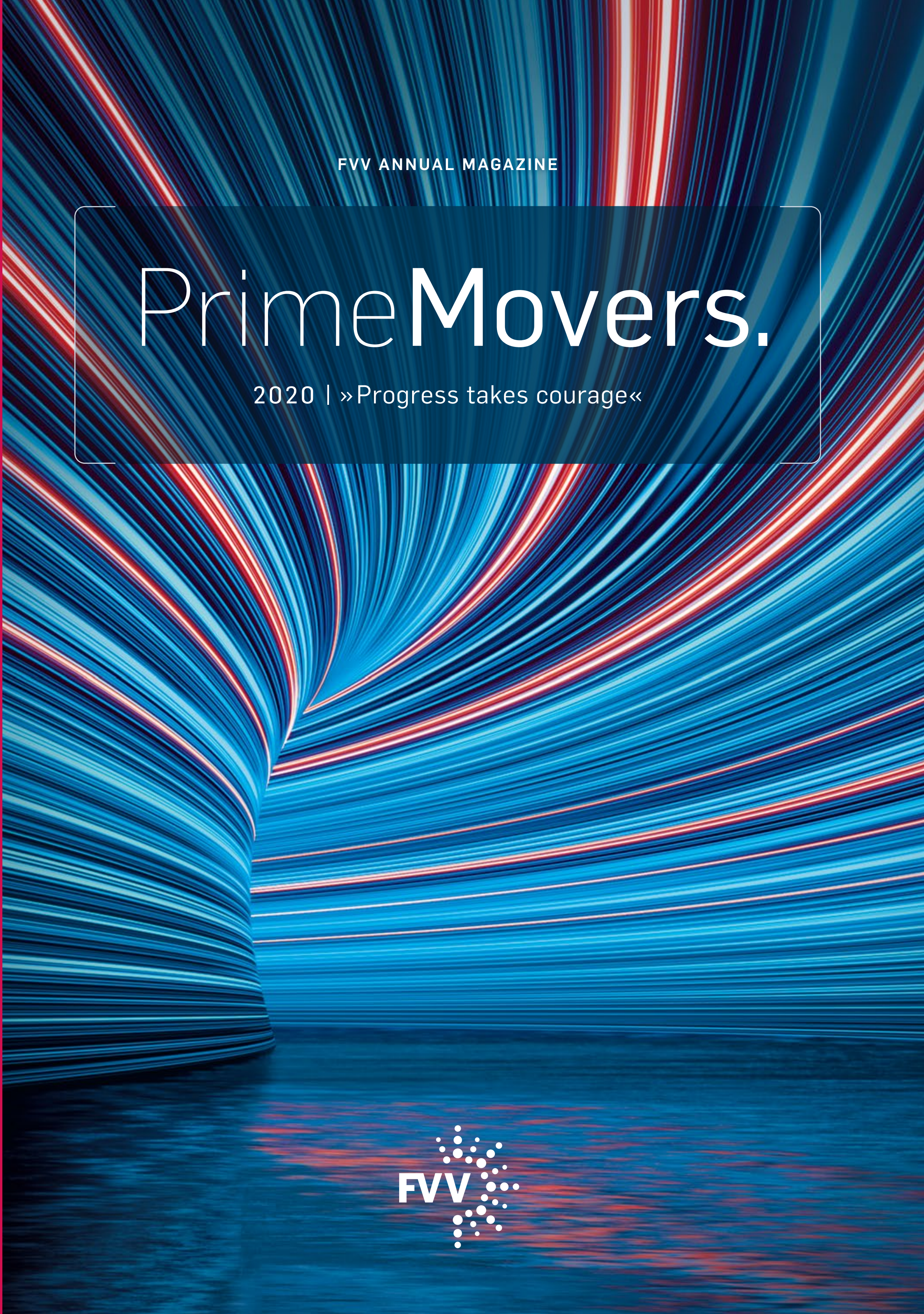
FVV ANNUAL MAGAZINE

PrimeMovers.

2020 | »Progress takes courage«



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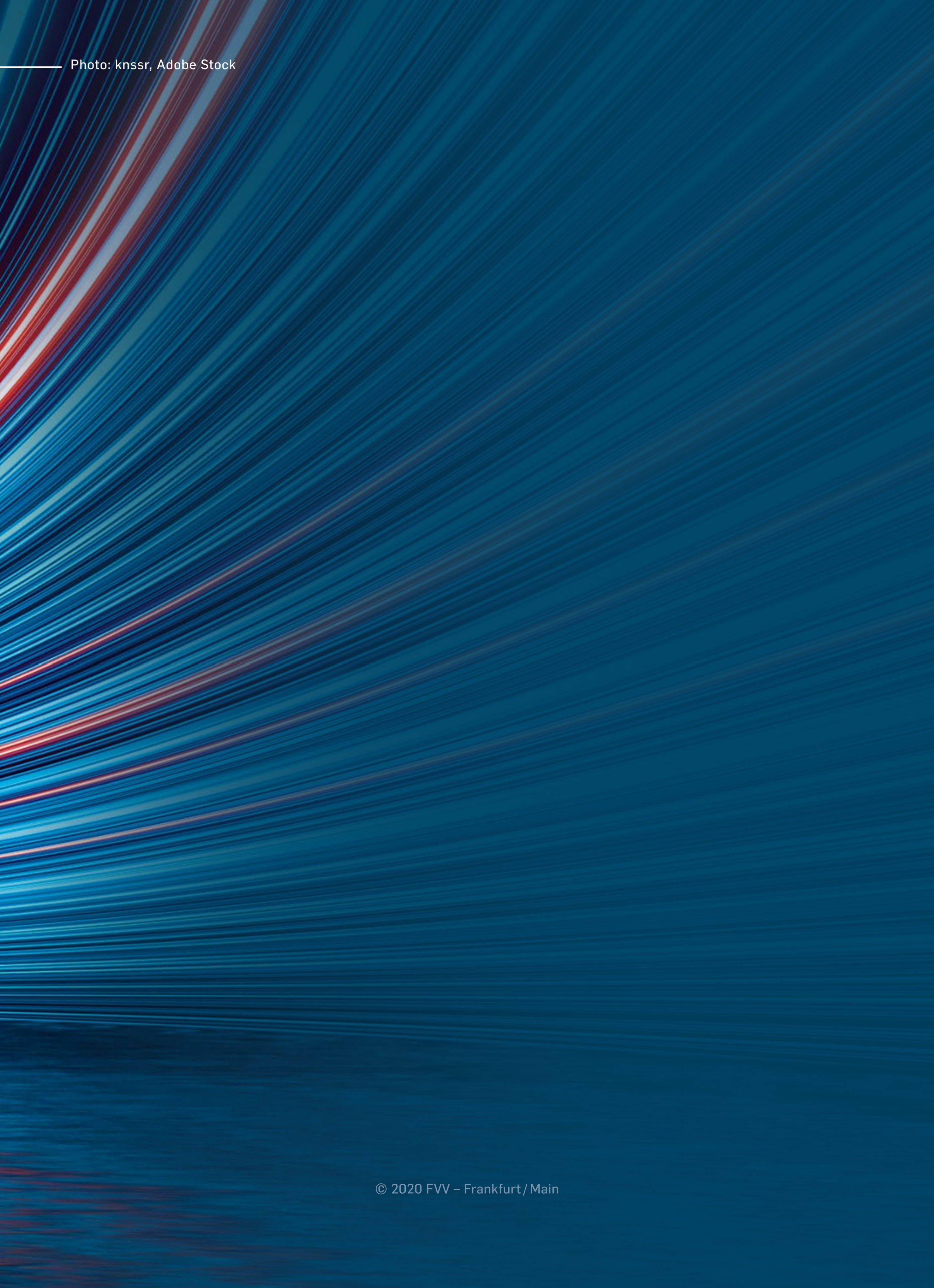

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FVV ANNUAL MAGAZINE | 2020

»Progress takes courage.«

Dear FVV members,
dear readers,

How will we look back on 2020 ten years from now? Of course, we cannot answer this question with the same scientific precision that we, as a research association, expect from the results of our projects. Even so, looking back on the present day from an imaginary future is an important method in futurology. After all, one characteristic of long-term changes is the fact that a large number of influencing factors come together and give history a new spin that only gradually becomes visible in structures. Looking back to the present day helps us recognise these influencing factors. So how will we look back on this extraordinary year in ten years' time? Will our collective memory include more than just the coronavirus pandemic and its consequences for society and the economy?

We think it will! In ten years we might see that, in 2020, Germany and Europe took decisive steps to combat climate change. People recognised that, although local production of renewable electricity from wind and the sun represents an important element of greener energies, it would not solve the fundamental problem

Where would our world be if courageous people had not invested their time and money in visionary approaches?

how to eliminate fossil fuels from all sectors. With the National and EU Hydrogen Strategies, Germany and Europe prepared the ground for renewable chemical energy carriers in transport and the decarbonisation of key primary industries.

The strategies and the associated funds sparked enormous change: for the first time, plants were set up that were capable of producing power-to-X energy carriers in large quantities. During the course of the 2020s, many of these plants were built not in Central Europe, but in regions of the world with more sun and wind – using mechanical engineering expertise from German and European companies. Although combustion engines, which form part of the name of our research association, were subsequently joined by fuel cells and electric powertrains, they performed a key role in getting greener energies up and running in all sectors. The same goes for the energy sector itself – while it is generating an ever-growing share of renewable electricity, it also relies on the storage possibilities of chemical energy carriers. We believe that turbomachinery will therefore continue to play a key part in the world of energy. At the same time, digitalisation and artificial intelligence have accelerated and expanded the development and connection of ever more complex technical systems. This has led to significantly smarter and more efficient transport and energy systems.

Admittedly, all of this is only a vision. But where would our world be if courageous people had not invested their time and money in visionary approaches? Progress takes courage. Overconfidence, on the other hand, can quickly lead to negative developments. It is precisely small and medium-sized companies that often lack the resources to pursue every possible technical development and, in particular, calculate the profitability of individual paths. This all presents a new challenge to the kind of Industrial Collective Research driven by the FVV: providing orientation on a sound technical and scientific basis. Following an intensive discussion process, the FVV Board and Directorate have therefore decided in favour of commissioning a larger number of these ›orientation studies‹ in the future.

One example of this is the meta-study for life-cycle analysis of alternative vehicle powertrains. Its basic concept is relatively simple: in order to assess the climate compatibility of a powertrain and evaluate a variety of concepts on the basis of this, merely examining the emissions generated during the use phase is not enough. Instead, the emissions generated during vehicle production, when establishing the energy infrastructure and through recycling must also be taken into account. A renowned consulting firm that specialises in the energy sector analysed more than 80 existing studies on our behalf. The results can be found on page 16. But we can say this

Photo: Uwe Nölke

much now: if we assume that combustion engine powertrains will be run solely on fuels that were produced in a climate-neutral manner in the future, they will use less of the CO_2 budget remaining to humanity than a battery electric powertrain. Further orientation studies on the fuels of the future and on ›zero-impact‹ emissions are being prepared and will be published over the next year.

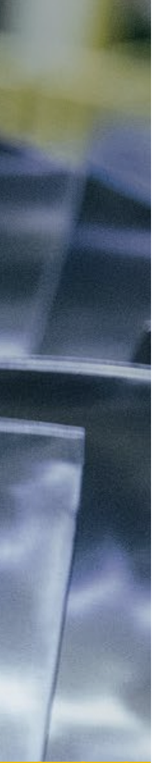
When pluralistic societies pursue a path of change, it does not take long for arguments to arise. In the past, we engineers have usually kept a low profile in public debates. When we did speak up, the way we explained things was often far too complicated and detailed. But however correct and important our insights are, we will not be heard without communication that achieves the right balance between factual correctness and accessible presentation. This is why we have decided to communicate our overview studies and the results of important research projects even more intensively from now on. The annual magazine you are holding in your hands now is an important element of our new communication offensive.

We would like to take this opportunity to thank all of our sponsors, in particular the German Federal Ministry for Economic Affairs and Energy and the German Federation of Industrial Research Associations as well as the RTD performers and the cooperation partners, without whose support the research findings we have achieved would not have been possible. In addition, we would like to thank everyone who is involved with the FVV on a voluntary basis – without their participation in committees and working groups, none of the project results presented on the following pages could have been achieved. Although meeting in person has been all but impossible in 2020, the FVV is and remains an association that invites people to take part and that thrives on personal encounters and the ideas of many clever minds – even under the difficult conditions we are currently experiencing. //

We are looking forward to the future!

PROF. DR. PETER GUTZMER
President

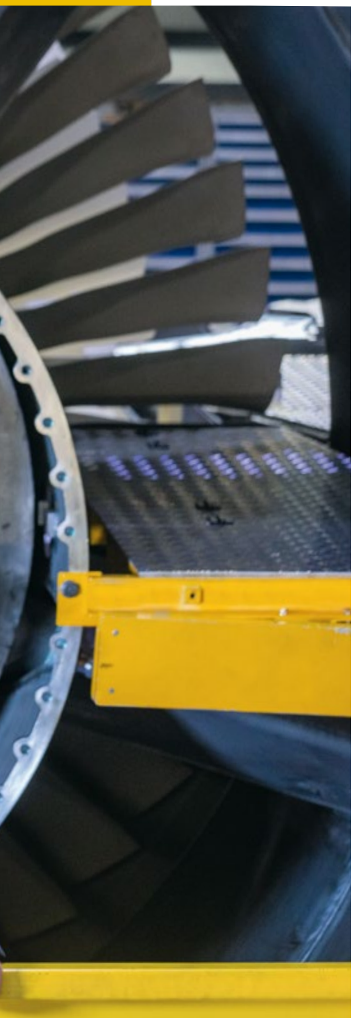
DIETMAR GOERICKE
Managing Director



Photos: Dirk Lässig

»Long-term, cost-efficient **security of supply«**

Christopher Steinwachs, the Deputy President of the FVV, explains the role that gas turbines and other turbomachines play in the energy mix of the future.



Mr. Steinwachs, in Germany during the first quarter of 2020, more electricity was generated from renewable energies than with conventional energy carriers. What is your assessment of this as an engineer and turbomachinery specialist?
In principle, the transformation of the energy sector is absolutely the right step. But if we are to achieve the climate goals and become completely carbon-neutral by 2050, we will need more technologies alongside wind turbines and PV modules. As sun and wind are not always available, energy needs to be stored, for example by chemical means or in batteries. In order to guarantee long-term, cost-efficient security of supply, we have to come up with other ideas. I believe that turbomachinery will continue to play a decisive role.

So the energy sector is characterised by renewable energy. What effect will that have on the way gas turbines are operated?
The plants will be run in a much more cyclical manner than they are at the moment. Even large 800-megawatt installations with combined heat and power will be started up and shut down several times a day. This is already happening today in Germany. That means that we have to design gas and steam turbines for a greater cyclical load than a few years ago, when turbines ran at base load for many thousands of hours a year. As we develop these, we can then look at different, more cost-efficient materials, for example. After all, if they run for significantly fewer operating hours in the future – perhaps just 1,000 rather than 8,000 hours a year – investment costs will play an even more important role.

In future, gas turbines will be run not only in a more cyclical manner, but also with synthetic fuels. Which technical changes are needed to run them with hydrogen?
When hydrogen burns, its flame speed is around three times higher than that of methane, and the time until auto-ignition is only around a third as long at the given temperature. We need to ensure that the combustion does not become unstable or take place too close to the metal walls, as this could damage the combustion chamber. This is a major challenge, especially in the case of high hydrogen contents. And, of course, the emission limits also have to be adhered to.

What experiences have been gathered with partial or complete operation with hydrogen to date?
When using the current turbines in the portfolio of new plants, we can already admix up to 30 % hydrogen with fuels for the large gas turbines, usually natural gas. We have recently sold commercial plants that are operated in this manner. With a hydrogen content of more than 50 %, the topics of flame speed, emissions and the time of auto-ignition become increasingly important. This is what we are working on. But the amount of development work required and the costs for enabling a higher hydrogen content are not linear. Getting from 70 to 100 % takes exponentially more work than the jump from 30 to 50 %.

»In pre-competitive research, we share ideas and often achieve results more quickly together.«

As part of EUTurbines – the European association for turbine manufacturers – we have committed ourselves to achieving 100 % hydrogen combustion in our machines by 2030. And we can be proud of that!

Are such large quantities of hydrogen – from renewable sources – even available?
That is certainly a problem. As I mentioned, Siemens Energy aims to switch its gas turbines to 100 % hydrogen by 2030. The roadmap stipulates that we start with the smaller turbines, as sufficient quantities of hydrogen cannot currently be made available for the larger machines. The volumetric flows in the large machines are enormous – a 350-megawatt gas turbine sucks in around a tonne of air every second, and the fuel needs to be available for that. This is not yet possible with green hydrogen. For pure hydrogen operation we will initially use smaller gas turbines anyway, such as those with a capacity of 25 megawatts. Hydrogen can already be provided on that scale today.

Will maximum efficiency remain the primary goal of development under these conditions?
In Irsching in 2008, we commissioned a combined gas/steam turbine power plant with an electrical efficiency of 60.75 % – a world record at the time. Now, ten years later, the electrical efficiency of a power plant like this is around 63 %. A great deal of research is required in order to attain further, relatively small, increases in efficiency. Alongside efficiency, we are also constantly balancing other very important parameters in order to maximise the benefits for the customer. So it is an important development goal – alongside others.

What are the other research and development goals in your view?
Above all, we need to enable even more flexible operation with 100 % hydrogen while also adhering to the NOx emission limits. And, of course, there is the development with regard to cyclical loading, which is greater than it was a few years ago.

What can and should Industrial Collective Research contribute to this?
We are collaborating closely for example, with aircraft engine manufacturers such as Rolls-Royce and MTU. This is pre-competitive research, for instance in order to find the right materials for the combustion of hydrogen or to control combustion instabilities. Additive manufacturing is another goal. These are topics that we in Europe need to move forward. Conventional topics such as the design of turbine blades with regard to vibrations also remain crucially important. These need to be incorporated into FVV's pre-competitive research.

How important is the FVV's work in your view?
In this pre-competitive research, we share ideas and often achieve results more quickly together than we could alone. We have access to important research findings we would not otherwise have. And one thing the FVV does really well, and that we have benefited from, is its collaboration with universities. This is really important in order to attract talented young staff.

You have been Deputy President of the FVV since the end of 2019. How would you describe your experiences so far?
Unfortunately we have only had video conferences due to the COVID-19 crisis. In a company, this works very well in many fields. But in a network in which you only see each other at two or three meetings a year, personal contact is important. I hope this will be possible again soon.

Thank you for the interview, Mr. Steinwachs. //

DIPL.-ING. CHRISTOPHER STEINWACHS
has been responsible for the global production network of hot gas components in gas turbines at Siemens Energy since August 2019. Before this, he headed the global research and development organisation for all gas and steam turbines and generators at Siemens. Steinwachs has been at Siemens since 1992, and joined the FVV Board in 2016. He was elected Deputy President in November 2019.

Shaping the **future** through research

Fuel cells, renewable fuels, hybridisation and artificial intelligence: Industrial Collective Research at the FVV has gained a number of new priorities in recent years. However, traditional research work on efficient and cleaner engines and turbines remains important.

Pre-competitive collaborative research in order to prosper in the face of the competition // The FVV has been pursuing this idea since its foundation more than 60 years ago. However, the transition to greener energies and forms of mobility has dramatically changed the conditions for competition. In order to protect the climate, virtually every country in the world is striving to achieve carbon neutrality and move away from fossil energy sources. For manufacturers of combustion engines, hybrids, turbomachines and fuel cells and the corresponding supply industry, this means that those who are able to meet these new conditions while generating the lowest additional costs have a significant advantage in the race to conquer the markets of the future.

The role of the Industrial Collective Research programme in this situation is to bridge the gap between fundamental research at universities and the development work being carried out by individual companies. The specific topics handled by the FVV depend on the needs of its member companies. »We are a platform for industry,« explains Martin Nitsche, Deputy Managing Director of the FVV. »Every member can contribute ideas – whether they are a small company with a handful of employees or a large corporation.«

This ›bottom-up‹ approach reflects the drive towards clean yet effective powertrains and technologies through innovative research topics. Alongside this, the FVV Board has initiated a strategic renewal process in recent years, culminating in the expansion of the association's research focuses. As part of this, the FVV is increasingly conducting orientation studies to contribute a fact-based technical and scientific point of view in discussions about the powertrains and energy carriers of the future [→ page 16].

The most striking example of FVV's future-oriented outlook is the foundation of the new ›Fuel Cell‹ research field in 2017. From the very start, its focus was not only on use as a vehicle drive, which was discussed intensively in the public arena, but also on a

Every member can contribute ideas – whether they are a small company with a handful of employees or a large corporation.

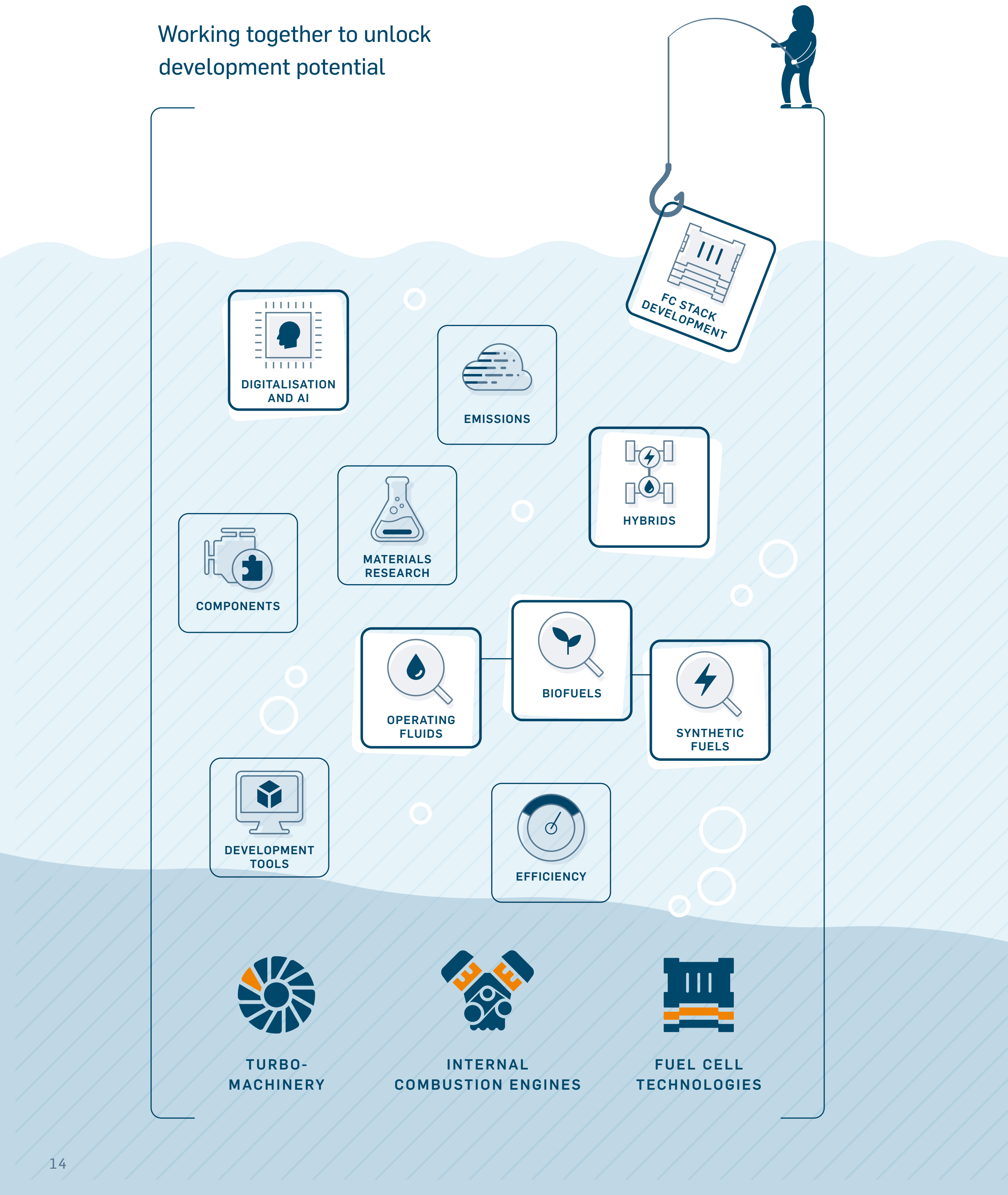
multitude of other applications – from construction machinery to stationary emergency power supplies. »We are not involved in product development here,« explains Nitsche. »Instead, we are looking at the subsystems that keep the fuel cell running smoothly during operation.« In specific terms, this means that most projects worked on in the FVV are about the periphery, i.e. the components responsible for media supply or thermal management. One important milestone for this is the successful completion of the ›Generic Fuel Cell Stack‹ project [→ page 54]; which provides a concept for a universally deployable research platform for the first time. For predominantly small and medium-sized component supplier companies, such a platform is essential for testing innovative ideas while keeping effort and expense at a reasonable level – comparable to a single-cylinder research engine.

