHLMANN / When it comes to storage, we are now able to achieve pressures of up to 800 bar using CFRP high-pressure containers. The containers are coated accordingly to ensure that the purity of the hydrogen is maintained. In theory, this solves the problem.

/ BLUMENRÖDER / In theory, yes. However, there is another technical problem related to the potential poisoning of the fuel cell if the required purity of the hydrogen is not attained. I cannot use impure hydrogen in a PEM fuel cell. Anyone who cannot achieve 99.99997 percent purity cannot use this technological path. No commercial fuel cell system provider is willing to risk losing a tenth of a percent of this purity level. So, using hydrogen in fuel cells will be a very narrow path for application.

/ POLTE / One point I would like to add regarding OEMs: Behind every drive concept there is actually a new car. Structurally, the vehicles look completely different, even if they may seem similar on the outside. We will not be able to equip all vehicles with a new drive concept in one go, but rather have to keep existing vehicles in mind.

/ BLUMENRÖDER / Yes, of course. In aviation and road transport, there is an existing fleet that needs to be covered. However, there are other industrial sectors, such as maritime transport, that are taking a much more innovative approach to the issue of existing fleets. Producing hydrogen is necessary and important for a whole range of products, for e-fuels, for direct combustion, for fuel cells. There's no question about that. But we have to be able to store and transport it. In maritime transport, transporting hydrogen over long distances makes no economic sense.

The International Maritime Organization (IMO) has defined methanol and ammonia as the fuels of the future for ships. Both fuels offer significant advantages over hydrogen in terms of transport and storage. And their green variants can be burned in fuel cells but also in combustion engines in a CO_2-neutral way. Both fuels are already widely used in the chemical industry and agriculture, and their production is well established on an industrial scale. Almost all Asian companies work with methanol.

/ SCHWARZ / As the »raw materials guy«, I would like to add that ammonia and methanol are both so-called global trading commodities. They have been around for 120 years and there is a global trading system in place. There is a pricing system and there is a functioning market.

/ BLUMENRÖDER / There are 120 ports around the world where methanol and ammonia are processed. And we are talking about quantities that are beyond our imagination. Global demand for ammonia is around 200,000,000 tons. This makes ammonia one of the most widely produced chemical products in the world.

/ UHLMANN / Returning to the automotive sector, what changes would I need to make to the engine and other components in a vehicle in order to use ammonia as a fuel?

/ BLUMENRÖDER / The piston engine essentially remains unchanged. The engine can be configured so that ammonia can be fed into the intake manifold and enriched with hydrogen, for example. However, ammonia in cars or trucks poses completely different challenges. Ammonia is toxic and corrosive, which requires additional safety measures for the vehicles themselves, but also for the storage and transport of ammonia. The infrastructure for using ammonia as a fuel is still under development.

/ POLTE / In the short term, battery-powered electric vehicles are a good solution then. We can upgrade the necessary infrastructure relatively easily. For example, many cities are already working with street lamp charging stations for electric vehicles.

/ BLUMENRÖDER / If we want to achieve a penetration rate of 30 or 40 percent for battery electric vehicles in Europe, we are talking about decades.

/ POLTE / That is also the information we have. Even just looking at the production of electric motors and axles, the currently available capacity on the market is nowhere near enough to meet the demand.

/ SCHWARZ / We can ramp up market capacities in five to ten years. I would like to throw in a point from the raw materials industry: Where do the metals required to build batteries actually come from? They are not available here in Germany, nor in the EU. If I need different metals in order to switch from existing systems to different ones, I create new demand for these metals. The EU Critical Raw Materials Act requires that, starting in 2030, ten percent of so-called technologically strategic metals be produced in Europe, with 40 percent of the demand in Europe being met from recycling. I do not see sufficient research capacity in this area in Germany. Do we consider the issue of raw material consumption when we are discussing strategies for drive technologies or not?

/ UHLMANN / Of course, we have to factor this in. For direct hydrogen combustion, for example, austenitic steels are required, as well as specialized coatings, which we already have mastered today. The technologies for producing these materials are available, there is no question about that. We do, however, need new materials, for example to make electric motors neodymium-free. Neodymium is a rare earth that we want to avoid using as much as possible. This brings us to exactly the point you just mentioned, namely that we need to develop alternative materials.

/ SCHWARZ / For the past 40 years, my career focus aside from the current topic of e-fuels has been on rare earth deposit sites. And that brings me to the question: We now know that implementing certain political guidelines from the last 10 to 15 years in Germany and Europe will at least take longer than was originally thought. You are now talking about neodymium-free engines. How long will it take to develop these materials and produce them in the quantities we need? When do you think these technologies will be available on an industrial scale so that we can also use them to power cars?

/ UHLMANN / Do you know the first principle of mechanical engineering?

/ SCHWARZ / No.

/ UHLMANN / The basic principle of mechanical engineering is: If you do not start, you will never finish. The problem is that we do not start working on certain things. We act as if everything has to be in place before we can get involved in a technology, instead of researching and developing it in an interdisciplinary way. That's why I insist, also in politics, that if we want to pursue direct hydrogen combustion, we must think about materials as well.

/ BLUMENRÖDER / Fundamentally, you are right. However, the issue of materials is the least of our problems when it comes to direct hydrogen combustion. Instead, we should just get on with it! Then we can argue about how to implement hydrogen combustion. We need to choose a combustion process that is actually safe. So far, all engine manufacturers have pursued approaches that work with a pilot injection process, which has the disadvantage of requiring the addition of gasoline or diesel, meaning that CO_2-free combustion cannot be achieved. And that is therefore not supported in European regulations.

Do we consider the issue of raw material consumption when we are discussing strategies for drive technologies or not?

Dr. Rüdiger Schwarz

/ UHLMANN / Then we need to find a technical solution and develop injectors that can inject hydrogen. The technologies are at least already being considered and have been partially implemented. Instead, our problem in Germany is that we often focus politically on just one technology and ignore everything else. We need to break this pattern and start asking ourselves what the logical next steps are and what the timeline should be. Mr. Schwarz, you see potential for e-fuels in aviation. They are already a prerequisite there. But are e-fuels an option for road transport, including for existing vehicles and given the costs involved?

/ SCHWARZ / If we factor in the question of timelines, I see e-fuels as a transitional technology, of course, even in road traffic. They can be produced immediately. If I change the framework conditions that affect the price of electricity, then I can also produce them economically. But then there are still CO_2 emissions. This brings me to a point we have not touched on yet: What do we actually do with the CO_2? And why are we politically opposed to removing CO_2 at point sources and use it as a recyclable material? Other countries already have business models for capturing CO_2 at locations where it is produced in large quantities. Another point: Four years ago, the Americans decided that the Department of Defense would essentially purchase any synthetic kerosene produced using a variety of new technological pathways at any price. And they will now decide which two or three of these new technological pathways' industrial implementation they will promote on a massive scale. This is technology-neutral funding in a way we do not have here in Germany, but urgently need.

»Electric only« will not be the right solution for all future applications either. We will have a blend of different drive technologies.

Kurt Blumenröder

/ UHLMANN / That is right, but we need to take different paths of transformation and pursue different technological approaches in order to get to zero-emission drives.

/ BLUMENRÖDER / »Electric only« will not be the right solution for all future applications either. We will have a blend of different drive technologies, which we will have to think through and implement from cradle to grave if we want to achieve carbon neutral mobility. What this blend will look like will vary depending on the application and infrastructure, but everyone will benefit from the synergies between the different approaches. ◆

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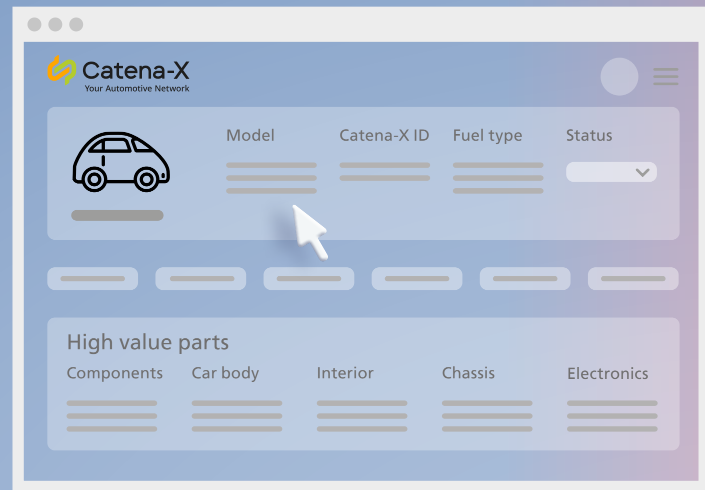
Virtual world

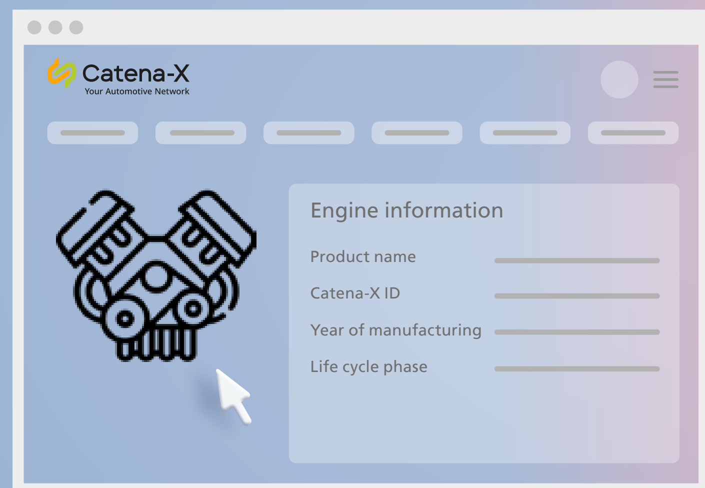
1.

A vehicle that is scheduled for disassembly can be inspected virtually, even before a single part has been removed. By entering the unique identification number of the vehicle that has to be disassembled, data made available within the Catena-X data ecosystem can be retrieved in the form of a digital twin.



2.

Using this digitally available data, individual components can be evaluated for reuse or recycling without having to be physically removed. For example, the average service life specified by the manufacturer can help to assess whether a component has been in operation for such a long time that reuse is no longer safe.



Physical world

3.

Using a robotic, intelligent camera system, the visible components of the extracted motor can be recorded and their condition assessed – a fully non-destructive and automated process.

4.

A worker dismantles the motor with the help of AR glasses showing her step-by-step instructions for removing the individual parts. At the same time, the glasses are recording the disassembly process.

Disassembly, Fully Digitalized

Politicians are calling for a more circular economy. This requires the digitalized, automated disassembly of used parts. And yet innovative, AI-supported solutions are lacking a solid data basis.

Researchers at Fraunhofer IPK have developed a comprehensive and coherent digitalization concept for the disassembly of vehicles. At the heart of this concept is the Circular Economy Assistant, a decision-making tool designed to make companies fit for the circular economy.

The CE Assistant also provides a straightforward overview of various disassembly options and their individual carbon footprints, making it stand out thanks to integrated solutions that cover the entire disassembly process.

NEXT STOP: AUTOMATION

The digitalized disassembly process shown here has not yet reached the end of the road. After all, the demands on disassembly are growing: Increasingly complex vehicle components have to be taken apart so that the individual parts can be recycled. To make this possible even when skilled specialized workers are hard to come by, further automation measures are needed. To accomplish this, AR glasses are used during the disassembly process to capture images that can be used to train an AI. On the basis of this multimodal data recording, robots will be able to perform the strenuous manual work in the future.

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Green on Blue

80 to 90 percent of all goods worldwide are transported on cargo ships. MAN builds engines for the world's largest freighters – and thus has a decisive influence on the future of shipbuilding. We spoke to Dr. Johanna Rauchenberger, Head of Group Quality & HSE, and Dietmar Pinkernell, Head of Sustainability & Product Safety at MAN Energy Solutions, about their strategy for sustainable maritime transportation.