Another focus of the research is the operation of combustion engines, hybrids, turbomachines and fuel cells with new fuels. After all, the transition to greener energies and mobility relies on chemical energy carriers and thermal energy converters. Regardless of which fuel replaces today's fossil fuels, however, efficient and clean operation will continue to depend on the energy carriers and converters being perfectly coordinated. »We are also looking at potential synergies between engines and turbomachines for the energy carriers,« explains Dirk Bösel, the project manager responsible for the turbomachinery research field for the FVV.

Synergy effects are also a focus of collaboration with network partners. A current project being conducted jointly with the German Technical and Scientific Association for Gas and Water (DVGW) is investigating the storage capacities offered by the natural gas grid for renewably generated hydrogen, as well as the gas quality requirements from the perspective of various applications [→ page 58].

Alongside these major topics, however, introducing alternative fuels often also entails a redesign of seals, combustion processes and materials, and

Working together to unlock development potential



The pool of topics is full of highly relevant focuses for research and industry.

even a complete rethink of exhaust gas purification concepts. As a consequence, the change of energy carriers means that the traditional FVV topics are once again on everyone's lips.

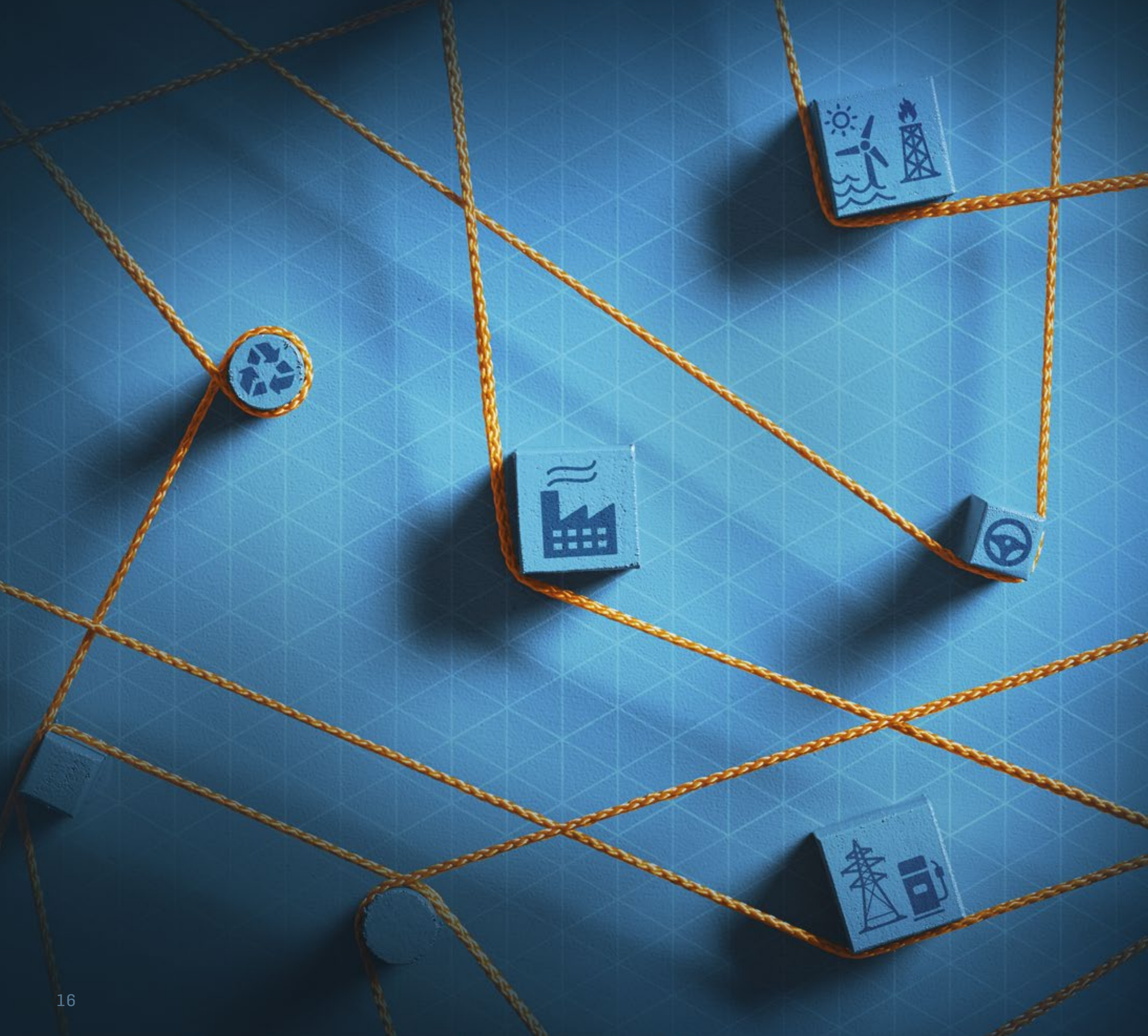
Regardless of which energy carriers are used, efficient combustion engines are crucial to the success of greener energies and mobility. Reducing fuel consumption through innovative technologies therefore remains at the heart of FVV research. One example of this is the ›ICE 2025+‹ project, which was completed in 2020 [→ page 24]. Using a systematic approach makes it possible to significantly reduce the CO_2 emissions of spark-ignition engines in cars – not only on the test bench, but in real world operation on the road. Part of this systematic approach is that the powertrains investigated all had an electrical component. Shaping hybridisation intelligently is another of the FVV's general objectives. The Board recently released an invitation for tenders mainly made up of questions, in which RTD performers were able to contribute their ideas.

With the new ›Digitalisation and Artificial Intelligence‹ research focus, the FVV is entering what at first glance appears to be foreign terrain. »Evaluating operating data through neural networks will be crucial to product development in the future,« says Nitsche. »We have to build up the methodical expertise needed for this in alliances with AI experts.« The aim is to enable even small and medium-sized component manufacturers to apply AI methods to classic problems in the field of mechanical engineering. In particular, detecting anomalies could enhance work with classic simulation models – which have long been developed as part of FVV projects. The first AI projects, such as on machine learning (ML), have been initiated over the last few months. But Nitsche also admits: »We are still in a learning phase.«

After all, researching together also means learning together. This applies even more to people completing their master's thesis or doctorate during the course of an FVV research project. However much the content of focus topics changes, supporting the careers of young scientists together is an aspect of pre-competitive Industrial Collective Research that should not be neglected. //

Taking **stock**

The carbon footprint of a powertrain technology depends not only on its operation, but also on its production, the establishment of the energy infrastructure, and recycling. An FVV meta-study on life-cycle analyses published in the summer of 2020 provides orientation here.



The study

Be it electric powertrains, hydrogen-driven fuel cells or the use of synthetic fuels in combustion engines, a wide range of technologies are currently being discussed in order to significantly reduce harmful CO_2 emissions from road transport. From a scientific point of view, it is not only the direct emissions generated during operation that need to be considered, but also the greenhouse gases released when manufacturing the vehicles, when producing the energy carriers, when distributing them and – not least – during the recycling processes at the end of the vehicle's life. In order to assess this in a meaningful way, the life-cycle analysis (LCA) approach has become established. One challenge here is that the results of LCA studies are strongly dependent on the assumptions made, producing a correspondingly large spread of results. In a meta-study performed on behalf of the FVV, the consulting firm Frontier Economics has now for the first time assessed more than 80 individual studies from the last 15 years, which encompass 110 different scenarios and 430 individual analyses. To ensure comparability, the results of all studies were standardised to a car with a total mileage of 150,000 kilometres.

The relevance

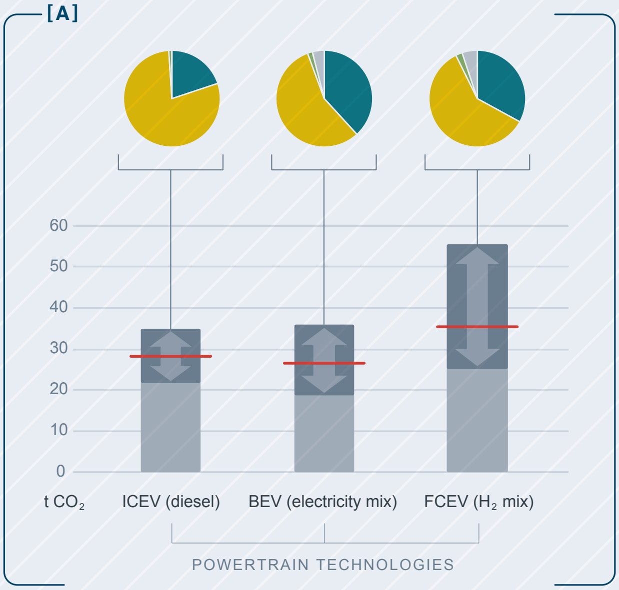
The long retention time of CO_2 in the atmosphere means that, when short time scales are applied, the year in which it entered the atmosphere is of no significance to climate change. This means that CO_2 emissions accumulate to form an atmospheric concentration that corresponds to the increase of the average global temperature. In order to limit the temperature increase to a maximum of 1.5 degrees Celsius compared to pre-industrial times, the IPCC (Intergovernmental Panel on Climate Change) has found that the remaining CO_2 budget that the whole of humanity can afford to release into the atmosphere is between 420 and 580 billion tonnes. In a business-as-usual scenario, this remaining global CO_2 budget would be exhausted by around the year 2030. It is therefore vital that the savings to be achieved in vehicle operation are not used up in advance through increased ›initial investments‹, i.e. CO_2 emissions produced during energy-intensive vehicle production or to establish the energy infrastructure.

Photo: Martisans / Stocksy, Adobe Stock

The results

The analysis of more than 80 studies conducted by renowned institutes shows that no technology is the clear winner when the entire life cycle is taken into account. It is important to differentiate between scenarios based on the current energy mix and those in which the energy carriers used during operation are from 100 % renewable sources. In the case of the latter, cars with a combustion engine have a smaller impact on the CO_2 budget than battery electric powertrains.

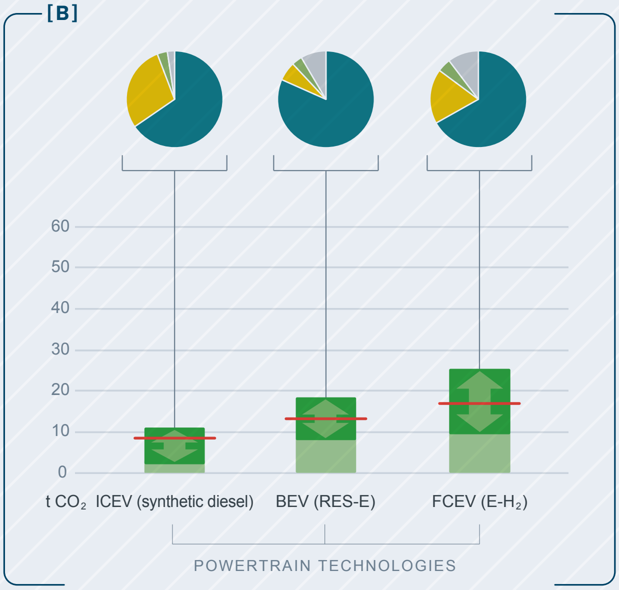
Life cycle emissions from current energy sources
[A]



[A]
If cars are powered by fossil fuels, by electricity from the current energy mix or by conventionally generated hydrogen, battery electric vehicles and internal combustion engine vehicles have comparable life cycle emissions.

[B]
If only renewable energy carriers are used during the use phase, a vehicle powered by synthetic fuels may even have lower CO_2 emissions than a battery electric vehicle. There is still room for optimisation of the fuel cell.

Life cycle emissions when using 100 % renewable energy for operation
[B]



- Range: 50 % of studies
- Median of all studies
- Production
- Energy WtW
- End-of-life
- Infrastructure

The propositions

On the basis of the results of the life-cycle study, the FVV Board formulated four propositions and published them in June 2020:

1. CO_2 targets must take the entire life cycle into account.

2. Efficient CO_2 reduction can be achieved with various powertrains.

3. The targets for 2030 prefer electric cars, but these are only part of the solution.

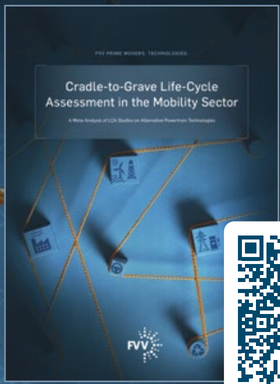
4. The mobility of the future must be diverse.

Based on these four propositions, the FVV Board makes the following recommendation: future regulations and guidelines regarding climate protection should be applicable across sectors, technology-neutral, global and designed for the long term.

As the study of various life-cycle analyses for cars does not reveal any significant differences between the combinations of combustion engine / synthetic fuels and battery electric powertrain / electricity, the powertrain technology of the future should be decided through technology-neutral competition. In particular, the framework conditions must be designed in such a way that the infrastructural investments necessary for the provision of energy – and which impact the CO_2 budget – are taken into account.

The details

The detailed results of the meta-study and the briefing paper based on them can be downloaded from the new FVV website dedicated to technology stories: www.primemovers.de/en/ | Science

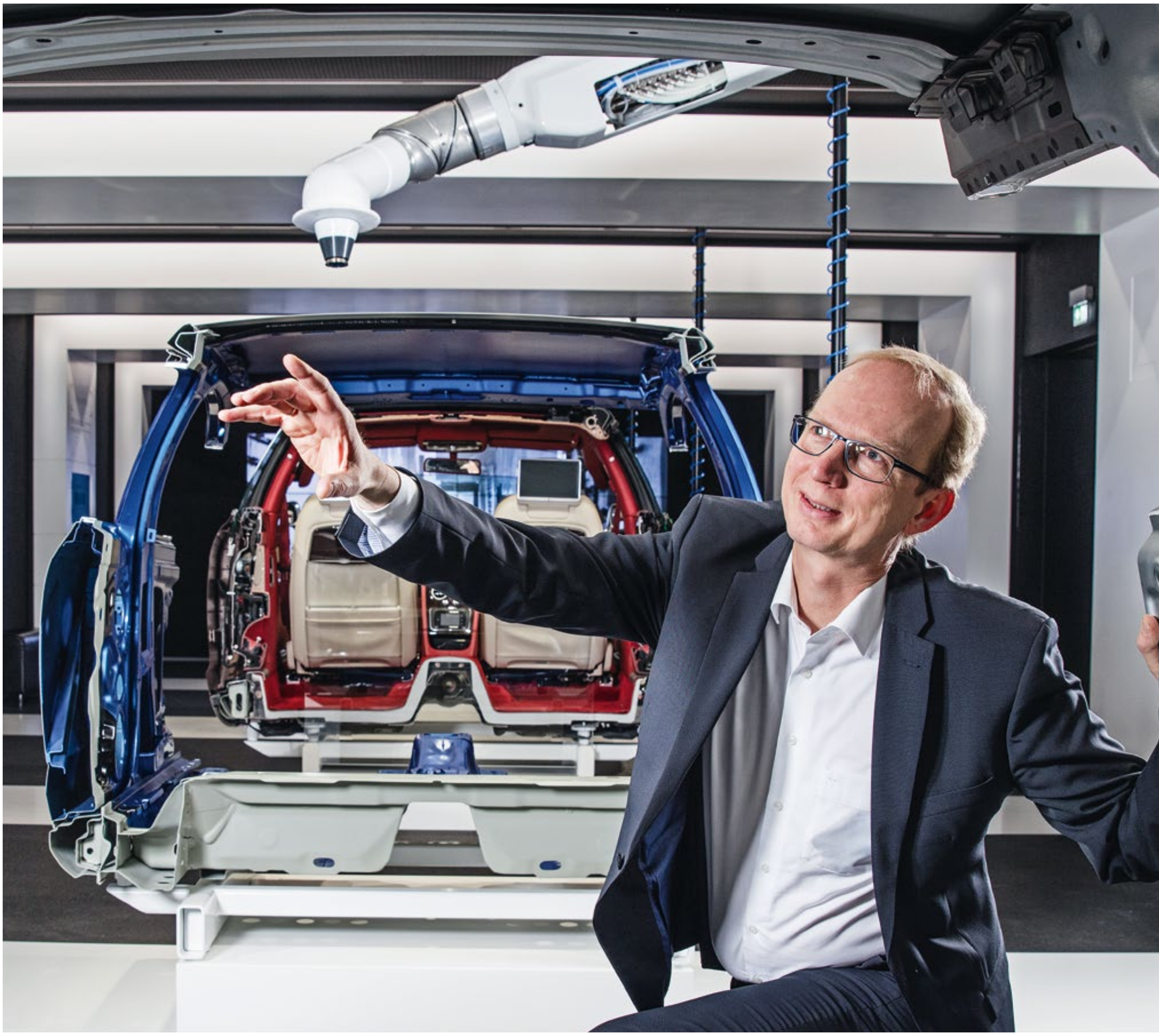


STUDY

›Cradle-to-Grave Life-Cycle Assessment in the Mobility Sector – A Meta-Analysis of LCA Studies on Alternative Powertrain Technologies‹

PAPER

›Efficient use of the global CO_2 budget in the mobility sector‹



»No longer just about **size and performance**«

Powertrains and energy carriers are changing. **Dr. Tobias Lösche-ter Horst,** who is leaving his role as Chairman of the Scientific Advisory Committee, explains what this means for vehicle technology and mobility concepts.

Dr. Lösche-ter Horst, in your career to date you have primarily dealt with vehicle powertrains. What will be your next step?
In future I will be responsible for mobility technologies, meaning the vehicle concepts of tomorrow, at Volkswagen Group Innovation. When tackling this area in research, we ask the following questions: how do we shape the mobility of the future? Which opportunities does electromobility offer us here? And which vehicle concepts will we actually need in the future? The worlds of powertrains and vehicles will increasingly merge in the years to come.

Although powertrains are changing, vehicles themselves seem to be remaining relatively conventional. Why is that?
The large underfloor battery in electric vehicles is already opening up completely new design possibilities, particularly for self-driving vehicles. As a result, there is more space to work with in general, which is also used in design concepts. But in the end, the key question is always what the customer really wants. From an environmental point of view, it would certainly be sensible to make battery electric vehicles smaller, as this in turn would allow the batteries to shrink in size once again. The classic idea of lightweight construction also applies in electric vehicles. One important factor here is the public charging infrastructure and the ability to charge batteries quickly.

Or you could also use a renewably produced chemical energy carrier on board …
In this regard, we have conducted a large number of studies comparing battery electric and hydrogen vehicles and have also examined synthetic fuels in detail. And yes, we can see that the weight to cost ratio tips in favour of hydrogen for large vehicles. This is generally the case when you want to carry a large amount of energy on board. Of course, there are also advantages for hydrogen when the vehicle is being operated 24/7. Commercial vehicles could benefit in particular here; after all, many fleets are refuelled at the company's own depot anyway.

Most cars will still be supplied with a combustion engine for the foreseeable future. What are the tasks here?
First of all, the topic of emissions remains a major challenge, namely when it comes to keeping emissions very low under all operating conditions. We are expected to keep them low at all times – throughout the entire range of temperatures, whatever the customer's driving behaviour and also for short trips. On top of this, it is important to increase efficiency further. However, we are already close to the optimum here when we take a look

at the cost-benefit ratio. Instead, I expect that engines will be scaled back a bit, with some of the dynamics coming from the electric part of the powertrain instead.

To me, that sounds like serial hybrid powertrains have a chance again.
As the battery size increases and electrical generators become more powerful, we can sensibly consider serial concepts. Unlike parallel hybrid powertrains, however, the performance of the electric motor and the combustion engine cannot be added together. But the charm of the serial hybrid is that it always behaves the same way from the customer's point of view, regardless of whether the combustion engine is running. Once customers have become more accustomed to electric powertrains, perhaps it will no longer be necessary to differentiate between different driving modes.

Do you believe that the fundamental concept of the ›car as the basis for individual mobility‹ will remain in the future?
I wouldn't question the basic concept of the car – rather, it's about using it in a more environmentally aware and sustainable way. After all, the demand for individual mobility won't go away. For the period following the COVID-19 pandemic there are even scenarios in which people travel alone more in the long term and self-sufficiency gains in importance.

To what extent does this challenge new concepts for urban mobility?
We should always differentiate within various scenarios: I don't believe that there will be a trend back towards cars in large cities or megacities. However, we cannot expect public transport to become the dominant means of transport in rural regions and smaller towns. One effect of the COVID-19 crisis might even be that fewer people consciously decide to live in very large cities. Recently, we have all gathered a lot of experience with the digitalisation of the world of work, and this will also continue in the future. As a result, it is becoming less necessary to be permanently present at a place of work.


Photo: Volkswagen AG

DR.-ING. TOBIAS LÖSCHE-TER HORST
has been responsible for the ›Mobility Technologies‹ area at Volkswagen Group Innovation since 1 July 2020. The mechanical engineer, who began his career in transmission development, was long responsible for powertrain research and then battery research at the Volkswagen Group. He was elected Chairman of the Scientific Advisory Committee of FVV in autumn 2015 – an office he will relinquish in autumn 2020 after five successful years.

»It is not about electromobility or the combustion engine, but rather the sensible interplay of the various powertrain technologies.«

Will the car stay the way we know it, or will we see radical new concepts?
Most cars will have four wheels in the future, too. There have already been many studies and even a few small-series vehicles aimed at closing the gap between scooters and small cars. Some really cool things are on offer, but nothing has really prevailed yet. The traditional car will continue to dominate the market in the future, too.

Apart from the powertrain, what can be changed in order to reduce the ecological footprint of cars?
The classical understanding is that a smaller car offers less than a large car. We will have to move on from this – it will no longer just be about size and performance. Smaller cars will also offer a lot more user convenience thanks to the corresponding digitalisation, but will also excel in terms of driving comfort. If we succeed in making smaller vehicles more attractive, the car will certainly be more sustainable. A network with shared mobility concepts, which enables a larger car to be used when needed, will certainly be needed for this.

What does all this mean for the FVV?
The FVV is in a phase of orientation and is fine-tuning its self-conception, as the world of powertrains appears to be rearranging itself and no-one can say exactly what the future of combustion engines holds. However, we must always remember that the FVV is about much more than just cars.

What would you recommend for the FVV?
I am glad that the discussion on the alignment of the FVV was started actively a few years ago and that the Board is very intensively involved in this. The fuel study or the current study on life-cycle analysis are examples of this. I believe it is important to continue down this path while also maintaining its focus on fact-based scientific evidence. This is not about electromobility or the combustion engine, but rather the sensible interplay of the various powertrain technologies. When choosing research topics, we should concentrate even more strongly on jointly defined future topics, examining overarching issues and on the synergies between the two research fields of engines and turbomachinery. The research activities on fuel cells, which have become a firm part of the FVV with a dedicated planning group, can also certainly be intensified further.