Interview with Dr. Johanna Rauchenberger and Dietmar Pinkernell, MAN Energy Solutions

| futur | **So-called »green corridors« are set to connect important trading ports in the future. Only cargo ships powered by environmentally friendly fuels will be permitted passage through them. How do you view their significance in shaping the future of shipping?**

/ RAUCHENBERGER / Pilot projects such as the »green corridors« are particularly important to us. They are more than just a test bed – they mark a real turning point for shipping. In an industry facing fundamental change, initiatives like these create the space to test new technologies under real-world conditions. For us as an engine manufacturer, they are a welcome opportunity to show what is already technologically possible – and where there is still a concrete need for action.

/ PINKERNELL / Above all, they offer the opportunity to not only discuss low-emission propulsion solutions in theory, but to actually test them in everyday use. And with every ship that is tested and moves through such a corridor, we learn more about how these fuels behave in operation – how reliable they are, how efficient they are, and how well they can be integrated into existing systems.

/ RAUCHENBERGER / In addition, »green corridors« also help at the regulatory level. They make it easier for legislators to create suitable regulatory frameworks – faster, more targeted and with a better understanding of the technical background. At the same time, such projects also drive infrastructure development: Where ships run on new fuels, you automatically need supply networks, refueling facilities and logistics solutions.

| futur | **MAN Energy Solutions relies on alternative fuels such as ammonia, bio-methanol from plants, and e-methanol from carbon capture technolgies for marine transport. What specific challenges arise in the production and material selection of ammonia or methanol engines compared to conventional marine propulsion systems?**

Dr. Johanna Rauchenberger

studied computer science at RWTH Aachen and went on to earn a doctorate in engineering sciences at the Fraunhofer Institute for Production Technology IPT in Aachen. She moved into mechanical and plant engineering in 2009, initially taking over quality management at MAN Energy Solutions at its Zurich location. After various positions in Germany and abroad, she now heads the central quality department at MAN Energy Solutions SE with global responsibility for quality, management systems, occupational safety, environment, sustainability, and product safety. »What particularly impressed me during my time at Fraunhofer was the interdisciplinary collaboration. Mobility is not an isolated topic, but rather an interplay between a wide variety of sectors: Drive technologies, infrastructure, political conditions, market mechanisms – everything is connected. The recipe for success is to combine the different perspectives and work toward a common goal.«

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/ PINKERNELL / Developing large engines for such alternative fuels is technologically demanding and presents entirely new challenges. Until now, marine engines have been designed primarily for heavy fuel oil or marine diesels – proven fuels whose behavior in engines we have known in detail for decades. With new energy sources, we are entering uncharted territory in many areas. This applies not only to the combustion properties themselves, but above all to material behavior, safety, and the entire engine architecture.

A key issue is corrosion resistance. Ammonia is extremely reactive and attacks many conventional materials, especially copper-containing alloys. This means that we have to switch to highly resistant materials, including special stainless steels and nickel-based alloys. The problem with methanol is somewhat different: Although it is less corrosive, it attracts water, which can increase material fatigue in the long term. Here, too, specially coated or stainless materials are used to ensure the service life of the components.

Besides the materials, another focus is on the injection and combustion systems. Ammonia has a high ignition temperature and is relatively difficult to ignite. In order to burn it efficiently, we either have to resort to pilot ignition with diesel or hydrogen, or develop completely new ignition systems. Methanol, on the other hand, is easier to ignite but has a lower energy density. This means that more fuel must be injected, which requires larger injection systems and carefully adjusted compression.

The safety requirements should not be underestimated either. Ammonia is toxic, which means that any leak in pipes or tanks poses a serious risk. The entire fuel system must therefore be extremely leakproof, complemented by sensors and emergency systems. Methanol is less toxic but highly flammable. Here, too, a well-designed safety architecture is required.

/ RAUCHENBERGER / An aspect that is often underestimated is the industrial scaling. It is not enough to build individual prototypes – what is crucial is that these new technologies are transferred to economical series production. In order to do this, we need to develop new processes for reliably and efficiently processing specialized materials in large quantities. The test procedures must also be adapted to new chemical and thermal loads in the engine.

| futur | **You are also working on dual-fuel engines that run on liquefied gas. What role do such propulsion technologies play in the decarbonization of the maritime industry?**

© MAN Energy Solutions

Dietmar Pinkernell

studied technomathematics and began his professional career in 1995 at MAN B&W in Augsburg, now MAN Energy Solutions SE. He progressed through various development positions and, among other responsibilities, led the engineering design for large diesel engines. In 2016, he moved to the company's central quality department, where he was responsible for occupational safety, environmental protection, and product safety in a staff function. Today, he leads an interdisciplinary team as Head of Sustainability & Product Safety and coordinates company-wide sustainability initiatives, strategic projects, as well as internal and external reporting in his area of responsibility.

/ RAUCHENBERGER / Dual-fuel engines are a key component of the maritime energy transition. Especially at a time when the industry is under intense pressure to reduce emissions without losing its economic foundation, they offer a way to combine both: immediate progress in reducing the carbon footprint and long-term investment security.

/ PINKERNELL / Methanol and ammonia will not be available in sufficient quantities in the foreseeable future. The DF concept is a way to make the switch gradually, and it can be adapted to how the supply infrastructure grows because ships can use whichever fuel is available. This gives shipping companies some breathing room to invest in the fuels of the future now and avoid stranded investments. There's more: Simply building new, climate-friendly ships is not enough to achieve global climate targets. On average, ocean-going ships are in service for 25 to 30 years. These existing fleets must also be modernized. The dual-fuel concept makes this possible because many ships can be retrofitted for DF operation with synthetic fuels without having to replace the engine.

Dual-fuel systems also accelerate technological development toward real zero-emission solutions. Those who operate a methanol or ammonia engine in dual-fuel mode today are gaining valuable insights into combustion behavior, material stress, and into how the systems interact. All of this feeds directly into the next generation of emission-free engines.

/ RAUCHENBERGER / That is precisely why we see dual-fuel technology not only as a practical compromise, but also as a strategic decision. It combines environmental protection, economic sense, and technological foresight.

| futur | **Ammonia and methanol are both hydrogen derivatives produced by reactions with nitrogen and carbon, respectively. What advantages do ammonia and methanol offer over green hydrogen as alternative fuels for ships?**

/ PINKERNELL / Green hydrogen is an exciting and significant building block of the energy transition in the long term. But for the maritime industry, which needs solutions today, methanol and ammonia offer a clear advantage. The limitations of hydrogen quickly become apparent at sea, especially when you consider the requirements for range, safety, and infrastructure. In many cases, methanol and ammonia are simply the more practical solutions.

Methanol and ammonia have a significantly higher energy density per volume than hydrogen. This is an unbeatable argument for long-distance maritime transport, where space and weight play a key role. Hydrogen, on the other hand, must either be extremely compressed or liquefied at minus 253 degrees Celsius – both of which place enormous demands on storage and insulation. In comparison, methanol can be stored at ambient temperature and ammonia under relatively simple conditions.

RAUCHENBERGER / Another point is the integration into existing drive concepts. Methanol can be used in modified diesel engines with manageable effort. Ammonia can also be used in large engines if certain technical adjustments are made. In contrast, we see hydrogen primarily in stationary applications.

/ PINKERNELL / Nor should we forget the energy losses along the chain: Liquefying hydrogen is extremely energy-intensive and can cost up to a third of the original energy content. When green hydrogen is used to produce methanol or ammonia, however, these energy carriers can be stored and transported much more efficiently.

| futur | **Safety is a key factor for the use of ammonia as a fuel. Which measures and technologies are necessary to ensure the safe operation of ammonia engines on board ships?**

/ RAUCHENBERGER / Ammonia is toxic, highly volatile, and has a corrosive effect. It requires a well thought-out safety concept, because the protection of the crew, the ship, and the environment must have the highest priority. The challenge already begins with storage and handling. Ammonia can be kept liquid either under pressure or at low temperatures – both of which require specially designed tanks and piping systems. Double-walled structures with integrated leak warning systems are used to prevent leaks in the event of a malfunction. And instead of copper or zinc alloys, specially coated or highly resistant materials are used as sealing materials.

A key element is permanent gas monitoring. Highly sensitive sensors are installed in engine rooms, storage tanks, and all safety-relevant areas. These sensors reliably detect even the smallest amounts of ammonia and trigger automatic safety mechanisms: The fuel supply is interrupted, exhaust air systems are activated, and endangered zones are ventilated or sealed off. This makes it possible to respond quickly and effectively in an emergency.

/ PINKERNELL / The fuel supply itself must also be designed for the highest level of safety. Injection systems are equipped with multiple safety valves to prevent the uncontrolled introduction of ammonia. After each operation, the system is automatically flushed – usually with an inert gas such as nitrogen – to remove any residues. Since ammonia is also highly flammable, great attention is paid to the combustion process and its control to make sure that the combustion process remains stable and controlled.

Of course, the protection of the crew is also the focus of attention. The crew must be specially trained, not only in handling the fuel, but also in emergency management. Personal protective equipment, respirators with ammonia filters, protective suits, and mobile eye wash stations are part of the basic equipment. Every refueling and every maintenance operation is carried out in accordance with established safety protocols, accompanied by emergency plans and regular training exercises on board. The overall approach is rounded off by international safety standards. The IGF Code issued by the IMO, which regulates the safe use of gaseous or low-flashpoint fuels, provides the legal framework here. SOLAS and MARPOL guidelines are also adapted to the specific properties of ammonia in order to maintain a consistent level of safety worldwide.

| futur | **In addition to the technical development, infrastructure is also crucial. How do you assess the future availability and economic viability of green ammonia and methanol as maritime fuels?**

/ RAUCHENBERGER / There are many factors at play here. What is clear, however, is that both fuels have the potential to play a key role in the decarbonization of shipping. The difference lies primarily in the time frame and the infrastructure conditions.

/ PINKERNELL / Green methanol currently has the edge in terms of availability and scalability. It can be produced in two ways – either from biomass or by combining green hydrogen with CO_2 from industrial processes. The big advantage is that many existing production facilities can be converted to these new sources. This means that methanol can be made available relatively quickly and in larger quantities – especially if there is political support and clear demand from the market.

Ammonia is a bit more complex, though. Its production is based on the synthesis of hydrogen and nitrogen – an established process, but one with high energy requirements, especially if the hydrogen is to be obtained from renewable sources through electrolysis. The expansion of wind and solar energy is the critical bottleneck here. Large-scale industrial plants for producing this green variant are still lacking, but there are numerous projects underway around the world that could deliver initial quantities in a few years.

Image:
Dual-fuel engine from MAN that can run on LNG, diesel, and HFO as well as more sustainable fuels such as biofuel blends and synthetic natural gas.
© MAN Energy Solutions

/ RAUCHENBERGER / Methanol also is a globally traded commodity, it is transported in large quantities and can be handled with manageable effort using existing storage and bunkering systems. Liquid at ambient temperature and not overly toxic – this makes it a fuel that can be used without fundamentally redesigning port systems. Ammonia, on the other hand, requires more: closed systems, special sensors, and high safety standards. Although it is already being used globally, especially in the fertilizer industry, targeted investments are necessary for its use on board ships and in ports.

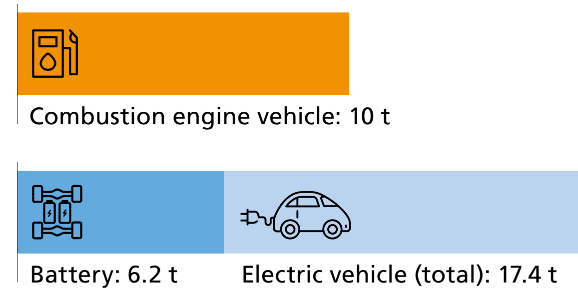
In terms of economic viability, both fuels are currently still more expensive than conventional fuels. But that will change. The more production capacity is created, the more economies of scale will come into play. At the same time, the political and regulatory costs of fossil fuels are rising – for example, because of the EU Emissions Trading System and CO_2 taxes. This is shifting the price structure and making green alternatives increasingly competitive.