Thank you for the interview, Dr. Lösche-ter Horst. //

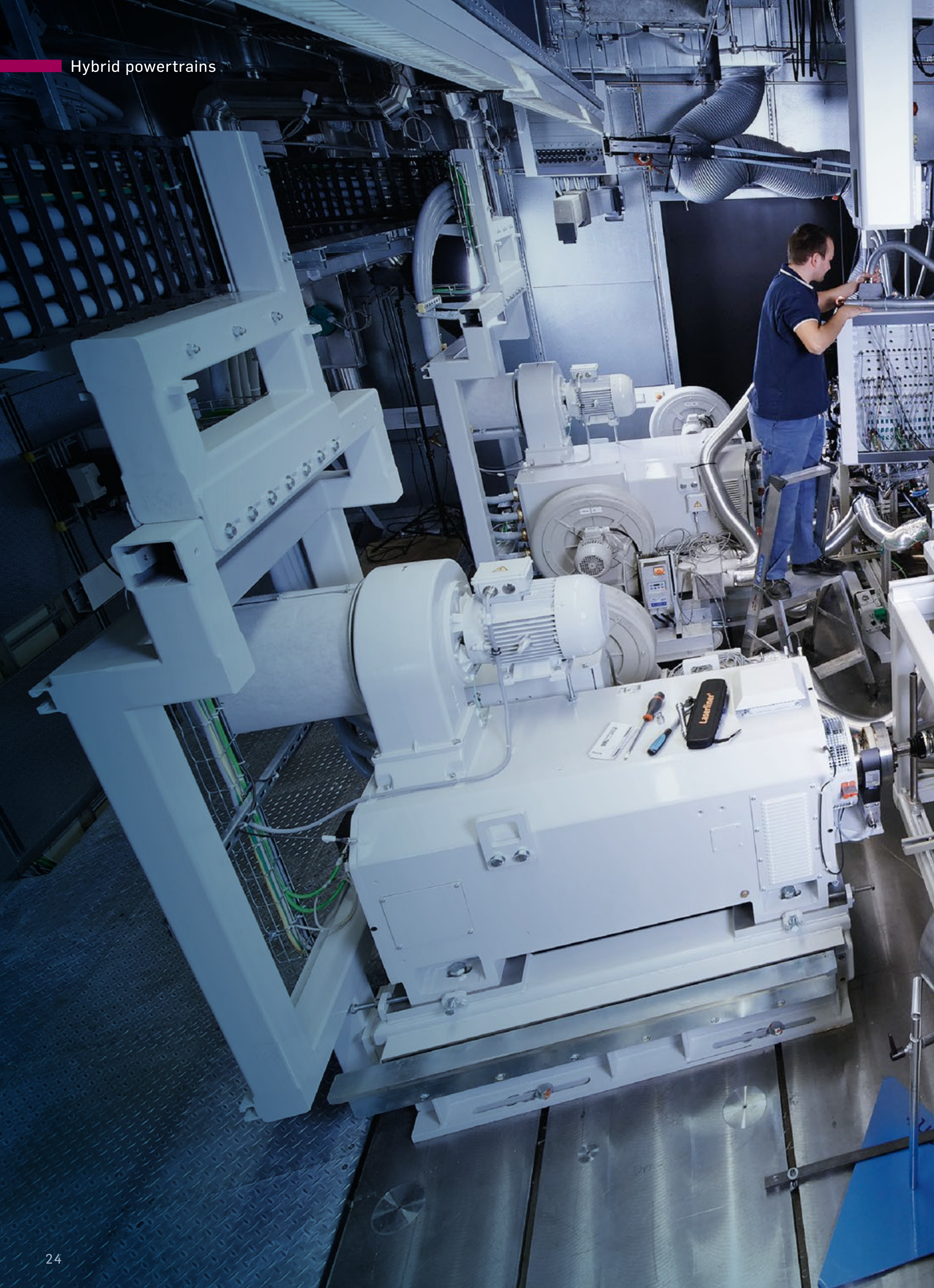
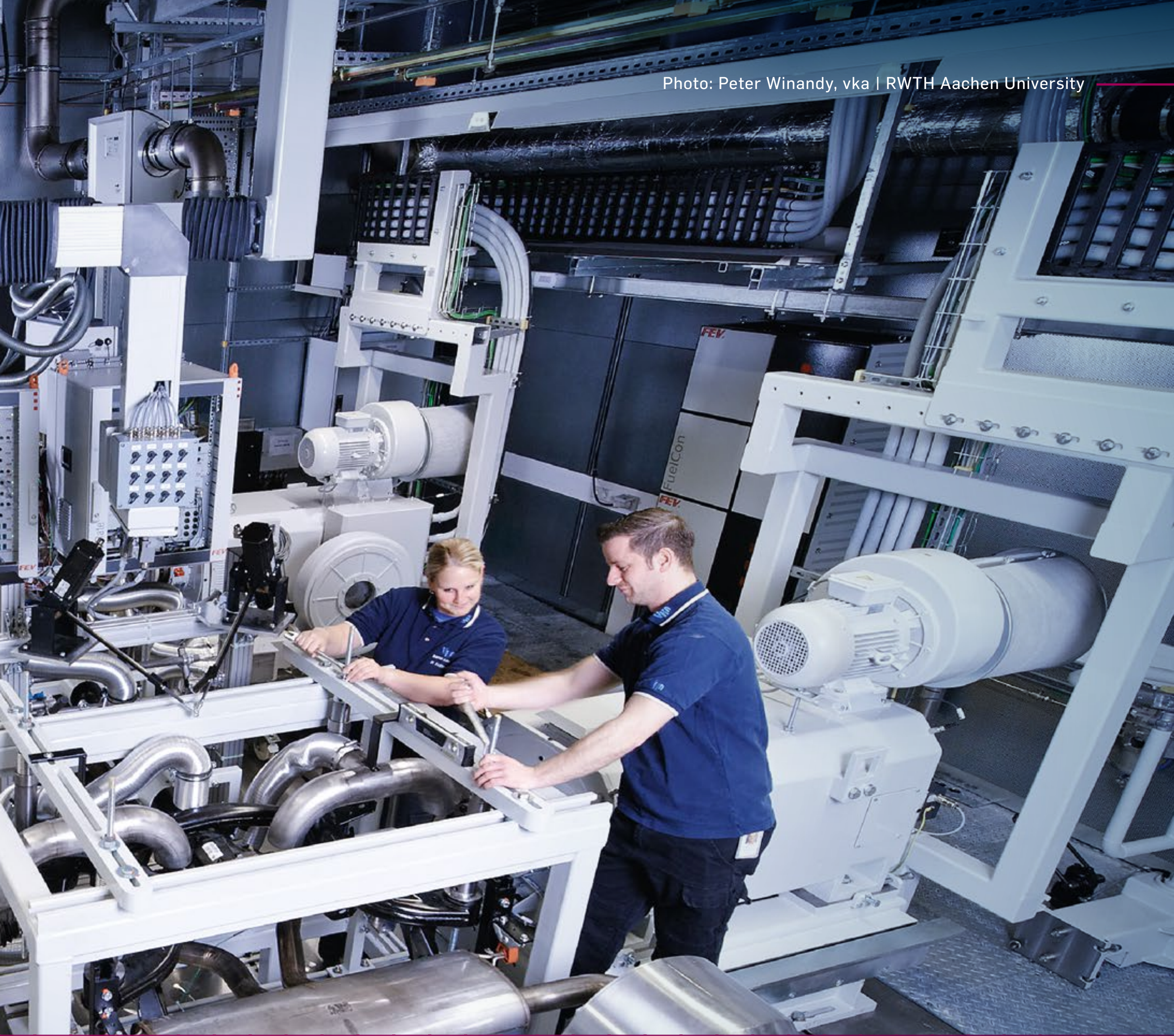


Photo: Peter Winandy, vka | RWTH Aachen University



Over 40

Can the fuel consumption of spark-ignition engines still be significantly improved? And which technologies have to be combined in order to achieve this? On behalf of the FVV, four universities worked together to research the petrol engine of the future.

»Our goal was to reach an average efficiency of more than 40 % in a realistic driving cycle such as the WLTC.«

PROF. DR. TECHN. CHRISTIAN BEIDL
Institute for Internal Combustion Engines and Powertrain Systems (vkm), Technische Universität Darmstadt

PROF. DR.-ING. PETER EILTS
Institute for Internal Combustion Engines (ivb), Technische Universität Braunschweig

PROF. DR.-ING. STEFAN PISCHINGER
Institute for Combustion Engines (vka), RWTH Aachen University

PROF. DR.-ING. MICHAEL BARGENDE
Institute of Automotive Engineering (IFS), University of Stuttgart

ICE 2025+: the ultimate system efficiency //
Theory is one thing, but practical application is another altogether. Over the last two years, four research institutes have investigated on behalf of FVV how close we can come to the thermodynamic optimum in real driving operation, and what this means for the efficiency of a vehicle. The key requirement here was that the researchers were only to consider technologies that would be ready for series production over the coming years and thus help adhere to the CO_2 limits applicable from 2030. In addition, their objective was not to achieve a single peak value in a certain point on a characteristic map. »Our goal was to reach an average efficiency of more than 40 % in a realistic driving cycle such as the Worldwide Harmonized Light-Duty Vehicles Test Cycle (WLTC),« explains Christian Beidl. In the ›ICE 2025+‹ project, the head of the Institute for Internal Combustion Engines and Powertrain Systems at the Technical University of Darmstadt and his colleagues Stefan Pischinger from Aachen, Peter Eilts from Braunschweig and Michael Bargende from Stuttgart investigated the extent to which the efficiency of spark-ignition engines can be improved in hybridised powertrains.

 Photos: Konstantin Eckert (Beidl) | Rui Camillo (Eilts, Pischinger, Bargende)

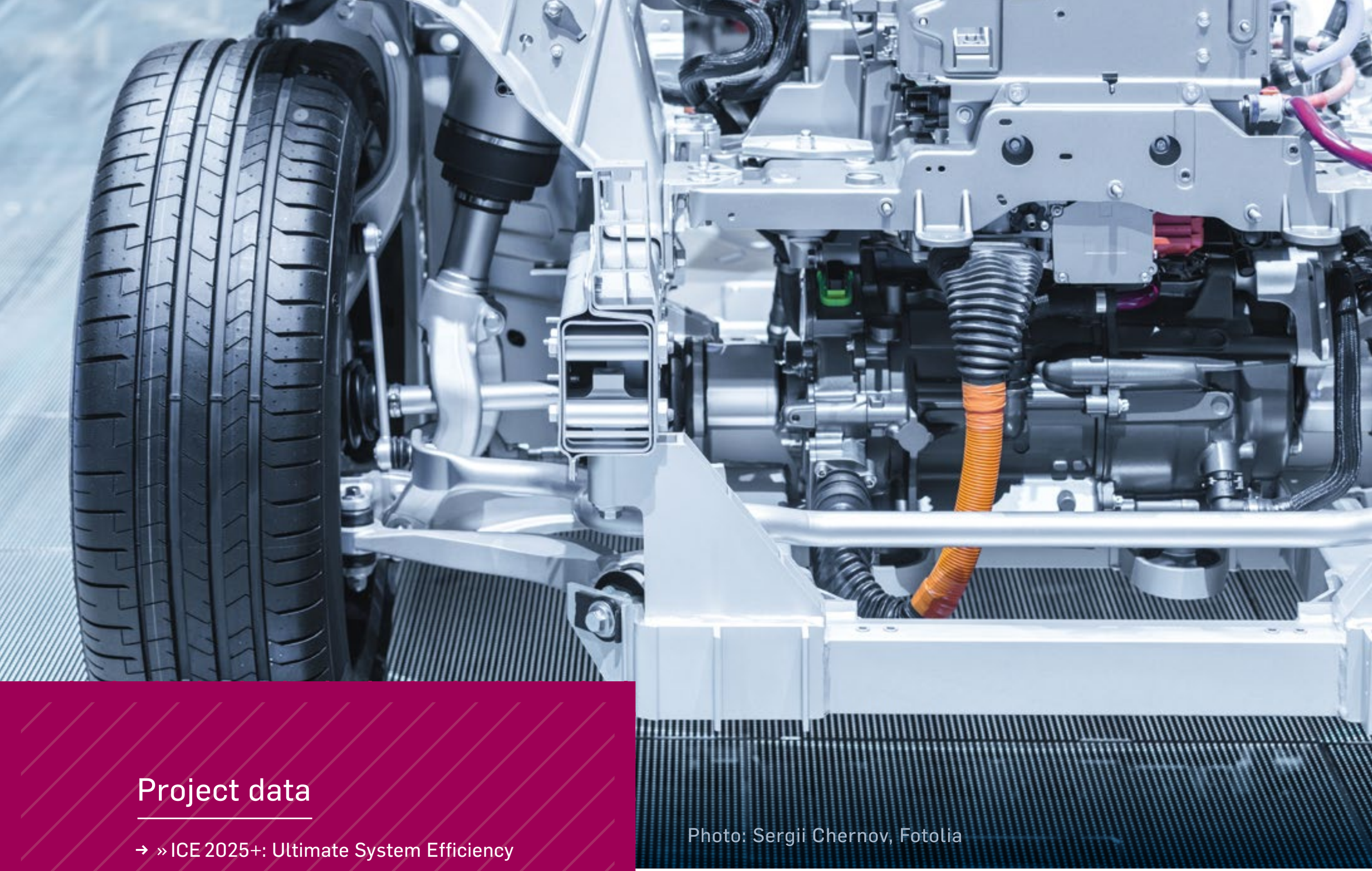


Photo: Sergii Chernov, Fotolia

Project data

→ » ICE 2025+: Ultimate System Efficiency [1307]: Limits to increasing the efficiency of gasoline engines in hybridised powertrains «

→ **PROJECT FUNDING**
€ 1.2 million // FVV

→ **PLANNING GROUP**
PG 2 ›Combustion SI‹

→ **PROJECT COORDINATORS**
Arndt Döhler, Opel Automobile
Dr. André Casal Kulzer, Porsche

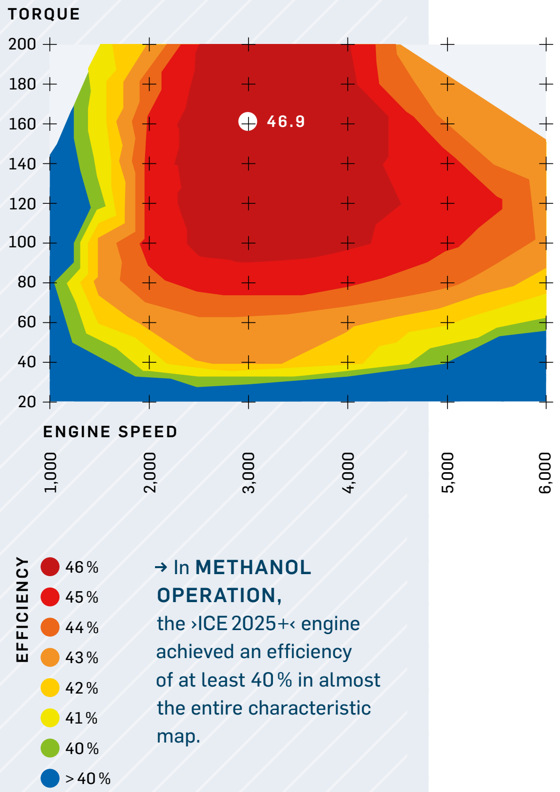
→ **RTD PERFORMERS**
Institute of Automotive Engineering (IFS), Chair in Automotive Powertrains, University of Stuttgart // Institute for Internal Combustion Engines and Powertrain Systems (vkm), Technische Universität Darmstadt // Institute for Combustion Engines (vka), RWTH Aachen University // Institute for Internal Combustion Engines (ivb), Technische Universität Braunschweig

The technologies that can be used to raise the efficiency of a piston engine are already known: variable compression and flexible valve control times, exhaust gas recirculation, control of the charge movement, pre-chamber ignition, water injection and long-stroke engine design. Hybridisation can also contribute to lower fuel consumption, as the vehicle is driven electrically in very low load ranges in which the spark-ignition engine has poor efficiency due to its functional principle. The framework conditions of the ›ICE 2025+‹ project specify that only electrical energy generated on board may be used.

One problem remains, however: consumption is only actually optimised when all the technologies used work together. Simply adding individual measures is not an option, as in extreme cases technologies can neutralise each other if the operating strategy is not adjusted. »That is why we have taken a systematic approach from the beginning,« says Beidl. To this end, it was not only the technologies that had to work together perfectly, but also the institutes.

	WLTC EFFICIENCY	ROUTE A SPORTY	ROUTE B SPORTY	ROUTE C MODERATE	ROUTE D MODERATE	AVE. EFFICIENCY RDE
Efficiency engine (without EGR)	39.9 %	41.7 %	41.8 %	40.5 %	39.7 %	**40.9 %**
Efficiency engine (with EGR)	40.6 %	42.6 %	43.2 %	41.3 %	40.4 %	**41.9 %**
Methanol engine	43.3 %	46.0 %	45.6 %	44.6 %	42.5 %	**44.7 %**

→ **REAL CONDITIONS COUNT:** The simulation results from the Technical University of Darmstadt show that the technologies investigated in the ›ICE 2025+‹ research engine actually perform better in real driving operation than in the test bench cycle.



→ In **METHANOL OPERATION,** the ›ICE 2025+‹ engine achieved an efficiency of at least 40 % in almost the entire characteristic map.

Consumption measurements for individual technology packages were initially performed on a single-cylinder research engine at the Institute for Internal Combustion Engines (ivb) at TU Braunschweig. These were then used at the Institute of Automotive Engineering (IFS) at the University of Stuttgart to create an engine simulation model and, on the basis of this, a characteristic map for a complete virtual engine. Next, the researchers in Darmstadt used this characteristic map to simulate complete vehicles and determine how much of the chemical energy from the fuel actually reaches the tarmac. During the process, they examined both different vehicle classes and a range of hybrid configurations. In further experiments at the Institute for Combustion Engines (VKA) at RWTH Aachen University, the normal petrol fuel was then replaced by alternative energy carriers. »One of the reasons we chose methanol was because it has outstanding combustion properties and is among the renewable liquid fuels that is most efficient to manufacture,« says Stefan Pischinger, head of the institute at RWTH Aachen University. The data generated during this stage was also used for the engine simulation at the University of Stuttgart, before the researchers in Darmstadt calculated the real driving efficiency on the basis of the findings.

These values are achieved not only in the WLTC test bench cycle, **but also in various RDE cycles.**

Two years after the project start and just before completion, it was already evident that the 40 % target for a mid-range vehicle (C-segment) is achievable if it is run with normal fuel and equipped with a P1 or P2 hybrid powertrain. »These values are achieved not only in the WLTC test bench cycle, but also in various RDE cycles,« comments Beidl. RDE stands for ›real driving emissions‹ and replicates driving in road transport. When the researchers in Aachen and Stuttgart replaced the standard fuel with methanol, the results were even better: the powertrain in the C-segment vehicle with transmission-integrated hybrid powertrain achieved an efficiency of 43.4 % in the standard cycle, and an average of 42.7 % in simulated road transport. »This is mainly due to the higher combustion speed of methanol,« says Michael Bargende from the University of Stuttgart.

If the technologies researched in ›ICE 2025+‹ entered series production, we would have an extremely efficient petrol engine. Due to its functional principle, it cannot quite reach the efficiency of a diesel engine as long as it is run with a stoichiometric air-fuel ratio (lambda = 1). However, the method of exhaust gas purification via three-way catalytic converter proven in spark-ignition engines still works, and the significantly more complex SCR technology seen in diesel engines is not needed. The additional potential of lean-burn operation was also investigated, albeit also with technologies oriented towards a series launch. »When the methanol engine is run with excess air, the consumption level is even better than that of a diesel car,« states Bargende. »An efficiency value of more than 40 % is achieved in a large part of the engine characteristic map, and even 46.9 % at its peak.« Compared to a current spark-ignition engine that corresponds to the state-of-the-art in every way, this gives a CO_2 reduction of up to 25 %.

»Exactly that was our goal,« stresses Beidl. »We wanted to achieve a significant reduction in consumption across the entire characteristic map, not just a single peak value at a certain operation point.« The specialist is convinced that, »Even if individual technologies such as variable compression do not make it into series production, the efficiency of the spark-ignition engine can still be improved considerably.« //

Pioneering spirit

Engine developer **Dr. André Casal Kulzer** enjoys breaking new technical ground – and in doing so continues his family's tradition.

Photos: Dirk Lässig

→ Kulzer restores old motorcycles in his spare time. This also revives memories of the days when his father developed racing motorbikes for Casal.

Names carry traces of the past //
And this is certainly the case for André Casal Kulzer. The Bavarian ›Kulzer‹ takes us back to a former agricultural machinery factory in Velden, founded by his great-grandfather. ›Casal‹, meanwhile, refers to his mother, the daughter of a Portuguese motorcycle manufacturer. His parents met as the result of a pioneering act: after the foundation of Metalurgia Casal in 1964, the two-stroke engines were initially supplied by Zündapp, but technical expertise was desperately needed on site. Kulzer's father was one of the four German engineers that Zündapp sent to Aveiro, an industrial city in the north of Portugal, which at the time was still regarded as a developing country. His father occupied various management positions in the motorcycle industry during the course of the 1970s. For young André, it was completely normal to wander around the site of the motorcycle factories. Occasionally he discovered retired mopeds and removed parts. When his busy father had some free time, he built model aircraft with his son. »That was my Lego,« comments Kulzer, remembering the time when he settled on his first big career wish: to be a fighter pilot or an astronaut.

The Portuguese economy increasingly opened up at the start of the 1980s. By this time, Casal had long since ceased to focus solely on mopeds for the domestic market, but rather exported and invested in the development of larger machines. The company's participation in racing had become an important marketing instrument. André's father also provided support in the development of racing engines, among other things through a rotary slide valve control unit, which enables very high engine speeds and thereby performance. He constantly took his son to competitions, keeping his passion for engines alive. When André realised that, as a top-class swimmer, he was physically fit, but could never be a fighter pilot due to having to wear glasses, there was only one route to follow: he wanted to develop engines and powertrains like his father and grandfather before him, and preferably in southern Germany. After completing his university entrance exams with very good grades, he graduated in mechanical engineering in Lisbon, including an Erasmus scholarship at the TU Braunschweig, and discovered his love of thermodynamics – a topic that many of his fellow students wanted to leave behind them as quickly as possible. Even today, Kulzer believes that »thermodynamics sometimes has something philosophical about it«.

DR.-ING. ANDRÉ CASAL KULZER, was born in 1975 and has been responsible for thermodynamics in advanced powertrain engineering at Porsche since 2012. The mechanical engineer, who earned his doctorate at the University of Stuttgart, worked at Bosch for nine years prior to this. He is involved in numerous working groups at the FVV and frequently initiates new research projects.

»Thermodynamics sometimes has something philosophical about it.«

After a brief period of orientation, Kulzer ultimately found a doctorate position at Bosch. The topic of the work conducted together with the University of Stuttgart was a challenging one: Kulzer looked for ways to start a spark-ignition engine directly – that is, without an electric starter. This can only work when the position of the pistons and the corresponding filling in the cylinder is known by shutting down the engine in a controlled manner, and when the carburation is precisely matched with the starting process. First, Kulzer spent a year developing theoretical simulation models capable of reproducing the entire start process, from carburation and combustion, up to torque balance. As test bench capacity was limited and

»Power density and performance are still important development goals for Porsche.«

expensive, Kulzer developed sensors and software on a Volkswagen Lupo. »It immediately started up the first time I attempted a direct start,« says Kulzer with a smile. During the rest of the project, however, it also became clear that a direct start is difficult to realise in warmed-up engines in particular. Nevertheless, Kulzer's work sparked a great deal of interest in the industry, and as a young man he was invited to present his findings to nearly all well-known car manufacturers – often directly to the development board. Even though the car without an electric starter did not make it into series production, the research results are important as they enable the combustion engine in modern hybrid vehicles to be restarted with the car occupants barely noticing. Kulzer's superior at Bosch guaranteed him a permanent post a year before he earned his doctorate. The young engineer started in research in 2003, where he worked on new combustion processes. One of these was compression ignition, which was discussed intensively at the time. »I had a lot of freedom and was constantly permitted to break completely new ground,« remembers Kulzer. It was also then that he established his initial contact with the FVV research association. He later switched internally to pre-development in the Gasoline Systems segment and was actually very satisfied there.