Methanol will therefore be available more quickly in the short term, while ammonia offers major advantages in the long run – such as its potential for CO_2-free combustion – but this will require more time and investment. There are also differences in the areas of application: Methanol may be preferred in passenger shipping due to its lower toxicity. Ammonia, however, is predicted to have great potential in the transport of goods. The bottom line remains: Alternative fuels complement each other – and together they could have a decisive impact on the transition to emission-free shipping. ◆

Steel Battery Housings: an Aluminum Alternative?

Steel as a sustainable lightweight material? What appears contradictory at first could revolutionize the design of battery housings for electric vehicles, making e-mobility even more eco-friendly.

Emissions during production



According to the Austrian Umweltbundesamt, 6.2 tons of the greenhouse gases produced in the manufacturing of electric vehicles stem from the battery alone. Savings here therefore have great potential for the future of e-mobility.

JOINT RESEARCH PROJECT ON STEEL BATTERY HOUSINGS

In the interdisciplinary joint research project, the research partners LWF (Paderborn), Fraunhofer IPK (Berlin), ika (Aachen) and Fraunhofer IPA (Stuttgart) worked closely together to develop and validate the application of steel battery housings with joining and testing processes and concepts for corrosion protection.

Electric mobility is widely recognized as one of the key technologies for sustainable transportation and a greener future. Not only must efficient drive systems be developed, all vehicle components need to be designed and produced in a more sustainable way. After all, a significant proportion of the CO_2 emissions generated during the life cycle of an electric car are produced during the manufacturing phase. While producing a conventional combustion engine releases about 10 tons of greenhouse gases, emissions for battery-powered electric vehicles add up to 17.4 tons. The battery alone makes up around 6.2 tons. An important aspect here is the battery housing, which accounts for around ten percent of manufacturing-related emissions, according to Agora Verkehrswende.

Researchers at Fraunhofer IPK are now investigating how CO_2 emissions can be reduced by cleverly substituting materials along the life cycle of battery housings. A research project on efficient laser beam welding and brazing for gas tightness and dimensional accuracy in steel battery housings shows that housings made of steel can be a promising alternative to the conventionally used aluminum. This is because steel has a significantly better environmental footprint during production and is easier to recycle.

THE CHALLENGE: GAS-TIGHT CONNECTIONS

It is not only the ecological footprint that speaks for steel. Its higher strength also makes the material a promising alternative to aluminum when producing battery housings for electric cars. The stronger the material, the thinner the walls of the housing can be. However, the steel used in the automotive sector is treated with a zinc coating that protects the material from corrosion in the long term. When these sheets are welded, the coating evaporates, causing porosity in the weld seams. This not only impairs the mechanical and technological properties, but also affects the gas tightness that is essential for battery housings. The challenge in the production of steel battery housings is therefore to achieve gas-tight welded joints. Innovative joining processes from the areas of laser welding, laser brazing and resistance spot welding, supported by structural welding simulations, are here to help.

SIMULATED + EXPERIMENTALLY VALIDATED = INTEGRATED

The project team combines modern structural welding simulations with experimental investigations. These simulations make it possible to precisely model temperature curves and mechanical stresses during welding. By comparing the results with real experiments, such as temperature measurements and micrographs, the researchers can optimize process parameters to ensure that the joints are gas-tight and dimensionally accurate.

A SMALLER FOOTPRINT HITS THE ROAD

In order to compare the investigated manufacturing processes, the researchers are using a cradle-to-gate approach to calculate and evaluate the environmental impacts of different welding processes. With emissions of 0.11 kg of CO_2 equivalent per meter of welded seam, resistance spot welding in combination with an adhesive is the most environmentally friendly joining method. Among the beam processes, laser remote welding without filler material causes the lowest emissions at 0.14 kg CO_2 equivalent per meter. All processes have a key advantage: They make it possible to produce steel battery housings, which, according to thyssenkrupp Steel, generate up to two-thirds fewer greenhouse gas emissions than aluminum housings.

A LOOK AHEAD

The research team's technologies open up new possibilities for the automotive industry in the production of battery housings – all while meeting high safety and sustainability requirements. However, this will only be convincing for manufacturers if the combination of joining processes with optimized process parameters can really ensure gas-tight joints, because the behavior of the battery in the event of a crash or fire is crucial for its use in practice.

The researchers now want to transfer their findings to other applications in the automotive industry, in collaboration with industry partners. If they succeed in further developing battery housings made of steel, refining the innovative technology and integrating it into automotive production, the project and industry partners will come a step closer to their goal: a sustainable future of mobility that quite literally forges a bond. ◆

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Systems for a Digital Take-off

A passenger flight in 2050: low-emission, quiet, safe, affordable? The aviation industry faces enormous challenges on the journey to a new generation of propulsion systems.

Accounting for around 3.5 to five percent of anthropogenic warming, aviation is one of the biggest climate polluters. Under these circumstances, it is difficult to imagine that flying in its current form will still be part of our everyday lives in the future. To make flying more sustainable, alternative concepts rather than gradual improvements are called for. In addition to the use of sustainable fuels, hybrid-electric propulsion systems are increasingly becoming the focus of research and development. These technologies combine renewable energy sources with conventional propulsion systems and could thus make a decisive contribution to reducing environmental pollution.

Image:
Innovative concepts for aircraft, drones, and air taxis such as this one require fundamental rethinking in development rather than incremental steps.