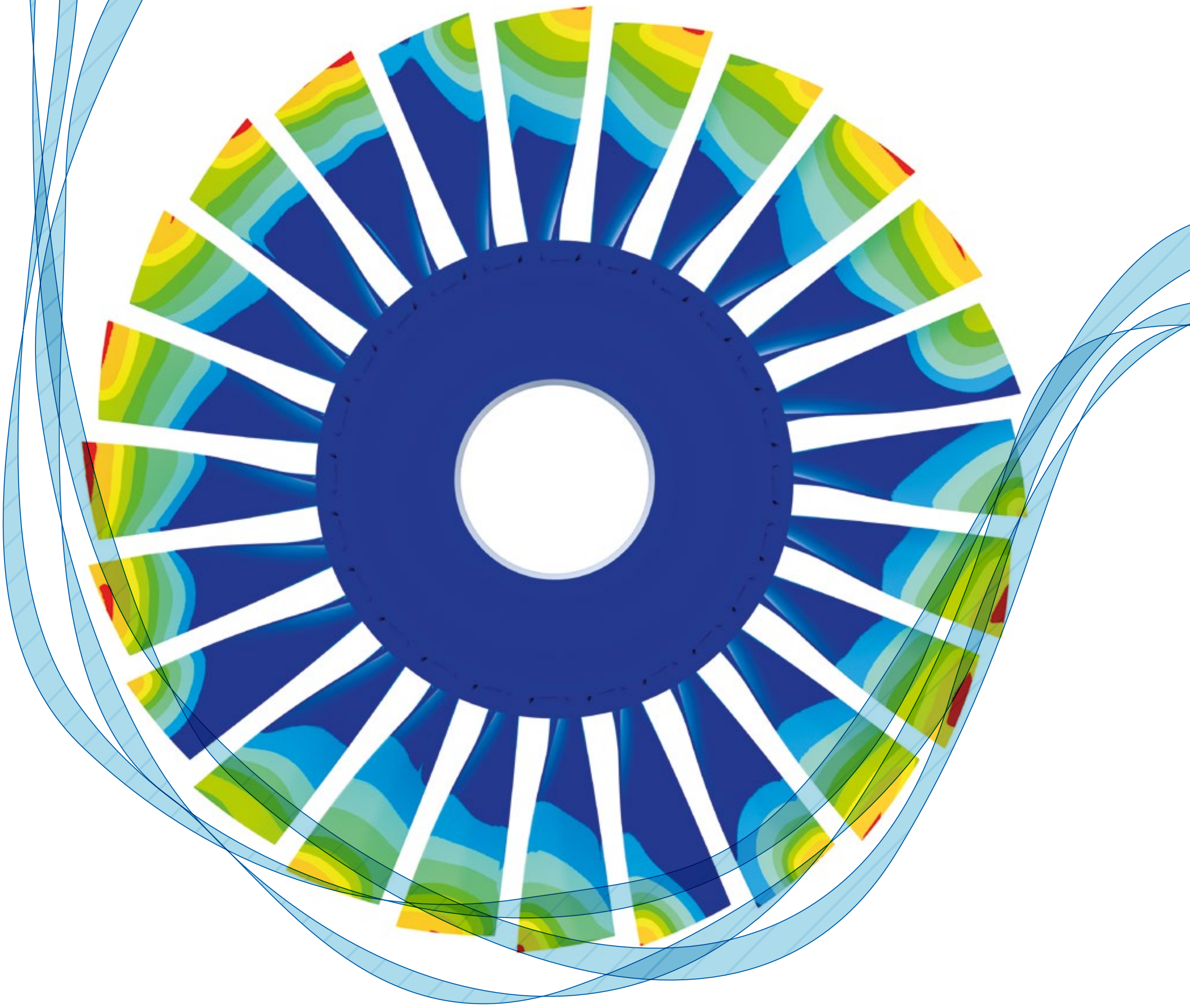
Yet he signed on the dotted line for Porsche in 2012. He was convinced by his then superior, who told him: »80 % of the developments we work on make it into series production.« Since then, he has been responsible for thermodynamics pre-development at the sports car manufacturer. This is a cross-disciplinary function, as Kulzer works on both electrified powertrains and pure GT engines. »Power density and performance remain important development goals for Porsche,« comments the expert. »But of course there is a growing

focus on drastically reducing emissions and taking the entire product life cycle into account when working on future powertrain generations.«

Kulzer has also represented Porsche in numerous FVV research projects aimed at resolving this balancing act. He initiated a now completed project in which various water injection methods were investigated – an important topic for reducing emissions in high-load operation through maximum efficiency. He is also project co-coordinator for the ›ICE 2025+‹ project, in which four renowned universities are working together to increase the efficiency of spark-ignition engines.

Looking to the future and tackling new things with a pioneering spirit is probably Casal Kulzer's most important inheritance from his family history. Two roadworthy Casal series motorcycles in his garage remind him of this. It is a matter of pride that he maintains them himself. //

Dr. André Casal Kulzer in the **workshop of the Porsche Museum,** which keeps the manufacturer's collection of classic vehicles roadworthy. The unique thing about the workshop is that visitors can watch the mechanics at work through windows.



Preventing mistuning with **ROMI**

Minuscule manufacturing tolerances can cause blades in turbomachinery to vibrate increasingly during operation. Researchers in Hanover have investigated the phenomenon, and have thus paved the way for even more efficient turbines.

»It was important to predict an increase in vibrational amplitudes – and we succeeded in doing that.«

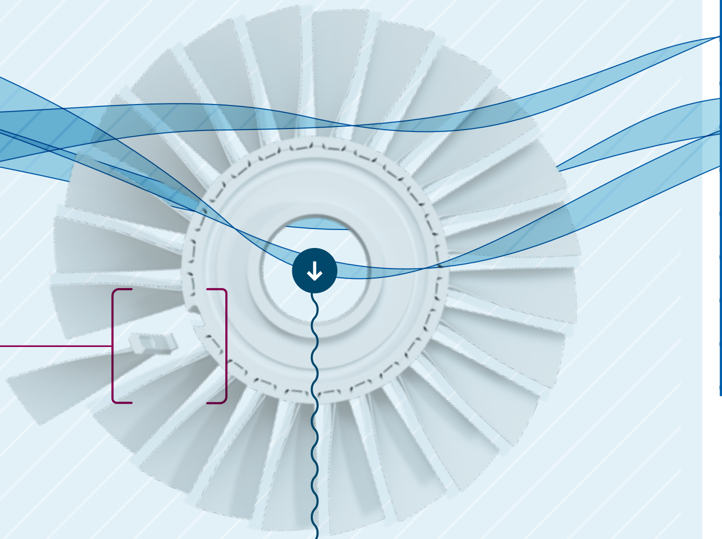
Simulation of mistuning with aerodynamic coupling // Turbomachines are precision machines; nevertheless, the geometry or material properties of the individual blades can vary minimally due to manufacturing tolerances. These deviations from the ideal geometry result in unwanted high vibrational amplitudes during operation – the system is ›mistuned‹. The mistuning effect occurs in all turbomachines, from small turbochargers to large steam turbines or aircraft engines. In an FVV project, researchers from Leibniz University in Hanover (LUH) examined how interactions with the fluid, such as steam or gas, affect mistuning. A simulation program was also developed in order to predict vibrational amplitude better in the future.

Until now, components have been designed to be stronger than necessary due to fear of these amplitudes, which can arise during operation as a result of mistuned blades. »The weight resulting from this cancels out the efforts to make turbomachines as efficient as possible,« explains Prof. Dr. Jörg Seume, Head and board member of the Institute of Turbomachinery and Fluid Dynamics at LUH. Seume reports that efficiency of highly effective gas power plants is increased by 0.3 percentage points every year, but only if the mistuning phenomena are conquered. Although this sounds like very little, over many years of operation it means that large amounts of fuel are saved – which would otherwise have caused CO_2 emissions. »The objective of the research and development work is to retain mechanical reliability while simultaneously increasing efficiency,« summarises Seume.

Mistuning not only occurs as a result of manufacturing tolerances, but also due to coupling effects of the blades. »In a blisk (blade-integrated disk), the blades and rotor disc ultimately consist of a single component and are coupled solely through this. The fluid that flows through also couples the blades, which stimulates vibration,« reports Dr. Lars Panning-von Scheidt, Head of the Dynamics of Rotating Machinery research group at the Institute of Dynamics and Vibration Research at the LUH.

Vibration calculation with ROMI

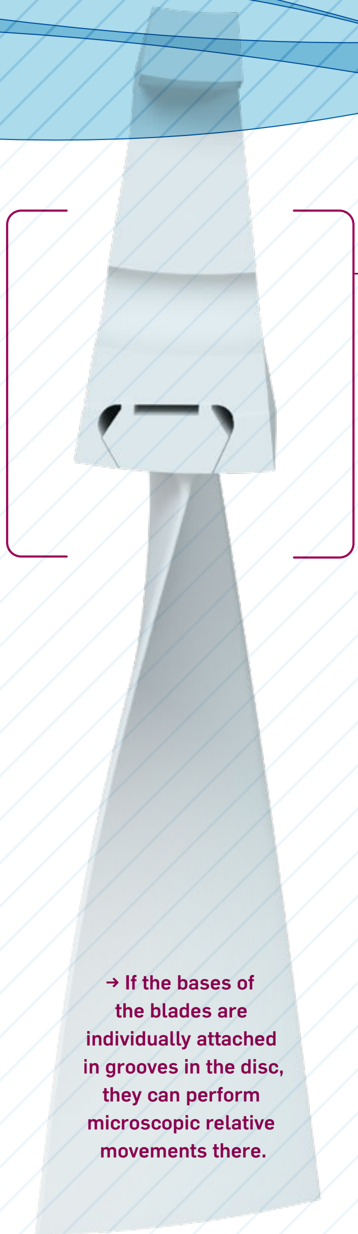
Mistuning of the blade properties leads to increased vibrational stress.



Non-linear, structural-mechanical couplings between blades and disc produce friction and lower the vibration amplitudes, which are determined by conducting experiments in a vacuum with vibration excitation using magnets.

The **aerodynamic coupling** of the blades influences damping in particular, which is determined by experiments on multi-stage turbo-machines under real flow conditions.

ROMI allows various effects to be observed both separately and simultaneously, with the aim of predicting vibrations of mistuned blades more accurately in the future.



→ **If the bases of the blades are individually attached in grooves in the disc, they can perform microscopic relative movements there.**

Project data

→ » Mistuning with Aerodynamic Coupling II [1269]: Mistuning of bladed discs with aerodynamic and structural coupling «

→ **PROJECT FUNDING**
€ 315,750 million // DFG, FVV

→ **PLANNING GROUP**
PG T ›Turbomachinery‹

→ **PROJECT COORDINATOR**
Dr. Harald Schönenborn, MTU Aero Engines

→ **RTD PERFORMERS**
Institute of Dynamics and Vibration Research (IDS) // Institute of Turbomachinery and Fluid Dynamics (TFD), both at Leibniz University in Hanover

If the bases of the blades are individually attached in grooves in the disc, they can perform microscopic relative movements there – further complicating the task of calculating vibrations.

In order to investigate the various possible influences, the researchers worked on two test benches with different configurations. The one at the Institute of Dynamics and Vibration Research was an idealised turbine stage in a chamber in which the effects could be reproduced without any disturbing influences. »Because the blades driven by an electric motor rotate in a vacuum here, we remove any interactions with the fluid,« comments Panning-von Scheidt. Structural-mechanical vibrations are created artificially: firstly with permanent magnets distributed throughout the chamber, and secondly in the static test with loudspeakers, which provide acoustic excitation. The test bench at the Institute of Turbomachinery and Fluid Dynamics, on the other hand, enabled real excitation through the flowing fluid and thus also allowed an investigation of damping. In modern gas or steam turbines, the mistuning in the last row of blades can be so great that the turbines cannot run in a stable manner without the additional damping effect of the flow.

The institutes used simulation software that was developed in a predecessor project and was now expanded. The ROMI (Reduced Order Model for Mistuned Turbine Blades) simulation program allows vibrations to be calculated while considering various coupling effects. Instead of external software developers, ROMI was written by a scientific staff member. And for a good reason: »We want to continue the project, so we always want to be able to adapt the code accordingly. That works better if we develop it ourselves,« explains Panning-von Scheidt.

During the course of elaborate test series spanning several months, the scientists examined how well the results of the simulation matched the real data. »There were small discrepancies due to the construction. With the current state-of-the-art in fluid dynamics, prediction errors are naturally somewhat greater,« says Seume, who is nonetheless satisfied: »It was important to predict an increase in vibrational amplitudes – and we succeeded in doing that.« //

»Preserve what makes us **strong**«

Whether energy-efficient construction machinery or synthetic fuels for carbon-neutral powertrain systems: the Industrial Collective Research programme is geared towards strengthening value creation chains in Germany. We discussed this with **Prof. Dr. Sebastian Bauer,** President of the German Federation of Industrial Research Associations (AiF).

Photos: AiF e.V.

You bear the name of the company founder, Professor Bauer.
Yes, my ancestor Sebastian Bauer founded a coppersmith's 230 years ago. At the beginning of the 20th century, our forefathers began to build water supply networks and water wells. My father then developed a scientific approach to well building. Back then, he was the only one who could use partial differential equations to calculate how the groundwater level changes due to wells. Using scientific methods to always be a bit better than the competition is part of our company's DNA. Today, we utilise this philosophy for our special foundation engineering equipment and procedures.

Did you know what to expect as President of the AiF?
When I had to make my decision, I asked a few professors in my circle of friends. They all told me I should do it! The AiF is an institute that is unique worldwide. It plays a key role in ensuring that young scientists here are not trained in an ivory tower, but instead do practically relevant work from the very beginning. It also helps universities conduct application-relevant research that directly benefits business.

The AiF is now made up of more than 100 different research associations that perform countless projects in parallel. How do you maintain an overview?
I don't have to examine individual research projects – I'm not even allowed to do that. Among other things, my mission is to explain to politicians why it is worth investing money in Industrial Collective Research. Another task is to keep the AiF network together and make sure that the organisation is always fit for the future.

Let us do an ›elevator pitch‹: if you were speaking to a politician with a humanities background, how would you explain that it is necessary to invest state money in this form of research funding?
Because of the structure of Industrial Collective Research, small and large companies work together in our organisation. Through this collaboration, we motivate SMEs to innovate – especially at times when the economic situation is not so positive. Greater leaps forward are often only made possible by collaboration. I can name an example of this from my own company. Thanks to a joint project conducted by two research associations organised in the AiF, we succeeded in reducing the energy consumption of our machines by 20 to 30 %. In our

large machines this translates to up to 30 litres less diesel – per hour! This was only possible because around 20 companies and research institutes contributed their specialist knowledge and inspired one another during the course of the scientific work.

But the politician might answer as such: we have collaborative research projects in Germany and Europe with millions of euros invested in them – why do we need the small-scale approach of the AiF, with € 180 million distributed across more than 100 research associations?
Research tenders are always carried out in the specialist areas that are currently on everyone's lips. But what use is a tender offer for nanotechnology to a chocolate manufacturer? In contrast, the Industrial Collective Research programme or the Central Innovation Programme for Small and Medium-Sized Enterprises (SMEs) [Zentrales Innovationsprogramm Mittelstand, ZIM] is not bound by any thematic restrictions. And the 50,000 companies behind the AiF projects support this approach. Furthermore, even a large SME such as my company with 3,000 employees has difficulty in getting involved in the large collaborative research projects. After all, examining tender offers and writing appealing applications ties up significant personnel capacities. The initial hurdle is much lower with AiF projects, also because they bring together companies with the same interests.

But many large corporations are also involved in your research associations. They could easily do all this on their own.
Yes, but the industrial value chains that make Germany so strong consist of exactly this collaboration of small, medium-sized and very large companies. This makes us incredibly strong compared to centralised economic models and we need to preserve it. It also means that we need to encourage this concept of an economy divided up into small actors through research activities that accommodate this model, instead of just concentrating on large projects. The global corporations that act as flagships for our economic strength will also benefit from this: they gain access to new ideas contributed by the smaller companies. In

»Every sector, no matter how small, has the opportunity to benefit from this and turn its companies into **champions.**«

addition, the practically oriented training that young engineers receive from us is good for large companies.

What are your goals for Industrial Collective Research in Germany?
The basic idea of Industrial Collective Research in an open competition of ideas has proven its worth. However, the sad thing is that we do not get all the cream, but also have to reject many good projects because the budget is not sufficient. Good ideas are wasted as a result! That's why I am working on increasing the funds for Industrial Collective Research in the budget of the German Federal Ministry for Economic Affairs and Energy to € 300 million over the coming years.

Today, your machines are solely driven by diesel engines that you procure. In your opinion, how important is the combustion engine today?
We will not be able to completely replace the combustion engine over the next 20 years. We presented our first large series-produced machine with pure electric powertrain in 2019. This is sensible where enough electricity is available. However, most construction sites only have an 88-kilowatt power supply while our mobile equipment needs between 200 and 700 kilowatts during operation. At 400 volts, that would require a really thick cable. This would not be easy to move, and you certainly couldn't drive over it. Another way to be climate-neutral is by using hydrogen or synthetic fuels, which also have an immediate effect in the fleet. Some of our equipment has been in use for 30 years!

Thank you for the interview, Professor Bauer. //

PROF. DR.-ING. SEBASTIAN BAUER
has been Managing Director (Research and Development) at BAUER Maschinen GmbH for 15 years. After graduating in mechanical engineering, he initially worked at Thomson Consumer Electronics in the USA before earning his doctorate at the Technical University of Munich; he joined the BAUER Group in 1996 as Head of the Design and Development Department (Equipment). Bauer was elected President of the German Federation of Industrial Research Associations (AiF) in 2018.

→ Around 100 research associations are represented in the AiF innovation network. Overarching topics such as greener energies, lightweight construction and fuel cell technology are discussed and worked on in research alliances. All this takes place on a pre-competitive basis, as it is not just individual companies that benefit from the knowledge transfer, but entire industries.

AiF Forschungsnetzwerk Mittelstand

IGF Industrielle Gemeinschaftsforschung

Under **high pressure**

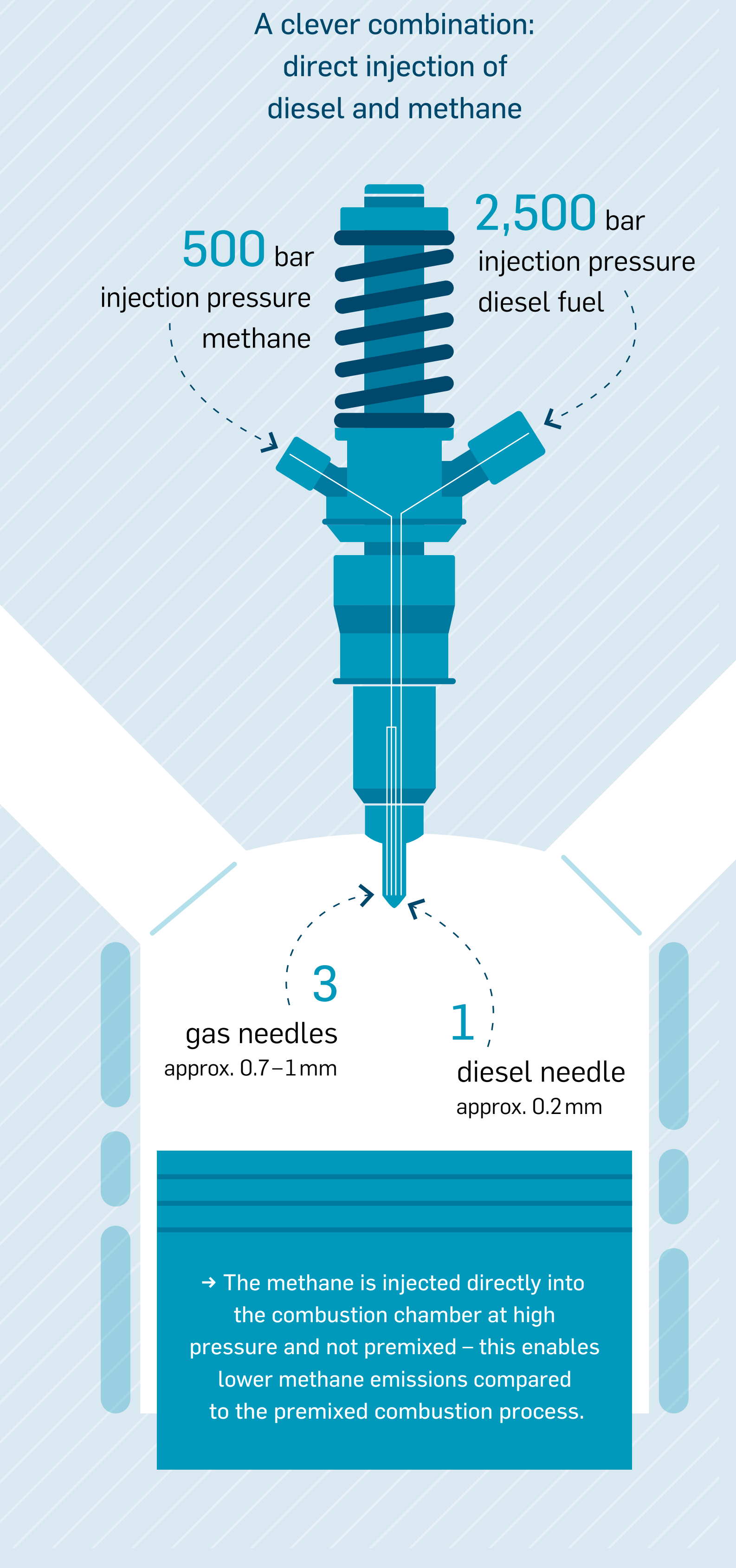
Gas engines can play a significant role in achieving the climate goals – if methane slip can be successfully avoided. In an FVV project, researchers from Zurich and Munich investigated a new gas-diesel combustion process with this aim in mind.

Gas-diesel combustion process // In the field of engine development, there is seldom the opportunity to save large amounts of CO_2 with a single process. Gas engines have the potential to do just this: if an injection and combustion process similar to that of a diesel engine can be realised, a gas engine would emit around a third less CO_2 per kilowatt hour of mechanical energy in total. In addition, performance could be increased, as the process similar to diesel is not naturally limited by uncontrolled auto-ignition. However, the conditional tense is no accident: due to the complexity of the process, it is not easy to bring high-pressure gas injection for gas engines to commercial maturity.

While gas engines in cars are conventionally realised on the basis of spark-ignition engines, a process similar to diesel is suitable for large and stationary engines – which enables a degree of efficiency of almost 50 %. A further advantage of the diesel-like process is that, in contrast to the process used in spark-ignition engines, hardly any unburned methane is produced. It is essential to prevent this material escaping into the atmosphere, as methane is a greenhouse gas 30 times as potent as CO_2.

However, there is still a lack of basic understanding of the injection, ignition and combustion procedure. In the recently completed FVV project on a gas-diesel combustion process, researchers from ETH Zurich and Universität der Bundeswehr München (UniBw Munich) jointly developed simulation methods and validated them in experiments.

»Our task was to use experimental and numerical techniques to find out exactly what happens in the combustion chamber, how the gas jet spreads out, mixes with air and ignites, and whether methane condenses at the nozzle exit,« explains Prof. Dr. Konstantinos Boulouchos, Head of the Aerothermochemistry and Combustion Systems Laboratory at ETH Zurich. In collabora-



tion with UniBw Munich, the aim was to validate the developed flow simulation tools in order to predict how a high-pressure injection procedure for gas engines can be realised.

At the Institute of Energy Technology at ETH Zurich, a number of test devices allow engine-like conditions to be created. In a heated constant volume chamber, temperatures and pressure can be approximately simulated in the manner in which they would occur in a diesel engine. The project partner Woodward L'Orange from Stuttgart provided prototype injectors. These are significantly different to those used in a diesel engine: nozzle design for gas engines is generally much simpler, as there are no cavitation phenomena. »But because the methane is ignited by a further diesel injector that is integrated with the gas nozzles in a housing during the gas-diesel combustion process, the injector as a whole is relatively complex,« reports Dr. Michael Willmann, Senior Manager New Technologies at Woodward L'Orange and Chair of the FVV research project. The simulation results gained during the project are being incorporated in design models, enabling future injectors working according to this functional principle to be designed even more effectively and allowing us to better understand combustion results.

The researchers in Zurich and Munich experimented with different injection pressures and durations, as well as various compression ratios. »The special thing about the chamber is that we have an optical port with which we can observe the dispersion of the gas in the combustion chamber, among other things,« comments Professor Boulouchos. To this end, the researchers used various procedures. The schlieren technique makes it possible to see how far the gas jet goes and how the gas spreads out in the combustion chamber. This qualitative method is based on the density gradient of the working medium – because the gas has a different density to air, the dispersion of the gas jet is visible.

The experts need a laser-based measuring procedure to quantitatively detect the concentration of methane within the gas jet. Stimulated by the laser, the methane fluoresces and the signal is picked up by a camera with a high spatial and temporal resolution. In addition, using the Mie scattering method, in which the scattered light of droplets is detected, the researchers investigated whether methane condenses. Comprehensive simulations on this had already been conducted at UniBW Munich. Here it became apparent that methane can condense to a liquid state under certain conditions, such as low pressure and temperature. »But would it also happen in an engine?« asks Professor Boulouchos, who immediately adds that droplets were no longer formed in the constant volume chamber under realistic conditions. »That answered the question for us: no condensation can be expected in engine applications,« states Boulouchos.

→ CO_2 is saved simply by switching from liquid fuel to methane.

–25 %
CO_2 emissions

→ If the thermodynamic potential of diesel is also used, gas engines achieve far higher degrees of efficiency.

Up to 50 %
efficiency

Project data

→ »Gas-Diesel Combustion [1236]: Improvement of understanding of penetration and ignition behaviour of high-pressure gas jets in Gas-Diesel combustion systems«

→ **PROJECT FUNDING**
€ 347,520 // FVV

→ **PLANNING GROUP**
PG 3 ›Combustion CI‹

→ **PROJECT COORDINATOR**
Dr. Michael Willmann, Woodward L'Orange

→ **RTD PERFORMERS**
Institute of Energy Technology (IET), Aerothermochemistry and Combustion Systems Laboratory (LAV), ETH Zurich // Institute for Thermodynamics, Universität der Bundeswehr München (UniBw M)

Photo: B. Schneider, LAV | ETH Zurich

The experts at UniBw Munich simulated the process in the nozzle up to the area close to the nozzle in the combustion chamber. Supersonic flows occur here when the gas is injected at up to 500 bar and the counterpressure in the cylinder is only 100 bar. In addition, methane does not behave as an ideal gas under these conditions – but rather as a real gas, which necessitates new simulation models. ETH Zurich was responsible for both the experiment and the modelling of the ignition. Methane is difficult to ignite and requires an additional ignition source. However, the classic spark plug is not an ideal solution, as the spark cannot be maintained for long enough at the extremely high gas speeds. »The question for a future research project is therefore how gas can best be ignited,« concludes Boulouchos. //

Continuity

Since earning his doctorate with an FVV project, **Dr. Christian Weiskirch** has enjoyed a successful career. Today he coordinates the powertrain development of a large commercial vehicle group – and continues to work for the research association.