However, integrating hybrid-electric propulsion systems in drones and aircraft is complex. Developing new product architectures involves many different manufacturers who realize the products. Long development times further complicate the situation, especially for aircraft manufacturers: Development, component and simulator tests, flight tests, certification, and other steps can take between five and 15 years. During this period, manufacturers, developers, suppliers, and authorities must remain in constant contact with each other. To make this complexity manageable, researchers at Fraunhofer IPK apply the concept of system orientation. The aircraft and its components, such as the propulsion system, are no longer viewed as stand-alone elements, but as parts of a larger system that influence each other. It is crucial to define the interfaces between the different systems and to develop a system architecture that enables seamless integration. However, this architecture is only the first step – to be truly effective, it must be integrated into the entire development, manufacturing, and testing process for these systems.

Another key to successfully implementing new propulsion concepts is using digital twins. These virtual models replicate the physical system and make it possible to link subsystems, identify target parameters, and analyze the behavior of the entire system. This can offer crucial advantages when developing and testing new hybrid electric engines, as the interaction between conventional combustion in a gas turbine, electric drive, and battery is highly complex. During flight, the parameters of all these systems must be continuously adjusted. The digital twin concepts developed in the DIREKT project help engineers design systems capable of handling this task: Both the electrical and conventional consumption of the powertrain and the current charge level of the electrical energy storage are continuously recorded – in combination with the remaining flight distance, this information can then be used to optimize the settings of the various drive parameters. And when developing the next generation of a propulsion system, the insights gained from the digital twin can be directly incorporated into the system architecture and support development decisions. This shortens development times and enables a continuous improvement process.

To make flying more sustainable, alternative concepts are called for: Hybrid-electric propulsion systems are increasingly becoming the focus of research and development.

Before a new engine can be used in flight, manufacturers must undergo a certification process that imposes rigorous requirements on documentation and the scope and quality of the underlying data. This is particularly complex when certifying completely new propulsion systems, since sufficient reliable empirical data is not yet available to define safety limits in hybrid-electric propulsion systems. Using digital twins can make a decisive difference here, because new engines also require suitable methods to investigate the effects of such fundamental changes. By integrating data from different suppliers and manufacturers, the players can work closely with certification authorities and exchange the data they have collected. This facilitates faster and safer development of the necessary safety standards. Investigating this potential is also a part of the DIREKT project. The challenges here do not only lie in complex data integration, but also in defining consistent business models that motivate the various partners to provide the necessary data.

The interplay between data-driven system orientation and the use of digital twins could lay the foundation for the next generation of flying: more efficient, more sustainable, and ready for the challenges of the future. ◆

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Designed from the Receiving End

Necessary evil or an opportunity for more sustainability? A case for battery passports as a value-creating application of data ecosystems

From February 2027, the battery passport will be a mandatory companion for every traction, two-wheeler or industrial battery with a capacity of over 2 kWh. As a pilot, it will play a pioneering role in the field of digital product passports (DPP) in the European Union – passports for other products such as furniture, toys and more will follow step by step.

The initiative is backed by a whole range of honorable goals: The battery passport is intended to create transparency in the battery industry, support the transition to a circular economy and promote sustainable and responsible supply chains. To accomplish this, the passport records and manages comprehensive information about a battery. The EU-wide Battery Pass project, which, with the participation of Fraunhofer IPK, has developed conceptual and technical frameworks and recommendations for implementing the EU battery passport, has identified several information categories that a battery passport should include (see info box on the right). In the interest of data sovereignty, this information in the battery passport is provided in a decentralized manner via systems operated by the economic actor who puts the battery onto the market.

A BATTERY PASSPORT SHOULD INCLUDE THE FOLLOWING INFORMATION:

Materials and composition: documents hazardous substances, chemical composition and critical raw materials

Carbon footprint: documents the environmental impact of the battery using CO_2 metrics, references to studies and performance classes

Performance and durability: records static parameters for capacity, power and expected lifespan, as well as dynamic data collected during use to assess the battery state

Circularity and resource efficiency: includes information on the ratio of recycled materials, instructions for disassembly, serial numbers for spare parts, safety measures, and information on return options through authorized channels

BENEFITS AWAIT AT THE END

According to the Battery Pass consortium's research, the battery passport is particularly useful at the end of a battery's usage period – in the areas of battery collection, recovery and recycling. The detailed information it provides can help authorities to more effectively prevent illegal exports and disposal methods, thus reducing what is known as »battery leakage« – the loss of batteries from the legal recycling loop.

The passport also makes it easier to determine the remaining value of a battery. Thanks to extensive data on performance and durability, companies and private users can more accurately estimate the true value of a battery. This not only reduces technical testing costs, but also increases the likelihood that batteries will be reused for second-life applications instead of being recycled or disposed of directly.

Where reuse is no longer possible or sensible, the battery passport supports efficient recycling by providing transparent information on the composition and instructions for disassembly. This reduces costs, for example for sampling, leading to more sustainable recycling overall.

COMPANY DECISION: BARE MINIMUM OR GOING THE DISTANCE?

Whether the passport of a specific battery is designed in ways that allow it to fully play to its strengths depends on decisions made by the distributor. Although implementation is mandatory, there is some leeway in the design, leaving companies with strategic decisions to make. These have a decisive impact on whether the distributor only takes the mandatory steps or effectively exploits the economic advantages a digital product passport can bring.

To prepare for the introduction in the best possible way, the Battery Pass consortium recommends considering four key questions:

1. To wait or to act?

Companies must decide whether to act early or rely on a later implementation. Delaying adoption can mean losing customer contracts or market access, as well as incurring additional costs caused by late implementation. On the other hand, unclear regulatory requirements or insufficient supplier data can make it difficult to implement quickly. A targeted cost-benefit analysis is crucial to determine the best timing for introducing the battery passport.

2. Compliance or added value?

Companies need to decide whether they view the battery passport merely as a legal requirement or as a strategic opportunity. A minimalist implementation is sufficient to meet basic compliance requirements, such as collecting data on battery health and lifespan. However, those who opt for detailed data, for example to monitor supply chains, production processes and circularity, can use improved transparency to increase efficiency and develop new business models.