Photos: Dirk Lässig

Patiently creating space for something new // Sometimes there is one decisive moment, and sometimes there isn't. In that case, things develop gradually and at some point, the next step seems obvious. Even in his youth, Christian Weiskirch programmed in BASIC and Turbo Pascal, but also enjoyed picking up a screwdriver and tuning bikes and mopeds, as well as the family's lawnmower. His father let him take care of the house electrical system, even though the main fuse blew several times. He knew he wanted to be an engineer even before he took his university entrance exams. He chose to study precision engineering at the TU Braunschweig. After gaining his intermediate diploma, Christian Weiskirch worked as a scientific assistant at the National Metrology Institute of Germany (PTB), programmed on behalf of a doctoral candidate and developed an optical micro-sensor as a course assignment, with which he aimed to measure the shape of injector bores – thereby coming into contact with compression-ignition engines for the first time.

»I benefited a great deal from the FVV as a young engineer.«

In his main course of study, Weiskirch increasingly focussed on engines, examined the size distribution of exhaust particles and ultimately decided to write a thesis investigating the ignition aspects of homogeneous diesel combustion. Eckart Müller, who was head of the institute, supported the young engineer but retired in 2003, when Weiskirch was still in the middle of his doctoral project. His position remained vacant until the appointment of Peter Eilts in 2007. Weiskirch acted as deputy for the temporary head, gathering his first management experience alongside his research. »I was really jumping into the deep end,« states Weiskirch. By the time Eilts arrived, the institute was in a good position, as both the number of scientific staff members and the budget of third-party funds had doubled.

Weiskirch earned his doctorate with an FVV project for reducing emissions through homogeneous diesel combustion. It became apparent that a variable compression ratio is required in order to achieve a stable, homogeneous combustion process in a large load range. He encouraged one of his student employees to equip the single-cylinder research engine with a fully variable valve train – and the engine is still used in different research projects today. Further developments were initiated over the years, with the FVV project being split into a part for cars and a part for commercial vehicles. Discussions in both working groups gave Weiskirch an insight into the two sectors: »The commercial vehicle developers discussed our results far more intensively,« he remembers. »The focus was purely on technology and not on company politics.« Most importantly of all, Weiskirch became a father for the first time during this period. As a father, he realised that he did not want to remain at the university.

He received an offer from IAV, which was expanding its commercial vehicles segment, at just the right time. In 2008, Weiskirch became team leader for the application of exhaust emission control systems for commercial vehicles. The Euro V emission standard had just been introduced for heavy trucks and exhaust emission control systems based on SCR catalysts were becoming the industry standard, yet some actors still relied solely on exhaust gas recirculation. It took another four years until the Euro VI emission standard became mandatory for heavy trucks. This reduced the limit values for particles by two thirds, and by 80 % for nitrogen oxides. Weiskirch and his colleagues picked up an important Euro VI project at MAN: the large new six-cylinder engines needed to be made ready for the next stage. After a bumpy start, a good collaboration blossomed between IAV and MAN until ultimately the question arose as to whether Weiskirch wanted to join the customer as a department head – a step he took in early 2012. In the subsequent years Weiskirch not only tackled the further tightening of the emission standard, but also addressed the issue that, although engines were becoming ever cleaner, only minor progress was being made in terms of fuel consumption. Weiskirch solved this problem by introducing heavy-duty steel pistons, among other steps.

He also took up his current post without having to write an application. In 2015, Volkswagen integrated the MAN and Scania brands to form a single commercial vehicle group, TRATON. The supervisory board drove forward cooperation talks, among other things regarding the successor to the top-tier 13-litre engine. Weiskirch was a part of the team from the very beginning and quickly established a rapport with his Swedish colleagues, even though there was initially a great deal of mistrust in both companies. »We have always had a rational dialogue among engineers and taken one another seriously.« Weiskirch was appointed to the CTO office of the new TRATON GROUP at the beginning of 2018. With a handful of employees he coordinates development activities for the entire powertrain – including new topics such as batteries and fuel cells. For more than two years, Weiskirch worked in Södertälje, a small industrial city south-west of Stockholm where Scania has its headquarters, before returning to Germany.

In the FVV, Weiskirch heads the Combustion CI planning group. When asked why he does not delegate his commitment in the FVV despite his career, he responds without hesitation: »I benefited a great deal from the FVV as a young engineer, so it is quite logical to give something back.«

DR.-ING. CHRISTIAN WEISKIRCH,
was born in 1975 and has been coordinating powertrain development at the TRATON GROUP since 2018. The mechanical engineer earned his doctorate with an FVV project at TU Braunschweig and today heads FVV's ›Combustion CI‹ planning group on a voluntary basis.

→ Christian Weiskirch's sons learn what a twin carburettor is at the garage at home: the three are working together to restore a Karman T34.

It is this continuity, or maybe just consistency, that is a common thread though every area of Weiskirch's life. He met his wife, an architect, in 1994, in the summer after his university entrance exams. The couple and their two sons live in a house designed by his wife in Altdorf near Nuremberg. However, continuity can also open up new possibilities, as evidenced by the innovative heating system at their home: the HVAC system is not powered with fossil fuels, but by means of a heat pump, heat exchangers and an ice bank. //

One **for all!**

If fuel cells are to have a chance in the race to be the powertrain of the future, all components and sub-systems need further optimisation. So far, however, there has been no universal research platform. This has now moved one step closer with the concept for a generic fuel cell stack developed on behalf of the FVV.

→ Dr. Joachim Scholta is head of the Fuel Cell Stacks department at the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) in Ulm.

Development of a generic fuel cell stack // 100 kilowatts of power from 304 cells and an active surface of 280 square centimetres on each cell. These figures might sound like the rules of a game, but they are actually the partial results of a fundamental research project that aims to help the fuel cell make the breakthrough in the mobility sector. Commissioned by the FVV, the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) developed the design concept for a generic fuel cell stack. The stack is needed as a research and test platform, as the fuel cell – or, specifically, the low-temperature polymer electrolyte membrane fuel cell used as a vehicle powertrain – needs to be far more cost-efficient in order to succeed in the market. To this end, the performance output per cell needs to be increased further.

»This is not just an issue regarding the cells themselves,« explains Dr. Joachim Scholta, who is responsible for the Fuel Cell Stacks department of the ZSW. »It requires the entire system to be optimised.« After all, combustion engines, too, achieve their high power density not only from optimised combustion in the cylinder, but also through carburation which has been refined over decades, especially regarding turbocharging and injection.

A fuel cell engine comprises similarly complex subsystems, for example to compress or humidify the feed air. Although the often-used collective term of ›peripheral systems‹ makes them sound marginal, they have a decisive impact not only on the performance of the cells, but also on their life cycles. As such, unequal hydrogen distribution across the cell membranes can result in premature ageing. Pollutants in the intake air also cause the catalyst material – usually platinum – to degrade prematurely. Greater knowledge of the relationship between pollutant input, filtration and ageing behaviour could help to reduce the amount of the precious metal needed. The problem when developing filters, compressors and other components is that testing has previously generally only been performed on commercially available fuel cell systems. For competitive reasons, the manufacturers of these systems often do not provide details on the system specifications, for example the materials used in the cells. As a result, individual test results are often not applicable for further research. This is exactly the problem the research project, sponsored by the FVV, aims to solve.

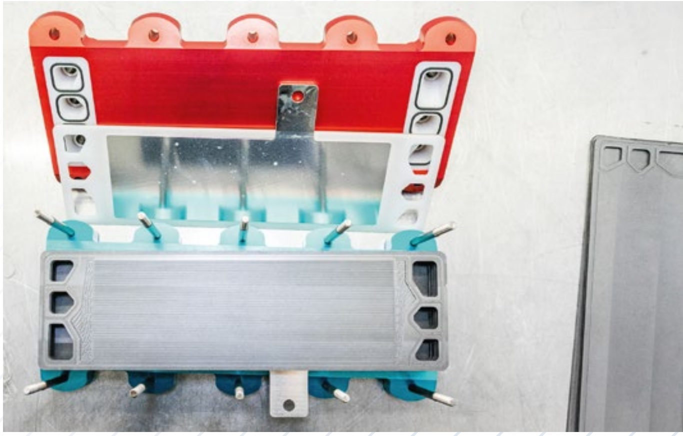
»With a generic stack, fundamental phenomena can be investigated in a reproducible way,« comments Dr. Jan Haußmann from Schaeffler, who led the accompanying working group. As is typical for the work of the FVV, the working group did not simply let the Ulm researchers start developing, but instead incorporated the view of the industry that was to use the technology at a later stage. Accordingly, a basic question had to be answered first – what performance and dimensions are required of a low-temperature fuel cell if it is to cover as many applications as possible later? The researchers initially conducted a survey of the FVV member companies to gauge opinions, which were then discussed intensively in the working group. It quickly became clear that the high level of power density required can only be achieved with metallic bipolar plates. Another advantage of these plates over the graphite plates also investigated at the beginning is that they can be manufactured in a forming process, thus enabling short cycle times in later series production.

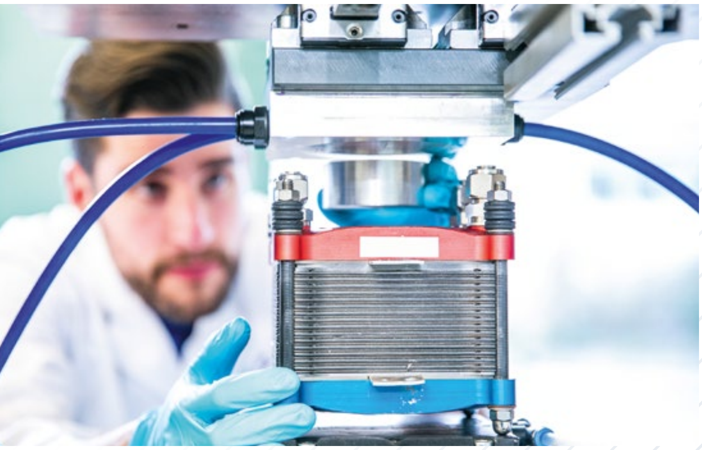
After making this fundamental decision, the ZSW developed a design concept that, for example, defines the active surface area per cell. The concept was then successfully validated on the basis of initial simulations – such as the flow in a single cell. »A certain level of robustness was important to us,« explains Scholta, »because the unit needs to withstand a great deal later on in long test series.« The complete design of a generic stack is the subject of a planned follow-up project. If everything goes well, a first prototype could be available as early as the start of 2022.

However, this will need to be tested thoroughly. From 2023, the researcher hopes that a generic stack will be available for all research on the system behaviour of fuel cells. »The stack will then be just as important as the single-cylinder research engine is at the institutes for combustion engines,« adds Scholta. It will be ready just in time to accompany the fuel cell on its journey from small to large series. Dr. Scholta, who has been researching fuel cells for 30 years, is certain that ›cold‹ hydrogen combustion in the low-temperature cell will be an important technology in the future. He regularly drives fuel cell vehicles and refills them at a fuel pump in front of his institute. »It is all completely unspectacular,« praises the physicist. »The technology works, it is just too expensive right now.« But this could change very soon. //

»The stack will be just as important as the single-cylinder research engine is at the institutes for combustion engines.«

30 years of experience, more than 1,000 stacks – fuel cell research at the ZSW.



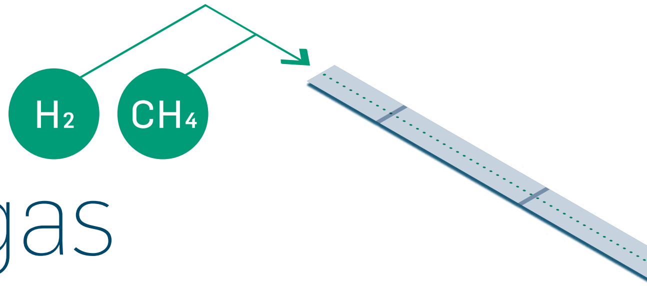


Project data

- » Generic Fuel Cell Stack [1366]: Development of a generic fuel cell as a test platform for automotive applications for executing pre-competitive fundamental research on PEM fuel cells in mobile use «
- **PROJECT FUNDING**
  € 100,000 // FVV
- **PLANNING GROUP**
  PG 7 ›Fuel Cells‹
- **PROJECT COORDINATOR**
  Dr. Jan Haußmann, Schaeffler Technologies
- **RTD PERFORMER**
  Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW)

VIDEO ABOUT THE PROJECT

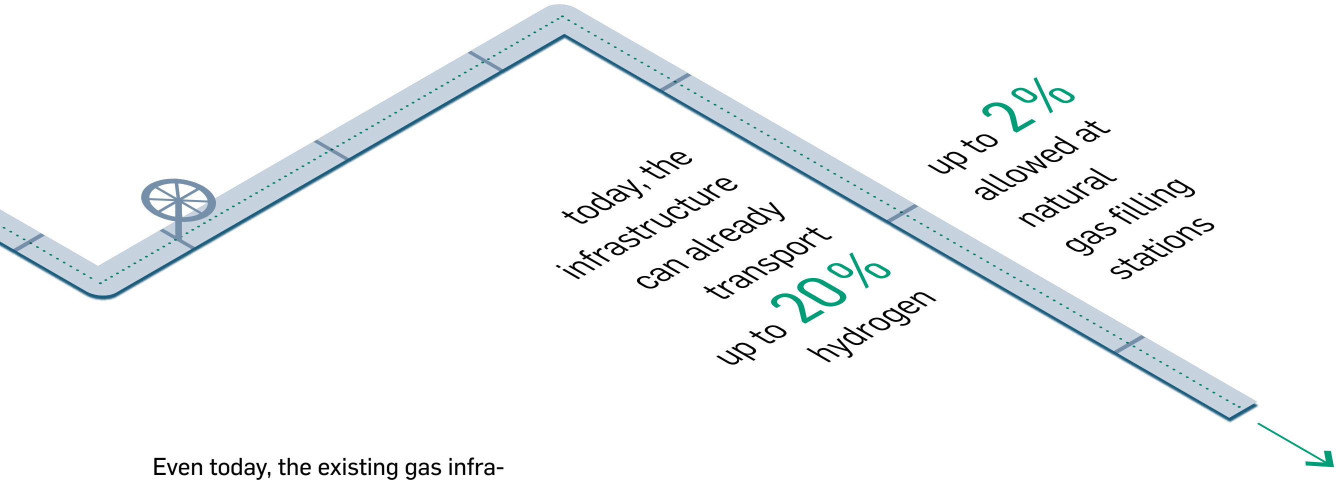
A new mix in the gas network



Hydrogen will play a decisive role in achieving the climate goals. A joint project initiated by the FVV with the German Association for Gas and Water (DVGW) investigates how the gas can be integrated in the existing natural gas infrastructure.

H_2 in the gas network // Whether in steel, chemicals or transport, hydrogen plays an important role in the future scenarios of a carbon-neutral industrial society. In the ›H_2 in the Gas Network‹ project initiated in early 2020, researchers have been investigating how a higher concentration of hydrogen in gas affects both the mobility sector and stationary gas engines, such as those used in combined heat and power plants. The starting point was the question as to how the existing gas network would need to be adapted to allow hydrogen to be mixed in. After all, hydrogen is corrosive and can damage seals and valves if they are not designed for high concentrations of H_2. While new pipelines are already ›H_2-ready‹, the existing gas infrastructure, such as compressors and reservoirs, needs to be modernised in a number of places. However, it is not only the technical side from the supplier's point of view that is relevant. »The customer will gain a completely new energy carrier – no longer methane, or natural gas, but a mixture containing hydrogen,« explains Dr. Dietrich Gerstein from the DVGW. A switchover would therefore have an impact on private households with gas heating, combined heat and power plants and the mobility sector.

As a first step, the experts want to determine the maximum possible hydrogen concentration in the gas network. Gerstein believes that the concentration will initially be increased in small increments without any significant modifications, to a 5, 8 or 10 % share of hydrogen in natural gas. In the future, however, it needs to be determined how far the hydrogen content can be raised in the network and for the consumers. In the project, the researchers assume that the H_2 level will fluctuate. »There can also be regional differences, such as if more hydrogen is produced in northern Germany through wind energy, which is then fed into the network,« explains Gerstein.



Even today, the existing gas infrastructure could transport up to 20 % H_2. However, not all natural gas engines are suitable for operation with hydrogen. In individual cases, compatibility with a hydrogen component of up to 100 % was demonstrated. »But the question is how to bring about compatibility for dynamically fluctuating hydrogen contents and for the entire fleet,« explains Georg Blesinger from the Institute for Internal Combustion Engines (IFKM) at the Karlsruhe Institute of Technology (KIT). In collaboration with the Institute for Thermal Energy Technology and Safety at the KIT, Blesinger is performing a risk and status analysis within the scope of the project. After all, there are a number of challenges: hydrogen attacks rubber and plastic parts, and even high-alloy steels, as used in valve seats and elsewhere, are not suitable for this application. Moreover, the gas is extremely flammable and burns five times as quickly as methane. As a result, there is a particularly high risk of pre-ignition and knocking. Under certain conditions, flashback into the intake area can even occur during gas exchange. However, IKFM head Prof. Dr. Thomas Koch is convinced that the challenges can be overcome.

In the future, vehicles running on natural gas could be filled with the H_2 / CH_4 mixture at natural gas filling stations. The proportion of hydrogen there currently cannot exceed 2 %, as the tanks of natural gas vehicles are not approved for higher concentrations. If necessary, the hydrogen could be separated from the natural gas again at the filling station if it is to be stored and not burned as a mixture. »If the gas network is suitable for transporting hydrogen in the future, there will also be sufficient storage options,« comments a convinced Gerstein.

The DVGW expert believes that a considerable hydrogen production infrastructure could be established in Germany within five to ten years. Above all, this requires the political will and the right framework conditions. Gerstein feels that the recently published hydrogen strategy is a big step in the right direction. Indeed, the technology is already available:

there are already pilot power-to-gas plants in which electrolysis is used to convert wind and solar energy into ›green‹ hydrogen, which is then fed into the network. However, these smaller plants are not sufficient to supply the gas nationwide. Therefore, the German federal government plans to import hydrogen from North Africa, where, with solar energy and low electricity costs, the gas can be produced much more cheaply than in Germany.

It is not only the technical aspects that determine long-term success: an economic perspective is also important. The switch to a higher share of hydrogen would likely be profitable in spite of the high costs, reports Gerstein: »If we had to build power lines to transport the same amount of energy, it would be much more expensive. Also, far more energy can be stored in the gas network than in power stores.«

The project has a planned duration of two years and focusses on Germany. However, scenarios for Europe are also being considered. Although vehicles with gas engines are very much a niche in Germany, a glance at the rest of Europe reveals the potential they hold: in Italy, ten times as many natural gas vehicles are registered as in Germany. //

3 months
storage duration in gas reservoirs at a maximum load of 85 GW

→ only 36 minutes in power stores

220 TWh
storage capacity in gas network and infrastructure

→ only 0.04 TWh in all power stores

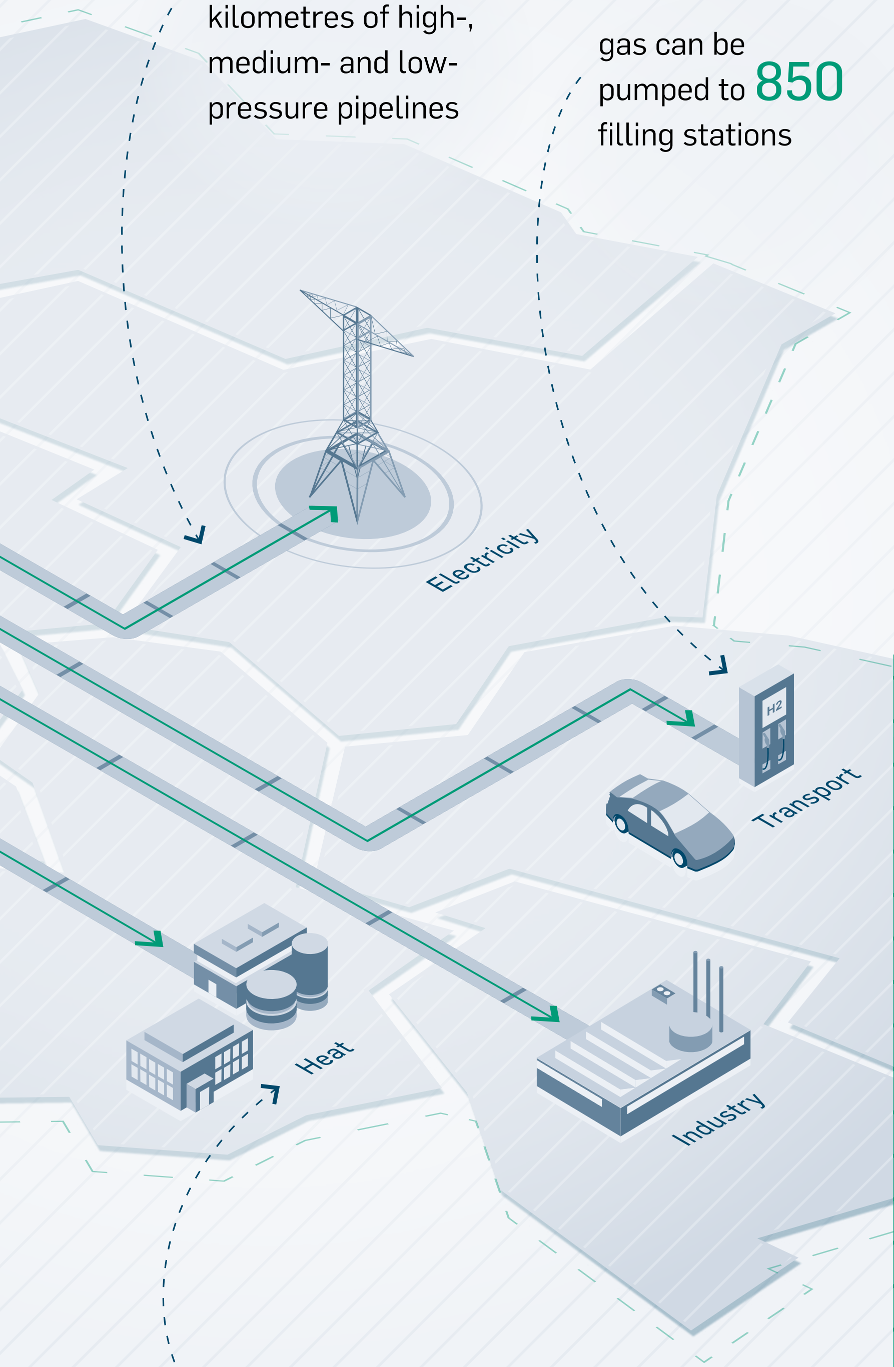
510,000
kilometres of high-, medium- and low-pressure pipelines

gas can be pumped to **850** filling stations

Potential of the gas infrastructure in Germany

→ In power-to-gas plants, electricity from renewable sources is used to generate hydrogen or methane – which can then be stored and transported.

→ The **›green gases‹** can be used via the existing infrastructure.



Every **2nd** household in Germany uses natural gas for heating

Project data

→ »H_2 in the Gas Network [1384]: Development of a market ramp-up for increasing the hydrogen concentration in the gas network // Description of solution approaches in the gas and automotive industries for preserving the integrity of CNG engines and their economic assessment«

→ **PROJECT FUNDING**
€ 560,000 // DVGW, FVV

→ **PLANNING GROUP**
PG 1 ›System‹

→ **PROJECT MANAGEMENT**
Dr. Dietrich Gerstein, DVGW
Dr. Ulrich Kramer, Ford-Werke

→ **RTD PERFORMERS**
Institute for Internal Combustion Engines (IFKM), Karlsruhe Institute of Technology (KIT) // DBI Gas- und Umwelttechnik // Test Laboratory Gas, DVGW Research Centre at Engler-Bunte Institute at the Karlsruhe Institute of Technology (KIT) // Frontier Economics

We at the FVV are a very lively research network. Cooperation, trust and openness are the key to our success. Creative ideas and dedicated people ensure the lasting benefit of this research network. In the projects we conduct together, we value the constructive cooperation of all network partners and, in particular, the excellence of our RTD performers. That is why we actively pursue collaboration with partners who share our ideas and goals.

The people and projects we have presented in this annual magazine are only a small sample of what makes the FVV as a whole special. Therefore, we would like to take this opportunity to say THANK YOU to our excellent network!