3. Develop in-house or external solutions?

Companies can choose between developing the battery passport in-house or using external providers. DPP service providers and consortia such as Catena-X already offer standardized solutions. Large companies with sufficient capacity can develop their own proprietary solutions to generate tailored added value. By contrast, small and medium-sized enterprises (SMEs) could benefit from outsourcing implementation to external providers to reduce costs and complexity. In addition, data ecosystems offer opportunities to realize the necessary data exchange along the upstream value chain.

4. Existing infrastructure or a fresh start?

Existing IT and data infrastructure is crucial for introducing the battery passport. Some companies already have systems in place that collect and manage a variety of relevant data, which facilitates the transition. Those who start from scratch are often confronted with high investment and implementation costs. However, sticking with older systems carries the risk that they are not equipped to meet future requirements. The introduction of battery passports offers the chance to rethink established IT structures and to establish future-proof solutions with a comprehensive digitalization approach.

DATA ECOSYSTEMS FOR CROSS-COMPANY DATA EXCHANGE

To exploit the full potential of digital product passports, it makes sense to design them based on the holistic concept of data ecosystems – after all, a DPP is essentially a data hub. Data ecosystems are complex networks in which data is considered a valuable resource that is generated, shared and processed by different actors. The actors include data producers, processors and consumers engaged in a dynamic information exchange.

The special feature and strength of data ecosystems is the so-called federated approach: Data is stored and processed in distributed systems instead of centralized databases. This approach makes it possible to integrate data from different sources while maintaining the data sovereignty of the individual actors and allowing them to retain control over who accesses which of their data, when and how. By using interfaces and standardized protocols, different organizations and systems can communicate with each other and exchange data without the need to centralize the data sets. This not only promotes collaboration and data access, but also strengthens mutual trust between the parties, as they retain control over their own data.

INITIATIVES ARE LAYING THE GROUNDWORK

A whole range of projects are already working on providing solutions for data ecosystems. Fraunhofer IPK plays a leading role in some of them. GAIA-X is a central element in the development of data ecosystems in Europe. It establishes a trusted and interoperable infrastructure that enables companies to share and use their data securely. With GAIA-X, a platform is created that facilitates the exchange of data and services between different sectors, while ensuring compliance with European data protection standards. By promoting openness and collaboration, GAIA-X aims to support a sustainable digital economy and strengthen Europe's digital sovereignty.

Catena-X represents a first implementation of a data ecosystem for the automotive industry based on GAIA-X. This data ecosystem can serve as a basis for data-sovereign information exchange, including information related to batteries. To enable the exchange of battery information, the data ecosystem contains standardized data models that ensure interoperable exchange between companies. In addition, the data ecosystem lays the groundwork for restricting the exchange of data to specific parties and specific use cases.

> Data ecosystems are complex networks in which data is considered a valuable resource.

> The battery passport is particularly useful at the end of a battery's usage period – in the areas of battery collection, recovery and recycling.

The Manufacturing-X project family aims to transfer solutions from Catena-X to other industries. A specific project within this family is Aerospace-X, which focuses on the aviation industry. In addition to the general technical infrastructure and the services for implementing the data ecosystem, the project addresses four use cases: capacity management, life cycle assessment and product carbon footprint (PCF), circular economy, and end-to-end quality management. Implementing these use cases requires information from the supply chain. Particularly for life cycle assessments (LCA), data such as energy consumption from production or transport, as well as the factors involved in the processing of materials, are used by partners in the early supply chain. In addition, the materials information can also be used to make appropriate decisions in the context of the circular economy.

All these initiatives are making a sustainable data future possible – one that values data for what it is: a resource for business success. In this context, digital product passports will make a significant contribution to the competitiveness of companies in the future. ◆

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More information

www.ipk.fraunhofer.de/battery-pass-en

www.ipk.fraunhofer.de/futur-24-data-spaces

https://thebatterypass.eu

Auto-Assembly, Auto-mated

A single car contains thousands of components of different geometries. Soon, robots will be able to handle their delicate assembly – flexibly and autonomously.

In vehicle manufacturing, entire subassemblies have long been fitted fully automatically. However, the systems used are often specialized to perform only a few or even just one single task. The resulting production lines are static and no longer meet the current requirements for assembly systems. Fact is, products are diversifying and markets are changing at an accelerating pace. This necessitates flexible systems that are highly mobile, adaptable and modular. This paradigm shift is not only a major challenge for automobile manufacturers, but also an exciting development area with a high potential for innovation. Together with Volkswagen Nutzfahrzeuge, researchers at Fraunhofer IPK have developed a model system for testing flexible approaches. Assembling interior vehicle paneling, a process that has been completely manual up to now, could soon be automated and serve as proof of the potential of autonomous assembly technologies.

STATIC SOLUTIONS: A THING OF THE PAST

One aspect of flexibility that was particularly important to the industrial partner is the solutions' independence from location. The »Tend-O-Bot« robot system has already been used for a wide range of applications, from machine tending to human-robot collaboration. It consists of a mobile platform with an integrated robot arm and is able to independently navigate through the production facility thanks to modern mapping and localization algorithms. Additional sensors on board ensure that the mobile robot can react flexibly to obstacles and avoid collisions. Building on this technology, it can also reliably detect and localize assembly-relevant targets, in this case the vehicle body. Based on its visual assessment of the assembly situation, the system can even determine which assembly steps have already been carried out and which still need to be done.

After detecting the body and moving to the correct position, the Tend-O-Bot must precisely capture the assembly environment. In a multi-stage positioning process – from rough to fine – the system first estimates the location of its target based on AI models and refines it using conventional sensor processing at close range to achieve an accurate result. This enables the mobile manipulator to later approach the necessary assembly positions independently and flexibly with precision down to the millimeter.

THE DELICATE TOUCH OF ROBOTIC HANDS

Now the actual assembly process can begin. The robot's task is to clip a fine bracket on the back of the component into an assembly point – previously a manual process that required a high degree of tactile sensitivity. However, one of the specifications of the industrial partner is that the selected gripper technology must be able to handle a wide range of components with different geometries, even beyond this example task. The team of developers therefore relies on the use of a suction-based, flexible gripper, whose controls are integrated into the platform's control system, to lift the component waiting to be mounted. The soft gripper adapts its shape to different geometries, thus enabling the assembly of a wide variety of components.