We usually meet in person at the FVV conferences. In 2020, unfortunately, you will receive this annual magazine by post. But please make a note of the following dates for 2021:

Spring – 25 / 26 March 2021

Autumn – 28 / 29 September 2021

See you there!

Photos:
FVV Autumn Conference, September 2019

Ideas sometimes need time and a fertile place to grow. Such as our meetings and conferences.

Face-to-face discussions between manufacturers and suppliers, designers and scientists, leading engineers from industry, renowned researchers and outstanding young talents from Germany, Europe and around the world not only promote mutual understanding, but also ensure a swift and efficient transfer of research results from science to industrial practice.

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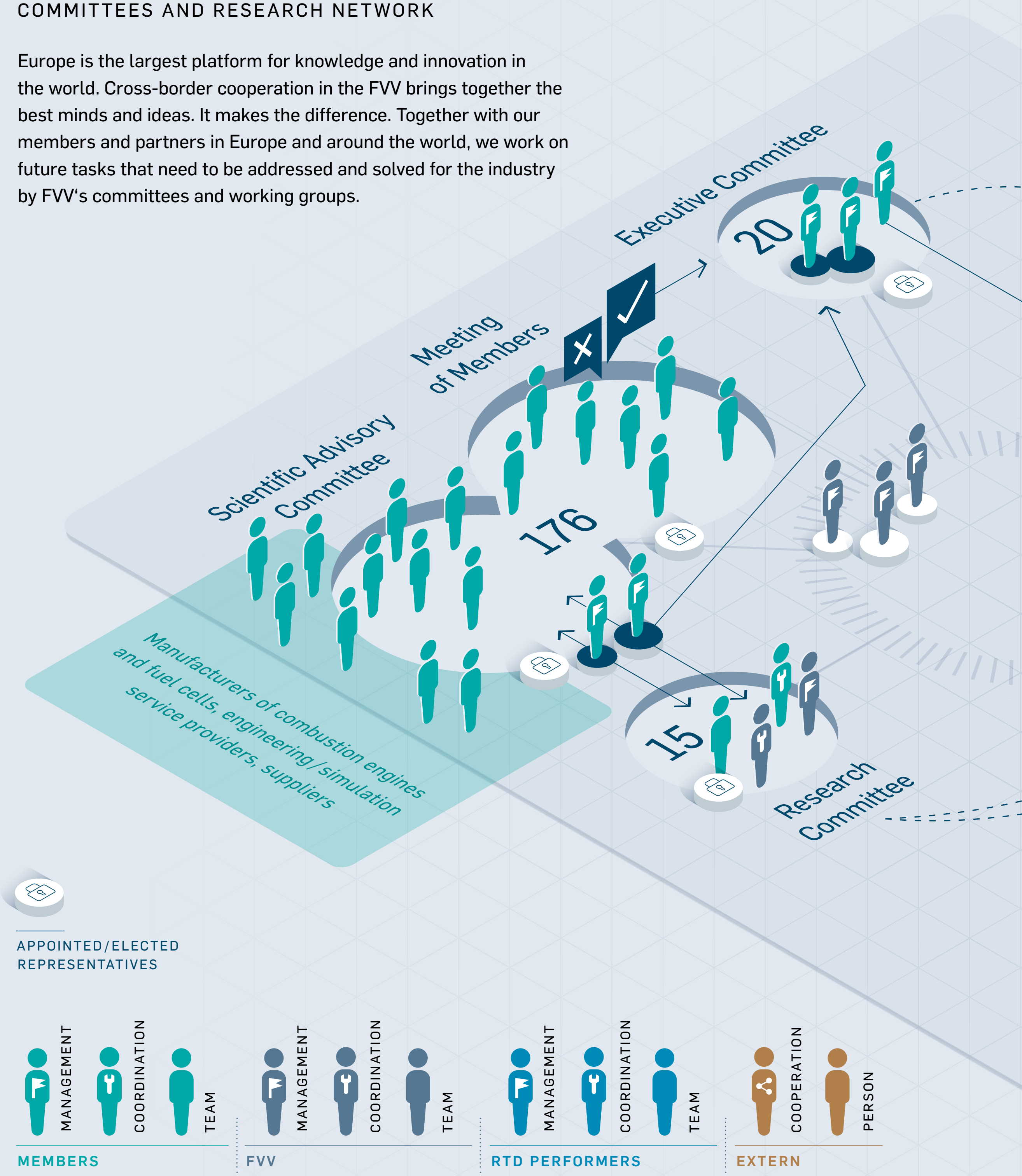
2019/2020

FVV

Structure of the association

COMMITTEES AND RESEARCH NETWORK

Europe is the largest platform for knowledge and innovation in the world. Cross-border cooperation in the FVV brings together the best minds and ideas. It makes the difference. Together with our members and partners in Europe and around the world, we work on future tasks that need to be addressed and solved for the industry by FVV's committees and working groups.



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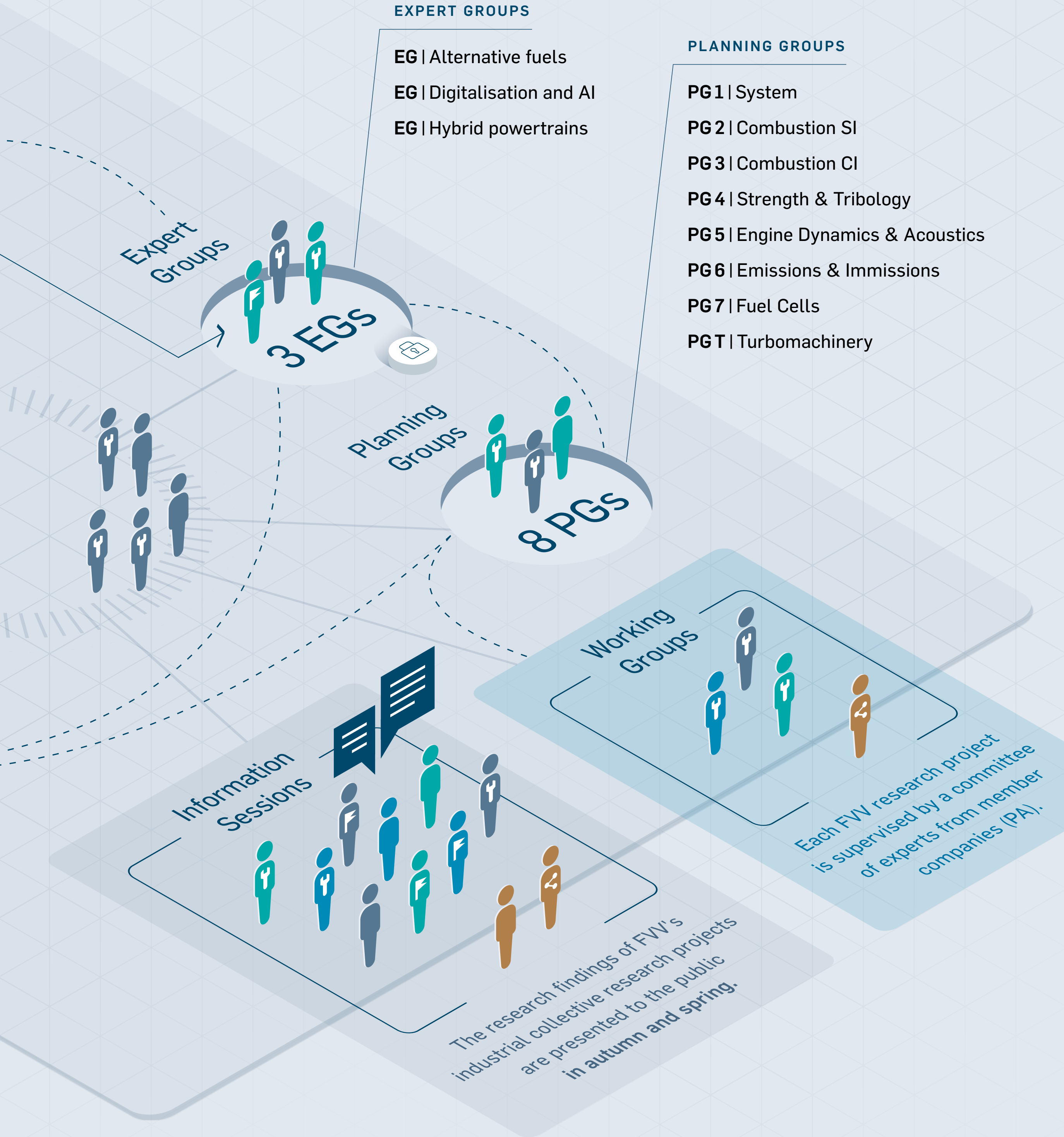

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↑ new member ↓ resigned member

	COMPANY	LOCATION (HEADQUARTERS)	REPRESENTATIVE (SCIENTIFIC ADVISORY COMMITTEE)
	INNIO Jenbacher GmbH & Co. OG	Jenbach (AT)	Dr. Stephan Laiminger
	INPROSIM GmbH	Kriftel	Hartmut Chladek
	Interkat Catalyst GmbH	Königswinter	Dr. Jörg Spengler
	INTES GmbH	Stuttgart	Dr. Reinhard Helfrich
	ISimQ GmbH	Warngau	Dr. Georg Scheuerer
	IST GmbH	Aachen	Dr. Jochen Lang
	ISUZU MOTORS Germany GmbH	Ginsheim-Gustavsburg	Ottmar Degrell
	↓ **iwis Motorsysteme GmbH & Co. KG**	München	
J	Johnson Matthey GmbH & Co. KG	Sulzbach	Dr. Claus Görsmann
K	Karl Dungs GmbH & Co. KG	Urbach	Karl Dungs, Peter Meijer
	↑ **KEYOU GmbH**	Unterschleißheim	Thomas Ebert
	Kingsbury GmbH	Göttingen	Dr. Morched Medhioub
	Kistler Erkelenz GmbH	Erkelenz	Dr. Frank Wytrykus
	Kistler Instrumente AG	Winterthur (CH)	Dr. Dieter Karst, Jürg Stadler
	KIT Campus Transfer GmbH	Karlsruhe	Dr. Olaf Toedter
	↑ **Kolben Seeger GmbH & Co. KG**	Steinbach	Dr. Dirk Bergmann
	Kompressorenbau Bannewitz GmbH	Bannewitz	Dr. Ingolf Lehmann
	KRATZER AUTOMATION AG	Unterschleißheim	Detlef Naundorf
	KST Motorenversuch GmbH & Co. KG	Bad Dürkheim	Anton Feil
L	LaVision GmbH	Göttingen	Dr. Joachim Deppe, Dr. Heinrich Voges
	LEC GmbH	Graz (AT)	Dr. Gerhard Pirker, Prof. Dr. Andreas Wimmer
	Liebherr Machines Bulle SA	Bulle (CH)	Dr. Bouzid Seba
	LOGE Deutschland GmbH	Cottbus	Vivien Günther
	Lubrisense GmbH	Hamburg	Dr. Sven Krause
M	M. JÜRGENSEN GmbH & Co KG	Sörup	Dr. Tobias C. Wesnigk
	MAHLE Behr GmbH & Co. KG	Stuttgart	Dr. Eberhard Pantow
	MAHLE International GmbH	Stuttgart	Rudolf Freier
	Main-Metall Tribologie GmbH	Altenglan	Wladimir Buchbinder, Erik Gutwein
	MAN Energy Solutions SE	Augsburg	Dr. Alexander Knafl, Dr. Thomas Polklas

	COMPANY	LOCATION (HEADQUARTERS)	REPRESENTATIVE (SCIENTIFIC ADVISORY COMMITTEE)
	MAN Truck & Bus SE	München	Norbert Schatz
	MANN+HUMMEL GmbH	Ludwigsburg	Markus Kolczyk
	Maschinenfabrik Guido GmbH	Neutraubling	Hans-Jürgen Guido
	MET GmbH	Rostock	Prof. Dr. Siegfried Bludszuweit
	Metal Improvement Company LLC	Unna	Oliver Schuchardt
	MIBA Gleitlager Austria GmbH	Laakirchen (AT)	Dr. Rainer Aufischer
	Miba Industrial Bearings Germany GmbH	Göttingen	Stephan Faulhaber
	Modine Europe GmbH	Filderstadt	Dr. Martin Wierse
	MOT Forschungs- und Entwicklungsgesellschaft für Motorentechnik, Optik und Thermodynamik mbH	Karlsruhe	Ralf Kloiber
	Motorenfabrik Hatz GmbH & Co. KG	Ruhstorf	Dr. Simon Thierfelder
	MTU Aero Engines AG	München	Dr. Gerhard Ebenhoch, Dr. Martin Metscher
	MULTITORCH GmbH	Sinsheim	Dr. Christiane Kuhnert
N	NEMAK Europe GmbH	Frankfurt am Main	Dirk Ragus
	↑ nexiss GmbH	Darmstadt	Dr. Markus Kaiser
	NGK Europe GmbH	Kronberg	Claus-Dieter Vogt
	Nissan Motor Co., Ltd.	Kanagawa (JP)	Dr. Toru Noda
	NOVA WERKE AG	Effretikon (CH)	Kurt Brüngger
	NUMECA – Ingenieurbüro Dr.-Ing. Th. Hildebrandt	Altdorf	Dr. Thomas Hildebrandt
O	↑ OMEGA RENK BEARINGS PVT. LTD.	Bhopal (IN)	Manbendra Bhakta
	Opel Automobile GmbH	Rüsselsheim am Main	Achim Königstein
P	Pankl Turbosystems GmbH	Mannheim	Rodrigo Costa
	Piller Blowers und Compressors GmbH	Moringen	Daniel Muth
	Prins Autogassystemen B.V.	Eindhoven (NL)	Bart Van Aerle
R	regineering GmbH	Pollenfeld	Stefan Innerhofer
	Rheinmetall Automotive AG	Neuss	Heinrich Dismon
	Ricardo Deutschland GmbH	Schwäbisch Gmünd	Dr. Simon P. Edwards
	Robert Bosch GmbH	Stuttgart	Dr. Andreas Kufferath
	Rolls-Royce Deutschland Ltd. & Co. KG	Oberursel	Dr. Dirk Hilberg
	Rolls-Royce Solutions GmbH	Friedrichshafen	Dr. Johannes Kech, Dr. Jürgen Salm
	RTA GmbH	St. Aegyd (AT)	Frank Haas
S	Scania CV AB	Södertälje (SE)	Christian Vogelgsang

↑ new member ↓ resigned member

	COMPANY	LOCATION (HEADQUARTERS)	REPRESENTATIVE (SCIENTIFIC ADVISORY COMMITTEE)
	Schaeffler AG	Herzogenaurach	Dr. Martin Scheidt
	Schaeffler Engineering GmbH	Werdohl	Lars Pfützenreuter
	SEG Automotive Germany GmbH	Stuttgart	Dr. Dieter Eppinger
	Shell Global Solutions (Deutschland) GmbH	Hamburg	Dr. Ingo Mikulic
	Siemens AG	Duisburg	Olaf Bernstrauch
	Siemens Industry Software GmbH	Köln	Dr. Helge Tielbörger
	Steinbeis Transferzentrum Bauteilfestigkeit und -sicherheit, Werkstoff- und Fügetechnik (BWF)	Esslingen	Dr. Stephan Issler
	Subaru Corporation	Tokio (JP)	Daisuke Yamada
T	TEC4FUELS GmbH	Herzogenrath	Dr. Klaus Lucka
	Tenneco GmbH	Edenkoben	Frank Terres
	TheSys GmbH	Kirchentellinsfurt	Peter Ambros
	TOTAL Deutschland GmbH	Berlin	Peter Scholl
	Toyota Motor Corporation	Aichi (JP)	Ashish Kamat, Paul Decker-Brentano
	↓ **TTI Turbo Technik Innovation GmbH**	Remscheid	
	Turbo Science GmbH	Darmstadt	Dr. Sebastian Leichtfuß
U	Umicore AG & Co. KG	Hanau	Dr. Jürgen Gieshoff
V	VEMAC GmbH & Co. KG	Aachen	Axel Koblenz
	Vitesco Technologies Emitec GmbH	Lohmar	Rolf Brück
	Vitesco Technologies GmbH	Regensburg	Stephan Rebhan, Gerd Rösel
	Volkswagen AG	Wolfsburg	Dr. Tobias Lösche-ter Horst
	Volvo Car Corporation	Göteborg (SE)	Dr. Frederik Ekström, Dr. Tomas Johannesson
	VOLVO Powertrain AB	Göteborg (SE)	Ulla Särnbratt
W	Winterthur Gas & Diesel Ltd.	Winterthur (CH)	Dr. Wolfgang Östreicher
	Woodward L'Orange GmbH	Stuttgart	Dr. Andreas Lingens
	WTZ Motorentechnik GmbH	Dessau-Roßlau	Dr. Christian Reiser
Z	ZF Friedrichshafen AG	Schweinfurt	Arne Temp

Committees

EXECUTIVE COMMITTEE AND MANAGEMENT

EXECUTIVE COMMITTEE (2020 – 2021)		
REPRESENTATIVE	**COMPANY**	**LOCATION** (HEADQUARTERS)
Prof. Dr. Peter Gutzmer, ***President***	Schaeffler Technologies AG & Co. KG	Herzogenaurach
Christopher Steinwachs, ***Deputy President***	Siemens AG	Duisburg
Prof. Dr. Burkhard Göschel, ***Honorary President***		
Dr. Tobias Lösche-ter Horst, ***Chairman of the Scientific Advisory Committee***	Volkswagen AG	Wolfsburg
Dr. Elmar Böckenhoff	Daimler Truck AG	Stuttgart
Karl Dums	Dr. Ing. h.c. F. Porsche AG	Weissach
Carsten Helbing	Volkswagen AG	Wolfsburg
Dr. Jörg Henne	MTU Aero Engines AG	München
Dr. Thomas Johnen	Opel Automobile GmbH	Rüsselsheim
Dr. Evangelos Karvounis	Ford-Werke GmbH	Köln
Matthias Kratzsch	IAV GmbH	Berlin
Dr. Michael Ladwig	GE Power AG	Mannheim
Dr. Rudolf Maier	Robert Bosch GmbH	Stuttgart
Dr. Markus Schwaderlapp	DEUTZ AG	Köln
Prof. Dr. Christian Schwarz	Bayerische Motorenwerke AG	München
Prof. Dr. Gunnar Stiesch	MAN Energy Solutions SE	Augsburg
Dr. Martin Teigeler	Rolls-Royce Power Systems AG	Friedrichshafen
Dr. Simon Thierfelder	Motorenfabrik Hatz GmbH & Co. KG	Ruhstorf
Dr. Peter Wehle	Rolls-Royce Deutschland Ltd. & Co. KG	Oberursel

MANAGEMENT

Dietmar Goericke, ***Managing Director***

Martin Nitsche, ***Deputy Managing Director***

Matthias Zelinger, ***Deputy Managing Director***

SCIENCE AND RESEARCH

SCIENTIFIC ADVISORY COMMITTEE

REPRESENTATIVE	COMPANY	LOCATION (HEADQUARTERS)
Dr. Tobias Lösche-ter Horst, ***Chairman***	Volkswagen AG	Wolfsburg
Dr. Dirk Hilberg, ***Deputy Chairman***	Rolls-Royce Deutschland Ltd. & Co. KG	Oberursel

For the list of members of the Scientific Advisory Committee, please refer to Members (pp. 68 to 73).

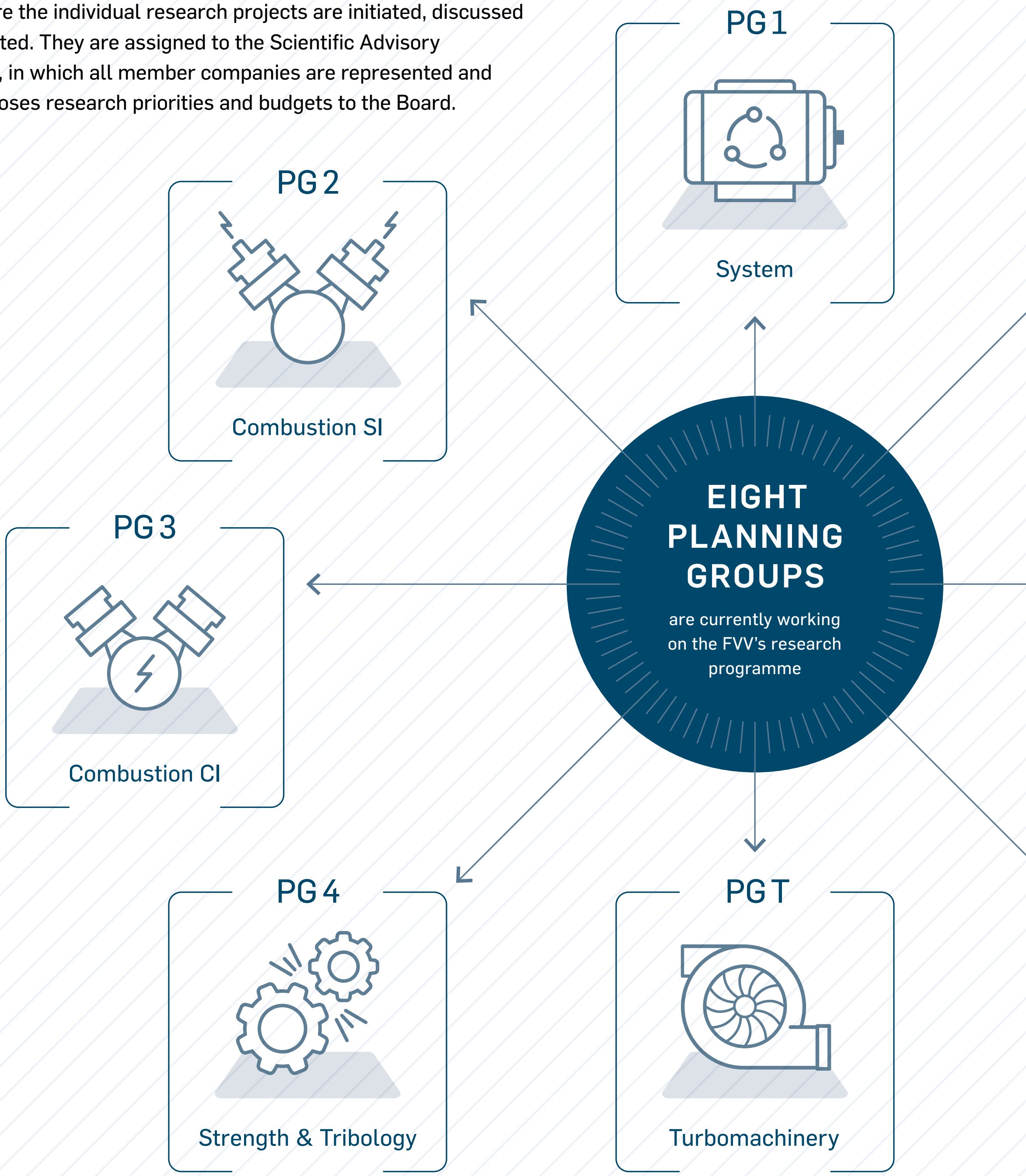
Research Committee

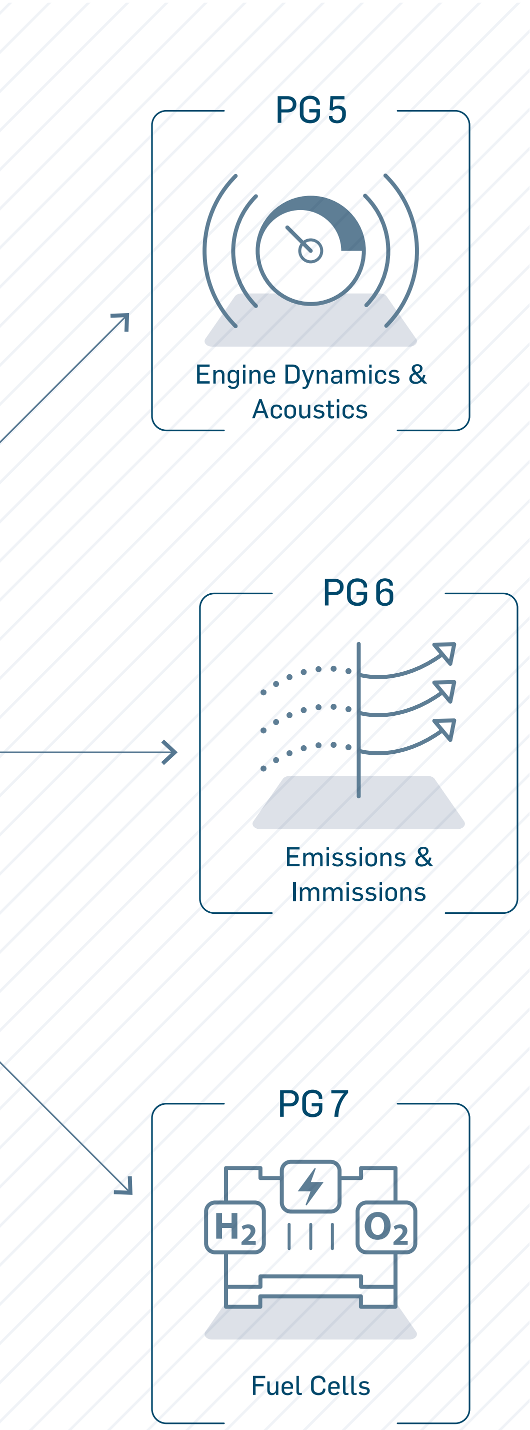
Prof. Dr. Christoph Brands	Schaeffler Technologies AG & Co. KG	Herzogenaurach
Paul Decker-Brentano	TOYOTA GAZOO Racing Europe GmbH	Köln
Dr. Bodo Durst (until 30.04.2020)	Bayerische Motorenwerke AG	München
Dr. Dieter Eppinger	SEG Automotive Germany GmbH	Schwieberdingen
Dr. Volker Formanski	Bayerische Motorenwerke AG	München
Prof. Dr. Uwe Gärtner	Daimler Truck AG	Stuttgart
Dr. Ulrich Kramer	Ford-Werke GmbH	Köln
Markus Kolczyk	MANN+HUMMEL GmbH	Ludwigsburg
Achim Königstein	Opel Automobile GmbH	Rüsselsheim
Dr. André Casal Kulzer	Dr. Ing. h.c. F. Porsche AG	Weissach
Dr. Andreas Kufferath	Robert Bosch GmbH	Stuttgart
Dr. Ekkehard Pott	Volkswagen AG	Wolfsburg
Dr. Peter Riegger	Rolls-Royce Solutions GmbH	Friedrichshafen
Marc Sens	IAV GmbH	Berlin
Dr. Christian Weiskirch	TRATON SE	München

Coordination and knowledge transfer

PLANNING GROUPS (PG)

The planning groups are the FVV's engine room:
this is where the individual research projects are initiated, discussed and supported. They are assigned to the Scientific Advisory Committee, in which all member companies are represented and which proposes research priorities and budgets to the Board.





THEMIS is the communication and knowledge platform for Industrial Collective Research (Industrielle Gemeinschaftsforschung – IGF) in the mechanical engineering industry. It contains the collected research knowledge from five research associations on the topics of mechanical and plant engineering / Industrie 4.0 (FKM), powertrain technology (FVA), construction equipment and building material machinery (FVB), air and drying technology (FLT) and combustion engines (FVV).

THEMIS enables more than 15,000 users, 6,000 of whom are members of the FVV research network, to exchange information on equal terms. Members can use the platform to jointly draw up ideas for new research projects, take part in project and committee work online, organise meetings and contacts, manage documents, access knowledge and connect with research partners.

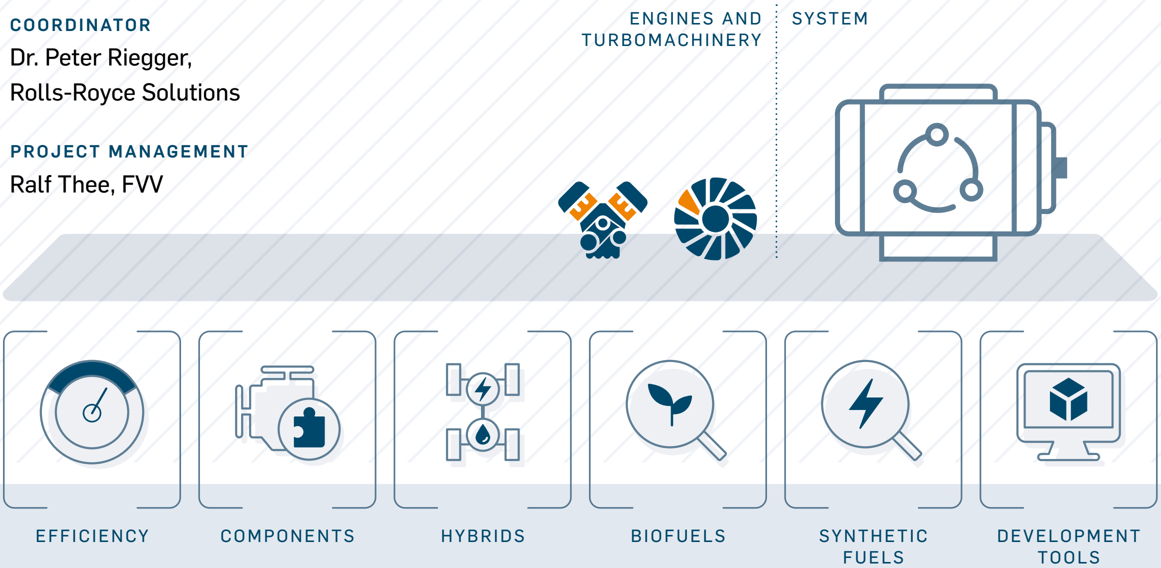
Here, members of the FVV research network will find all the relevant information on the current research programme, the planning groups and projects, and the latest news.

System

PLANNING GROUP 1

COORDINATOR
Dr. Peter Riegger,
Rolls-Royce Solutions

PROJECT MANAGEMENT
Ralf Thee, FVV



RESEARCH PRIORITIES

Planning group 1, ›System‹, is dedicated to the following topics:
Future engine concepts, hybridisation | Alternative fuels | Digitalisation in the powertrain | Life-cycle analyses

And tackles the following lines of research / focuses:
System analysis of new technologies, alternative powertrains and fuels | Recovering lost energy | (Ultra-low) temperature management | Control, regulation, sensors | Turbocharging | Large and nonroad engines

PUBLICATIONS

→ **ATZ heavyduty 01/2020:** Technical Evaluation and Life-Cycle Assessment of Long-haul Heavy-duty Vehicles in 2050

→ **MTZ worldwide 02/2020:** Extension of the Characteristic Map of a TC Compressor by active Cross-Section Variation

→ **MTZ worldwide 07-08/2019:** Thermochemical Heat Storage for Consumption Reduction in Internal Combustion Engines

→ **MTZ worldwide 05/2019:** Energy Paths for Road Transport in the Future

→ **FVV proceedings:** R587 | 2019 Spring Conference, R590 | 2019 Autumn Conference and R593 | 2020 Spring Conference

PG1 DATABASE

THEMIS

PG 1 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0320	Gas Engine Performance II	**Dr. Udo Schlemmer-Kelling,** FEV Europe
M0619	Zero Impact Vehicle Emissions (Conceptual Study)	**Prof. Dr. Kurt Kirsten,** APL
M0920	CO_2-neutral Long-haul Heavy-duty Powertrains 2050 II	**Herbert Schneider,** ISUZU MOTORS
M1320	NRMM, MD & HD Diesel Engines, In Field Operation, Emission Measurement	**Dr. Dirk Bergmann,** Kolben Seeger
M1818	Adaptive Semi-physical Combustion Control	**Stefan Lindner,** Opel
	Ongoing projects	
1305	Exhaust Gas Aftertreatment Before Turbine // FVV-EM // 01-05-2018 to 31-12-2020	**Dr. Frank Bunar,** IAV
1312	48V Mild Hybrid with Semi-Homogeneous Diesel Combustion // BMWi/AiF // 01-01-2018 to 30-09-2020	**Dr. Achim Lechmann,** IAV
1316	Exhaust Gas Composition at Low Temperatures // FVV-EM // 01-07-2018 to 31-10-2020	**Dr. Michael Becker,** Pierburg
1321	Working Cycle Dissolved Turbine Efficiency in Turbochargers // FVV-EM, DFG // 01-10-2018 to 31-03-2022	**Dr. Mathias Vogt,** IAV
1327	Lubrication Large Bore Engines // FVV-EM // 01-09-2018 to 31-10-2020	**Dr. Tobias C. Wesnigk,** M. JÜRGENSEN
1339	Calibration and Validation of Self-learning System Controllers // FVV-EM // 01-03-2019 to 28-02-2022	**Prof. Dr. Peter Prenninger,** AVL List
1342	Sensor Concept for E-Fuels // FVV-EM // 01-02-2019 to 28-02-2021	**Dr. Bernd Becker,** IAV
1355	Powertrain 2040 // FVV-EM // 01-04-2019 to 30-09-2021	**Dr. Thorsten Schnorbus,** FEV Europe
1363	Method Hybrid Testing // BMWi/AiF, FVV-EM // 01-07-2019 to 30-06-2021	**Dr. Marcus Gohl,** APL
1382	Lubrication Large Bore Engines II // FVV-EM // 01-05-2020 to 30-04-2022	**Dr. Tobias C. Wesnigk,** M. JÜRGENSEN
1384	H_2 in the Gas Network // FVV-EM // 01-01-2020 to 31-12-2021	**Dr. Dietrich Gerstein, DVGW**
1385	T/C for Lean Burn Concepts // FVV-EM // 01-04-2020 to 31-10-2021	**Marc Sens,** IAV
1394	Modelling of Pre-ignition in Gas Engines // CORNET, FVV-EM // 01-04-2020 to 31-03-2022	**Dr. Markus Wenig,** Winterthur Gas & Diesel
1410	SocioMotion // FVV-EM // 01-11-2020 to 31-10-2021	**Prof. Dr. Thomas Garbe,** Volkswagen

↓ Continue on the next page

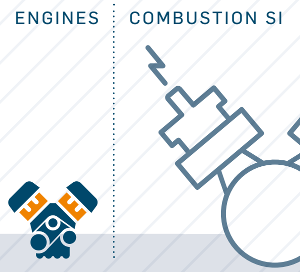
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Completed projects	
1204	Fuels Sensor for Detection of Fuel Condition // FVV-EM // 15/10/2015 to 31/07/2019	**Prof. Dr. Thomas Garbe,** Volkswagen
1253	Fuels for PHEV Vehicles // FVV-EM // 01-01-2017 to 30-09-2019	**Prof. Dr. Thomas Garbe,** Volkswagen
1254	Gas Engine Performance // FVV-EM // 01-12-2016 to 30-11-2019	**Dr. Udo Schlemmer-Kelling,** FEV Europe
1264	Investigation Twin-scroll Turbines // BMWi/AiF // 01-03-2017 to 31-08-2019	**Dr. Helmut Kindl,** Ford
1265	Mechatronik-Simulations-Survey // BMWi/AiF // 01-03-2017 to 31-08-2019	**Dr. Thorben Walder,** Porsche
1266	Accurate Temperature Management // BMWi/AiF // 01-03-2017 to 31-08-2019	**Yann Drouvin,** TOYOTA GAZOO Racing Europe
1303	CO_2 Neutral Long-haul Heavy-duty Powertrains // FVV-EM // 01-01-2018 to 28-02-2019	**Matthias Erath,** Rolls-Royce Solutions
1314	TC Model Parameterisation // BMWi/AiF // 01-01-2018 to 30-06-2020	**Dr. Panagiotis Grigoriadis,** IAV

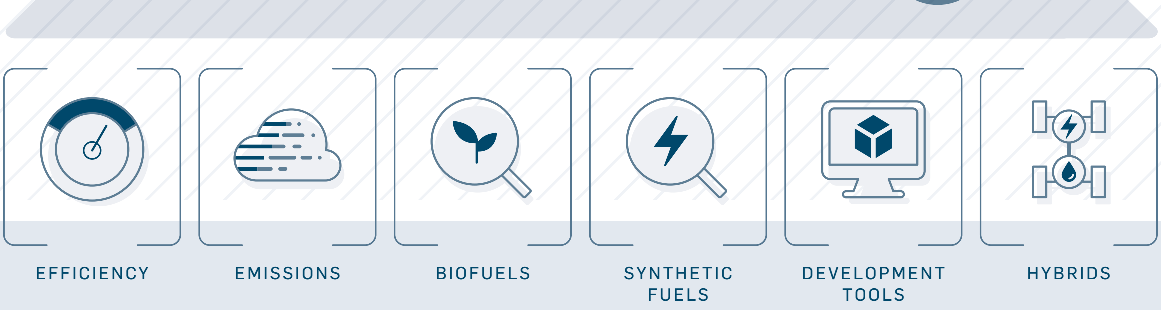
Combustion SI

PLANNING GROUP 2

COORDINATOR
Dr. Bodo Durst,
BMW GROUP (until 30.04.2020)

PROJECT MANAGEMENT
Ralf Thee, FVV





RESEARCH PRIORITIES

Planning group 2, ›Combustion SI‹, is dedicated to the following topics: Efficiency of the engine | Hybridisation | Alternative fuels | Artificial intelligence in development, big data and digitalisation

And tackles the following lines of research / focuses: Combustion modelling/simulation | Combustion processes and fuel preparation | Water injection | Wall heat transfer | Knocking and pre-ignition | Particle formation in the combustion chamber | Downsizing concepts

PUBLICATIONS

- → **MTZ worldwide 06/2019:** Combustion Development for Gas Engines with Extreme BMEPs above 30 bar
- → **MTZ worldwide 04/2019:** Investigation of the Mixture Formation in Gasoline Engines with Small Bore Diameter
- → **MTZ worldwide 02/2019:** Scale-resolving Simulations for Combustion Process Development
- → **FVV proceedings:** R587 | 2019 Spring Conference, R590 | 2019 Autumn Conference and R593 | 2020 Spring Conference

PG2 DATABASE

THEMIS

PG 2 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0120	Oil Input into Combustion II	**Dr. Eike Stitterich,** Hengst
M0220	DI Hydrogen Combustion Process	**Michael Günther,** IAV
M0820	High-efficiency H_2 SI Engine with Direct Injection	**Dr. David Lejsek,** Robert Bosch
M1319	Oxyfuel Combustion Process for Stationary Gas Engines	**Marc Sens,** IAV
M1520	SACI Combustion System with Active Pre-Chamber	**Dr. André Casal Kulzer,** Porsche
M1719	Modelling of Turbulence III	**Dr. David Lejsek,** Robert Bosch
M1916	Cause-and-Effect Chain Simulation	**Dr. Dirk Linse,** BMW
M2718	Heuristic Search and Deep Learning for 1D Simulations	**Dr. Aras Mirfendreski,** TOYOTA GAZOO Racing Europe
M2719	Alternative Ignition Concept for High-pressure Gas Combustion	**Dr. Michael Willmann,** Woodward L'Orange
M3218	Characteristic Fuel Numbers Biofuels III	**Dr. Ulrich Kramer,** Ford
	Ongoing projects	
1260	Thermodynamics Top Land Volume // BMWi/AiF, FVV-EM // 01-01-2017 to 31-12-2020	**Oliver Dingel,** IAV
1281	Pilot Injection Gas Engine // BMWi/AiF // 01-08-2017 to 31-07-2020	**Dr. Martin Schenk,** BMW
1307	ICE2025+: Ultimate System Efficiency // FVV-EM // 01-03-2018 to 31-10-2020	**Arndt Döhler,** Opel **Dr. André Casal Kulzer,** Porsche
1311	Gas Pulsation and Turbochargers Interaction // BMWi/AiF // 01-01-2018 to 31-12-2020	**Marc Sens,** IAV
1313	Engine Knock Model // BMWi/AiF // 01-01-2018 to 30-11-2020	**Dr. André Casal Kulzer,** Porsche
1328	Initial Pre-ignition // CORNET, FVV-EM // 01-05-2018 to 31-12-2020	**Albert Breuer,** Ford
1336	Post-Oxidation // CORNET, FVV-EM, BMWi/AiF // 01-10-2018 to 30-09-2020	**Christine Burkhardt,** EnginOS **Yoshihiro Imaoka,** Nissan
1343	Spray Modelling for DI Gasoline Engines // FVV-EM // 01-01-2019 to 31-12-2021	**Yoshihito Yasukawa,** Hitachi
1348	Fuel Composition for CO_2 Reduction // FVV-EM // 01-03-2019 to 28-02-2022	**Dr. Yoshihiro Okada,** Toyota **Terutoshi Tomoda,** Toyota
1349	Influencing Wall Heat Losses in SI Engines // BMWi/AiF, FVV-EM // 01-01-2019 to 30-09-2021	**Dr. Thorsten Unger,** Porsche

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1357	Homogenisation Model SI Engines II // BMWi/AiF // 01-07-2019 to 31-03-2022	**Marc Sens,** IAV
1367	Water Injection in SI Engines II // FVV-EM // 01-10-2019 to 31-03-2022	**Dr. André Casal Kulzer,** Porsche
1370	Fast Knocking Prediction for Gasoline Engines // FVV-EM // 01-10-2019 to 30-09-2021	**Dr. Michael Fischer,** Tenneco
1374	Fuel Influence on Particulate Characteristics // BMWi/AiF // 01-09-2019 to 31-08-2021	**Dr. Wolfgang Samenfink,** Robert Bosch
1387	Benchmark Platform for Scale Resolving Simulations // BMWi/AiF // 01-01-2020 to 30-06-2022	**Kathrin Giefer,** Ford
1395	Experimentally Validated LES Models for Wall Heat Transfer in Otto Engines // CORNET, FVV-EM // 01-01-2020 to 31-03-2021	**Gabriel Dilmac,** Porsche

Completed projects

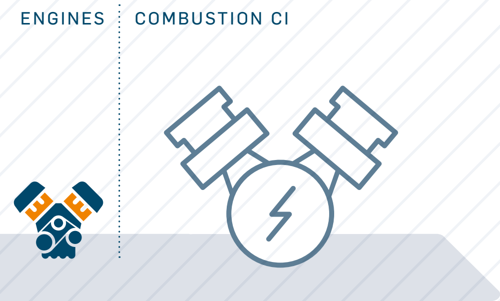
1202	CNG-DI-Engine at λ=1-Operation with Highload-EGR // FVV-EM // 01-10-2015 to 31-10-2019	**Dr. Helmut Ruhland,** Ford
1213	Methane Fuels II: Combustion Modelling // FVV-EM // 01-04-2016 to 31-12-2019	**Dr. Martin Schenk,** BMW **Dr. Frank Altenschmidt,** Daimler Truck
1222	Evaporation of Biofuels // BMWi/AiF // 01-02-2016 to 31-01-2019	**Jerome Munier,** Porsche
1233	Modelling of Turbulence II // BMWi/AiF // 01-07-2016 to 31-07-2019	**Dr. David Lejsek,** Robert Bosch
1256	Water Injection in SI Engines // FVV-EM // 01-04-2017 to 30-11-2019	**Dr. André Casal Kulzer,** Porsche
1257	Homogenisation Model SI Engine // BMWi/AiF // 01-01-2017 to 31-10-2019	**Oliver Dingel,** IAV
1263	Near Drop Neighbourhood // BMWi/AiF // 01-02-2017 to 31-10-2019	**Jerome Munier,** Porsche
1282	Soot Formation at DI Gasoline Engines // FVV-EM, BMWi/AiF // 01-08-2017 to 30-11-2019	**Prof. Dr. Peter Prenninger,** AVL List
1283	Oil Input into Combustion // BMWi/AiF, FVV-EM // 01-08-2017 to 31-01-2020	**Dr. Eike Stitterich,** Hengst
1286	Wall Heat Transfer in Otto Engines // FVV-EM, CORNET // 01-09-2017 to 31-08-2019	**Gabriel Dilmac,** Porsche
1317	Spray Diagnostics of Gasoline E-Fuels // FVV-EM // 01-08-2018 to 31-03-2020	**Dr. Eberhard Kull,** Vitesco

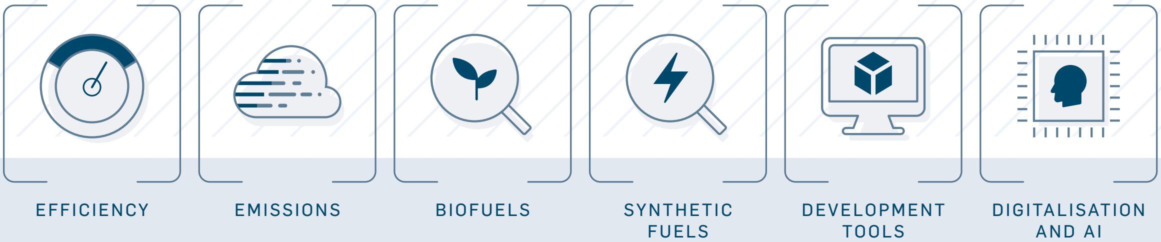
Combustion CI

PLANNING GROUP 3

COORDINATOR
Dr. Christian Weiskirch,
TRATON GROUP

PROJECT MANAGEMENT
Ralf Thee, FVV





RESEARCH PRIORITIES

Planning group 3, ›Combustion CI‹, is dedicated to the following topics:
Efficiency of the engine | Alternative fuels, hydrogen combustion | Artificial intelligence in development, big data and digitalisation

And tackles the following lines of research / focuses:
Combustion modelling/simulation | New/dual combustion processes, gas/dual-fuel engines | Fuel distribution and preparation, high-pressure injection / spray diagnostics | Variable valve control, air path | Coatings, additive manufacturing

PUBLICATIONS

→ **FVV PrimeMovers. Technologies. 06/2020:** A race against time: DME as an alternative Fuel for Compression-Ignition Engines

→ **MTZ worldwide 05/2020:** Advanced and Future-oriented Research on Compression-ignition Engines

→ **MTZ worldwide 03/2020:** Oxygenated Fuels in Compression Ignition Engines

→ **MTZ worldwide 07-08/2019:** Modeling of the Combustion Process for a Dual-fuel Diesel System

→ **FVV proceedings:** R587 | 2019 Spring Conference, R590 | 2019 Autumn Conference and R593 | 2020 Spring Conference

PG3 DATABASE

THEMIS

PG 3 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M1020	Hydrogen Combustion and Comparison SI/CI Concepts	**Dr. Reza Rezaei,** IAV
M1620	AI Route Opimisation	**Dr. Markus Wenig,** Winterthur Gas & Diesel
M1919	Diesel Engine Process Chain	**Dr. Wolfgang Bauer,** MAN Truck & Bus
M2219	AI Integration into the Development Toolchain	**Amodio Palma,** Winterthur Gas & Diesel
M2619	Stoichiometric Combustion Systems for CI Engines	**Dr. Werner Willems,** Ford
M2818	DME Fuel Properties	**Dr. Werner Willems,** Ford
M3319	CO_2 Reduction by Shorter Burn Duration	**Dr. Patrick Gastaldi,** Aramco
	Ongoing projects	
1275	VVT for Diesel LNT Rich Purge // BMWi/AiF // 01-04-2017 to 31-07-2020	**Christine Burkhardt,** EnginOS
1280	Propeller Operation with Four-stroke Dual-fuel Engines II // FVV-EM // 01-09-2017 to 28-02-2021	**Dr. Philipp Henschen,** MAN Energy Solutions
1284	RCCI in Heavy Duty Engines // CORNET, FVV-EM, BMWi/AiF, FVV-EM // 01-08-2017 to 30-06-2020	**Dr. Ingo Mikulic,** Shell
1310	HC/CO Model // BMWi/AiF // 01-01-2018 to 31-07-2020	**Dr. Markus Wenig,** Winterthur Gas & Diesel
1320	Spray Diagnostics of Future Diesel Fuels // FVV-EM // 01-02-2019 to 31-07-2020	**Dr. Uwe Leuteritz,** Liebherr-Components
1318	Air Insulation by Spray and Chamber Design, Burn Duration Reduction // FVV-EM // 01-07-2018 to 31-12-2021	**Dr. Patrick Gastaldi,** Aramco
1338	Water Injection on Diesel Engines // BMWi/AiF // 01-11-2018 to 31-10-2020	**Peter Bloch,** Robert Bosch
1346	Potentials of Airpath Variabilities for HD Gas Engines // FVV-EM // 01-01-2019 to 31-12-2021	**Dirk Weberskirch,** MAN Truck & Bus
1352	Partially Premixed Diesel Combustion // CORNET, FVV-EM, BMWi/AiF // 01-01-2019 to 31-12-2020	**Dr. Simon Schneider,** Mahle International
1368	Innovative HD Combustion System Design // FVV-EM // 01-07-2019 to 28-02-2022	**Dr. Reza Rezaei,** IAV
1403	eSpray // CORNET // 01-06-2020 to 31-05-2022	**Dr. Uwe Leuteritz,** Liebherr-Components

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NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1405	Closed-cycle Hydrogen CI Engine // FVV-EM // 01-09-2020 to 31-10-2021	**Dr. Markus Wenig,** Winterthur Gas & Diesel
1408	Cold Start Emission Reduction // FVV-EM // 01-09-2020 to 28-02-2023	**Dr. Maximilian Brauer,** IAV