A crucial factor in the clipping process: Even the slightest spatial deviations inevitably lead to assembly failure and can potentially damage the vehicle body. This is why the process demands the highest standards of measurement accuracy and assembly process monitoring. Human workers can rely on their senses in situations like these, especially on haptic sensations and acoustic signals. Inspired by this tried-and-true human approach, the project team is evaluating the clipping process based on sensory feedback with an innovative procedure.

COMPLEX INTERACTION OF MODERN TECHNOLOGIES

When many different hardware components come together, the potential for errors and interfacing difficulties is high. Wireless communication via 5G and the power supply on board the Tend-O-Bot pose additional challenges for the mobile solution. To meet the complex requirements of the task, the underlying software is both scalable and modular. Individual modules can be moved between the robot's onboard computer and external cloud computers, which is ideal for coordinating signal runtimes, energy requirements and the utilization of available computing resources. Distributed development also leaves plenty of room for functionally expanding the solution in the future.

1

Images:
1
Assembling the many components of modern vehicles requires a delicate touch. With innovative sensors and actuators, robots will soon be ready for the job.
2
The body and mounting points are first scanned with millimeter precision so that the components being assembled can be positioned accurately.

2

Closely integrating robotics, network technology, image processing and AI proved to be the key to success in the project with Volkswagen Nutzfahrzeuge. Using this real-world example, automotive manufacturers can now explore how even complex assembly tasks could soon become automated and autonomous. ◆

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Driving and Building – between Aspiration and Feasibility

Rail is considered one of the most climate-friendly modes of transport. In Germany, however, it is often criticized. A guest article by Dr. Sascha Reinkober, Head of Large-Scale Machinery Deployment at DB InfraGO AG.

Delays, cancellations, disgruntled travelers – our railway infrastructure demands a lot from our customers in terms of quality and capacity. Since the rail reform of 1994, operating performance has increased by an impressive 27 percent, while the network has shrunk by 15 percent. Despite this development, DB InfraGO operates the largest rail network in Europe today in what is known as mixed traffic. This means that freight transport, local public transport and long-distance passenger transport share the same infrastructure. On more than 33,000 kilometers of track in Germany, an average of 50,000 trains from more than 450 railway companies are on the move every single day. This high frequency of trains and some very long train connections – the longest rail route between Hamburg and Munich via Frankfurt Airport is 1,301 kilometers – place the highest demands on operational stability. Rail traffic flows like a string of pearls: As soon as one element comes to a standstill, the entire chain is affected.

Our task at DB InfraGO AG is to design this complex rail network for optimal performance and to maintain it in the long-term. This includes creating timetables, operational management, construction management, maintenance and the continuous development of the rail infrastructure. In doing so, we follow the premise of »Driving and Building« and implement a nationwide optimally synchronized timetable for passenger and freight traffic with the »Deutschlandtakt«. Our aim is for long-distance trains to arrive in Germany's largest cities every 30 minutes in the future, always at the same time. Regional transport connections will then be adapted to this schedule. With that we provide better connections, shorter transfer times and more reliable services, even in rural areas. In addition, this type of regular-interval timetable helps us to identify bottlenecks in the rail network at an early stage, prioritize certain trains and implement the necessary infrastructure measures systematically.

The latter not only includes new construction and expansion projects, but also maintaining the highly stressed rail network: inspection, maintenance and repair of tracks, switches and signals. Here, too, we work in intervals. A large part of our maintenance work on large-scale machine technology takes place in regularly scheduled and planned periods, mainly at night during track possessions (periods of time when the tracks are closed for maintenance) between 10 p.m. and 5 a.m. We use highly specialized rail grinding and milling trains to proactively and reactively repair worn tracks and switches, inspect bridges and tunnels, and stabilize tracks with tamping and renovation work. With these continuous and systematic measures, we reduce the likelihood of disruptions, avoid delays in operations due to areas with speed restrictions or even train cancellations, and contribute significantly to ensuring that trains run as smoothly as possible during the day.

But mobility is more than just transportation. DB InfraGO AG is also responsible for designing and operating around 5,400 stations throughout Germany. To improve and enhance the quality of travelers' time spent at these, we work together with federal states and municipalities, authorities and railway

Dr.-Ing. Sascha Reinkober

was a research scientist and most recently head of the Manufacturing Technologies department at Fraunhofer IPK. After completing his doctoral degree, he joined Deutsche Bahn in 2020 and has been managing the deployment of large-scale machinery at DB InfraGO AG since August 2024. His team of more than 200 employees mostly works at changing locations throughout Germany, 95 percent of the time in night shifts. Reinkober naturally travels by train both privately and for work. »I have come to appreciate being able to go for a coffee, stretch my legs or even work on the train«, he says, but he also admits to adapting his travel plans to the reliability of the train connections. His recommendation: »I usually travel very early in the morning or very late at night because the trains are more punctual then. I also try to avoid transfers and accept a longer travel time instead.«

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companies to develop attractive stations that are not just functional stops, but also customer- and service-oriented destinations that invite travelers to linger. A good example is Leipzig Central Station, which, as the largest terminus station in Europe, is also an architectural highlight and features over 140 shops and restaurants.

In all our efforts to improve both the quality of the rail network and the stations, focusing on the public good of the railway infrastructure has been more important than ever since 2024. This means that we consistently align the management and expansion of the infrastructure with the needs of citizens, the economy and the environment. Our interaction with the German Federal Government as the owner of Deutsche Bahn is central here: The Federal Government formulates political goals for the infrastructure based on the common good and ensures financing. DB InfraGO AG implements these goals efficiently and transparently. Our timetable for the next few years is set: We want to double our passenger transport volume, expand our rail freight transport market share from 19 to 25 percent, implement the Deutschlandtakt – and ultimately ensure that even more transportation is diverted to our environmentally friendly railways. ◆

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