Completed projects

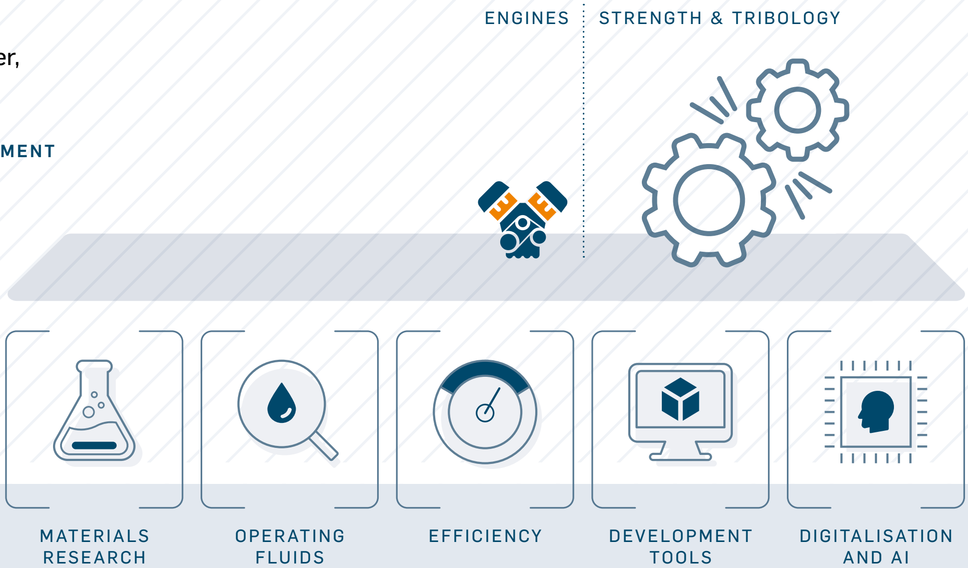
1005	XME Diesel // Collaborative research // 01-06-2015 to 31-03-2019	**Dr. Werner Willems,** Ford
1235	Modelling Emissions of Diesel Engine Combustion with Variable Valve Timing // FVV-EM // 01-08-2016 to 29-02-2020	**Matthias Diezemann,** IAV
1236	Gas-Diesel Combustion // FVV-EM // 01-10-2016 to 30-09-2019	**Dr. Michael Willmann,** Woodward L'Orange
1287	Diesel Combustion Chamber Insulation // FVV-EM, CORNET // 01-09-2017 to 29-02-2020	**Dr. Maximilian Brauer,** IAV

Strength & Tribology

PLANNING GROUP 4

COORDINATOR
Dr. Dieter Eppinger,
SEG Automotive

PROJECT MANAGEMENT
Max Decker, FVV



RESEARCH PRIORITIES

Planning group 4, ›Strength & Tribology‹, is dedicated to the following topics:
Materials research | Artificial intelligence in calculation models | Digitalisation in data acquisition and processing | Hydrogen contact and its effects

And tackles the following lines of research / focuses:
New operating fluids and coolants | Tribology and coatings | Damage characteristics under different loads | Lifespan calculations | Strength calculations

PUBLICATIONS

→ **MTZ worldwide 01/2020:** Effects of New Gasoline on the Aging of Lubricants

→ **MTZ worldwide 11/2019:** Impact of Biogenic Fuels on the Fatigue Behavior of Steels

→ **FVV proceedings:** R587 | 2019 Spring Conference,
R590 | 2019 Autumn Conference and R593 | 2020 Spring Conference

PG4 DATABASE

PG 4 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0119	Gaseous H_2 Inhibitors	**Patrick Fayek,** Robert Bosch **Angelika Schubert,** Robert Bosch
M0319	Lifetime Model Winding Insulation	**Zeljana Beslic,** SEG Automotive
M0419	Corrosion Loads due to new Drive Concepts	**Regina Franke-Hörth,** SEG Automotive
M0420	Base Engine Components for H_2 ICEs	**Dr. Daniel Hrdina,** MAHLE International
M0519	TMF Al-additiv	**Jan Becker,** Porsche **Dr. Florian Rödl,** Porsche
M0520	Machine Learning- MLμσ	**Dr. Michael Berg,** IAV **Dr. Reiner Böschen,** Rolls-Royce Solutions
M0618	Oil Circuit and Tribosystems of Hybrid Engines with Water Injection	**Dr. Peter Berlet,** IAVF
M1220	Additively Manufactured High-pressure Components	**Dr. Wolfgang Scheibe,** Heinzmann
M1420	Rheology of Novel Unconventional Fluids	**Klaus Meyer,** Robert Bosch
M1819	Wear Prediction and Wear Simulation	**Dr. Martina Weise,** IAV
M2315	VALOEKO	**Dr. Arnim Robota,** Federal-Mogul Burscheid
	Ongoing projects	
1289	High-pressure Components made of Ultra-high-strength Steels // BMWi/AiF // 01-11-2017 to 31-01-2021	**Dr. Wolfgang Scheibe,** Heinzmann
1309	Firing Friction Measurement Methodology // FVV-EM // 01-04-2018 to 30-11-2020	**Tai Ono,** SUBARU
1323	Flow Erosion // BMWi/AiF // 01-08-2018 to 31-01-2021	**Jens Strassmann,** Volkswagen
1350	Fatigue Influence Braze Quality // BMWi/AiF // 01-01-2019 to 30-06-2021	**Prof. Dr. Matthias Türpe,** MAHLE Behr
1377	Shaft Bores // BMWi/AiF // 01-11-2019 to 28-02-2022	**Stefan Roth,** MAN Energy Solutions
1379	Tribomaps for Friction Enhancing Laser Structures // BMWi/AiF // 01-12-2019 to 31-05-2022	**Dr. Anton Stich,** AUDI
1393	Fretting Fatigue Strength Assessment // BMWi/AiF // 01-01-2020 to 31-03-2022	**Dr. Reiner Böschen,** Rolls-Royce Solutions
1396	Fuel/Oil Flow Measuring // CORNET // 01-01-2020 to 31-12-2021	**Motoichi Murakami,** Toyota Motor **Dr. Marcus Gohl,** APL
1402	Exhaust Gas Effected Tribosystems // BMWi/AiF // 01-06-2020 to 30-11-2022	**Dr. Heiko Haase,** Rolls-Royce Solutions

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1404	Simulation Damage Characteristics – Validation Tests and Lifetime Calculations // FVV-EM // 01-09-2020 to 30-04-2021	**Jan Becker,** Porsche
1409	Machine Learning – MLμσ (Preliminary study) // FVV-EM // 01-08-2020 to 31-10-2020	**Dr. Michael Berg,** IAV

Completed projects

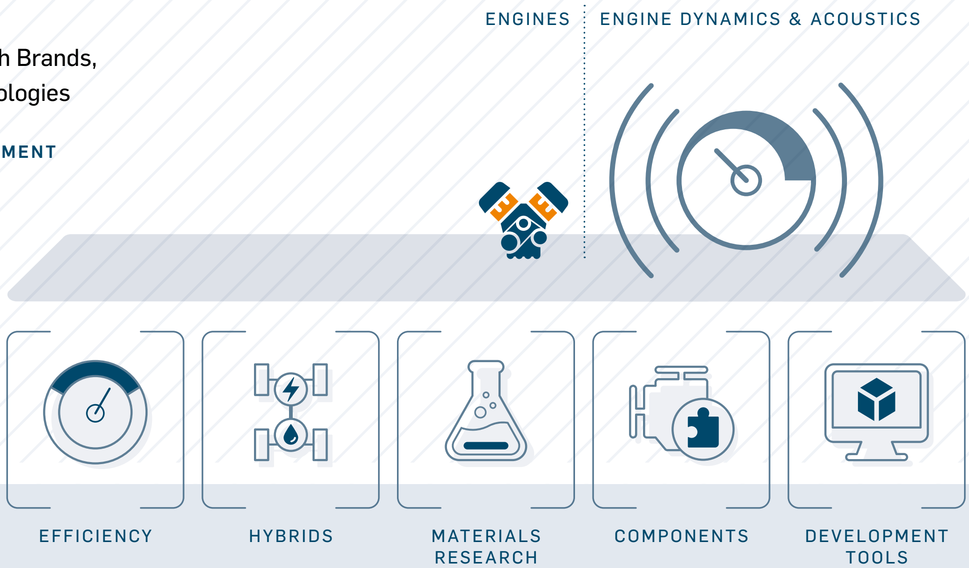
1224	TMF Weld Seam // BMWi/AiF // 01-04-2016 to 30-06-2019	**Frank Schilling,** Rolls-Royce Solutions
1237	Fretting Corrosion III // BMWi/AiF, FVV-EM // 01-10-2016 to 30-06-2019	**Dr. Reiner Böschen,** Rolls-Royce Solutions
1276	Piston Pin Bearing II // BMWi/AiF, FVV-EM // 01-04-2017 to 30-06-2020	**Dr. Rolf-Gerhard Fiedler,** Mahle International
1277	Tribological Fluid Models II // BMWi/AiF // 01-04-2017 to 31-03-2020	**Klaus Meyer,** Robert Bosch
1285	JFTOT Diesel II // FVV-EM // 01-09-2017 to 30-11-2019	**Dr. Alexander von Stockhausen,** Robert Bosch

Engine Dynamics & Acoustics

PLANNING GROUP 5

COORDINATOR
Prof. Dr. Christoph Brands,
Schaeffler Technologies

PROJECT MANAGEMENT
Max Decker, FVV



RESEARCH PRIORITIES

Planning group 5, ›Engine Dynamics & Acoustics‹, is dedicated to the following topics:
Efficiency of the engine | Dynamic and acoustic behaviour of new powertrain variants / operating strategies | Hybridisation

And tackles the following lines of research / focuses:
Acoustic behaviour of powertrain components | Interferences | Vibration damping | Detecting acoustic phenomena in conventional and new powertrain variants

PUBLICATIONS

→ **MTZ worldwide 01/2020:** Dynamic Acoustic Optimization of Engine Components, Engines and Powertrain Systems

→ **MTZ worldwide 05/2019:** Structure-borne Sound Propagation in the Crankshaft Drive

→ **FVV proceedings:** R587 | 2019 Spring Conference, R590 | 2019 Autumn Conference and R593 | 2020 Spring Conference

PG5 DATABASE

THEMIS

PG 5 | RESEARCH PROJECTS

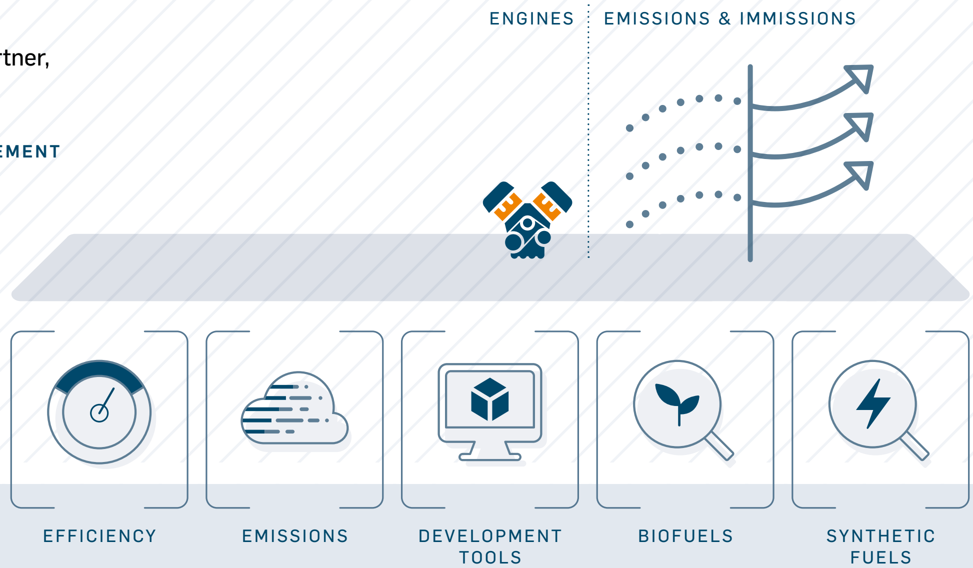
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0620	Dissonance (Part-)Electric Drives	**Rainer Weber,** Vitesco
M3719	Calculation of Transfer Pathes Using Neural Networks	**Dr. Matthias Wegerhoff,** HEAD acoustics
M3819	Exterior Noise of Electric Vehicles	**Dr. Stefan Heuer,** MAN Truck & Bus
M4019	NVH Hydrogen Powertrains	**Dr. Stefan Heuer,** MAN Truck & Bus
M4119	E-Motor Eccentricity Tolerance for NVH in HEV	**Hans Johannesson,** Volvo
M4219	Engine Mount NVH Optimisation in HEV PU	**Hans Johannesson,** Volvo
	Ongoing projects	
1304	Perceptional NVH-Aspects of Downspeeding // FVV-EM // 01-03-2018 to 30-09-2020	**Dr. Harald Stoffels,** Ford
1306	Prediction Diesel Roughness with TPA // FVV-EM // 01-06-2018 to 31-12-2020	**Dr. Bernd Philippen,** HEAD acoustics **Roland Kühn,** Daimler
1340	Interior Noise Hybrid Powertrains // FVV-EM // 01-01-2019 to 31-12-2020	**Rainer Weber,** Vitesco
1369	Interference Noise in the Vehicle Compartment with Electrified Drives // FVV-EM // 01-09-2019 to 31-08-2021	**Dr. Stefan Heuer,** MAN Truck & Bus
	Completed projects	
1361	Acoustic Transmission Loss in Turbochargers II // FVV-EM // 01-07-2019 to 31-05-2020	**Bernd Müller,** Porsche
1274	Disturbing Engine Noise in the Vehicle Interior // FVV-EM, BMWi/AiF // 01-04-2017 to 31-03-2019	**Dr. Stefan Heuer,** MAN Truck & Bus

Emissions & Immissions

PLANNING GROUP 6

COORDINATOR
Prof. Dr. Uwe Gärtner,
Daimler Truck

PROJECT MANAGEMENT
Max Decker, FVV



RESEARCH PRIORITIES

Planning group 6, ›Emissions & Immissions‹, is dedicated to the following topics:
Emissions for new powertrain concepts | Alternative fuels | Fluctuating operating strategies and their effects | New materials in components that come into contact with exhaust gas

And tackles the following lines of research / focuses:
Purification and reduction of exhaust gas, alternative means of reduction | Modelling approaches for reaction kinetics on the catalyst | Local condition monitoring of emissions | High-resolution online measuring techniques | Lifespan of exhaust gas purification components | Non-regulated exhaust gas components

PUBLICATIONS

→ **MTZ worldwide 04/2020:** Deposit Formation on Diesel Oxidation Catalysts

→ **FVV proceedings:** R587 | 2019 Spring Conference,
R590 | 2019 Autumn Conference and R593 | 2020 Spring Conference

PG6
DATABASE

THEMIS

PG 6 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0720	Near-Zero Emission Concept for H_2 Otto Engines	**Dr. Wolfgang Samenfink,** Robert Bosch
M1019	TWC Reaction under High-frequency Lambda Switching	**Toshihiro Mori,** Toyota
M1519	Residual Emissions on the Road to Zero Impact Combustion	**Dr. Harald Beck,** MAN Truck & Bus
M2019	Exhaust Gas Condensates of Future Fuels – Composition and Impact on EATS	**Raimund Vedder,** Atlanting
M2616	Generation of RDE Test Scenarios	**Florian Rass,** Honda
M2918	Predictive EATS in RDE Cycles (PEARC)	**Dr. Bernhard Lüers,** FEV
M0219	Zero Impact Tailpipe Emission Powertrains	**Dr. Frank Bunar,** IAV
	Ongoing projects	
1315	Oxygen Storage // FVV-EM // 01-07-2018 to 30-09-2020	**Jeremias Bickel,** Robert Bosch
1319	H_2-DeNOx // FVV-EM // 01-06-2018 to 31-12-2020	**Dr. Frank Bunar,** IAV
1324	CFD Analysis of Particle Formation During Transient Engine Operation // BMWi/AiF // 01-07-2018 to 31-12-2020	**Dr. Paul Jochmann,** Robert Bosch
1333	FaconSCR // FVV-EM // 01-11-2018 to 31-10-2020	**Dr. Harald Beck,** MAN Truck & Bus **Dr. Andreas Roppertz,** Emission Partner
1341	Impact of New Silica-containing Fuels on Exhaust Gas Aftertreatment Components // FVV-EM // 01-03-2019 to 28-02-2021	**Andreas Döring,** MAN Energy Solutions
1359	NO_2 with Diesel E-Fuels // BMWi/AiF, FVV-EM // 01-05-2019 to 31-10-2020	**Dr. Bernhard Lüers,** FEV
1372	Cold Start CNG Catalyst // BMWi/AiF // 01-08-2019 to 31-07-2021	**Dr. Michael Fischer,** Tenneco
1391	Cleaning Mechanisms in the Exhaust Path // BMWi/AiF // 01-01-2020 to 31-12-2021	**Raimund Vedder,** Atlanting GbH
1398	TWC Impact on Particulate Properties // BMWi/AiF // 01-03-2020 to 28-02-2022	**Dr. Julie Le Louvetel-Poilly,** Toyota
1400	Deposits from AdBlue II // FVV-EM, CORNET // 01-04-2020 to 31-03-2022	**Dr. Carolus Grünig,** IAV
1292	Ascheverhalten in Wandstromfiltern // BMWi/AiF // 01-12-2017 to 30-11-2020	**Dr. Bernhard Lüers,** FEV

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NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1294	22030+ Requirements on Emission Control Systems – MD/HD // FVV-EM // 01-02-2018 to 31-07-2020	**Dr. Claus Görsmann,** Johnson Matthey **Dr. Uwe Zink,** BASF

Completed projects

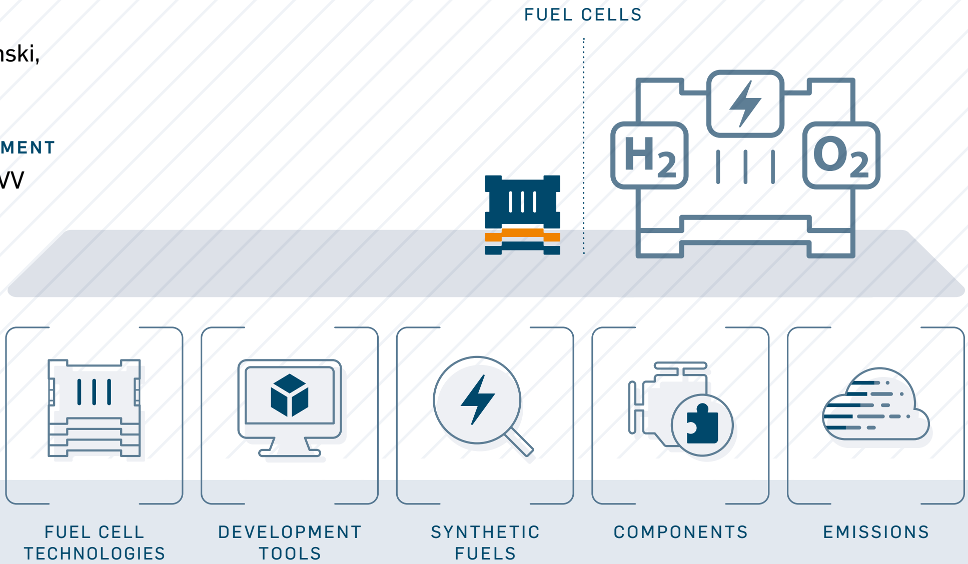
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1268	Ash Behaviour in Open-pore Filters // BMWi/AiF // 01-03-2017 to 29-02-2020	**Dr. Bernhard Lüers,** FEV
1262	AdBlue Deposits // FVV-EM, CORNET, BMWi/AiF // 01-01-2017 to 30-04-2019	**Johannes Scholz,** IAV
1271	EAS-Clogging // BMWi/AiF // 01-04-2017 to 31-08-2019	**Dr. Bernhard Lüers,** FEV

Fuel Cells

PLANNING GROUP 7

COORDINATOR
Dr. Volker Formanski,
BMW GROUP

PROJECT MANAGEMENT
Martin Nitsche, FVV



RESEARCH PRIORITIES

Planning group 7, ›Fuel Cells‹, is dedicated to the following topics:
System integration of fuel cells in mobile/stationary applications | Reduction of costs through innovative solutions | Hydrogen compatibility

And tackles the following lines of research / focuses:
Operating types and conditions of fuel cells | Hydrogen compatibility, handling, material properties of hydrogen-carrying components | Air path and filtering | Thermal management | Interfaces to the fuel cell and related components/units, e. g. compressors, expanders

PUBLICATIONS

- → **VDMA Magazin 10/2020:** Off into the Cell: Development of a Generic Fuel Cell Stack
- → **FVV PrimeMovers. Technologies. 04/2020:** One for all: Developing a Generic Fuel Cell Stack
- → **FVV proceedings:** R587 | 2019 Spring Conference, R590 | 2019 Autumn Conference and R593 | 2020 Spring Conference

PG7
DATABASE

THEMIS

PG 7 | RESEARCH PROJECTS

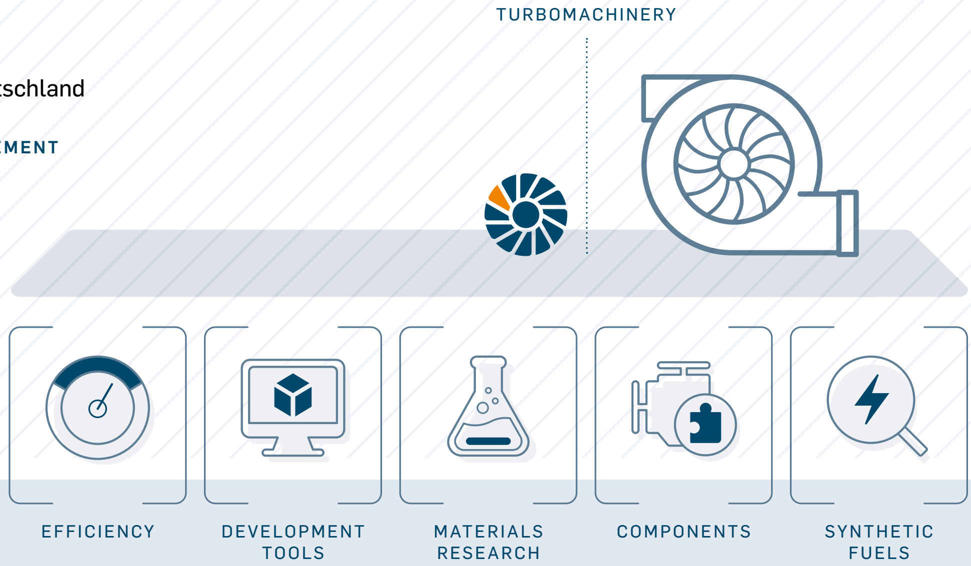
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M1817	Control for PEMFC Durability	**Alexander Schenk,** AVL List
M1918	CFD Simulation of Droplet Separators	**Dr. Michael Harenbrock,** MANN+HUMMEL
M3619	FC Cold Start	**Dr. Stefan Kaimer,** Ford
	Ongoing projects	
1295	Cathode Air Quality Requirements for LT-PEM Fuel Cells // FVV-EM // 15-01-2018 to 31-12-2020	**Dr. Michael Harenbrock,** MANN+HUMMEL
1362	Corrosion Products and Contaminations in the Fuel Cell Hydrogen System // FVV-EM // 01-08-2019 to 31-12-2020	**Dr. Christian Lucas,** Volkswagen
1406	Energy Recovery in Fuel Cell Applications // FVV-EM // 01-09-2020 to 31-08-2022	**Dr. Dirk Jenssen,** Volkswagen
	Completed projects	
1296	Cooling Fuel Cells // FVV-EM // 01-01-2018 to 30-09-2019	**Dr. Markus Kaiser,** nexis
1298	Fuel Cell System Simulation – Membrane Water Management // FVV-EM // 01-01-2018 to 31-01-2020	**Dr. Helge Tielbörger,** Siemens Industry Software
1366	Generic Fuel Cell Stack // FVV-EM // 01-09-2019 to 30-06-2020	**Dr. Jan Haußmann,** Schaeffler Technologies

Turbomachinery

PLANNING GROUP T

COORDINATOR
Dr. Dirk Hilberg,
Rolls-Royce Deutschland

PROJECT MANAGEMENT
Dirk Bösel, FVV



RESEARCH PRIORITIES

Planning group T, ›Turbomachinery‹, is dedicated to the following topics:
Efficiency of turbines and compressors | Alternative fuels, hydrogen combustion | Innovative operating fluids and coatings

And tackles the following lines of research / focuses:
Aerodynamics of turbomachines | Turbine and centrifugal and axial compressor as a complete system | Blade cooling, secondary air systems | Component stress, damage and failure mechanisms | High-temperature materials and coating | Additive manufacturing

PUBLICATIONS

→ **MTZ worldwide 09/2019:** Mistuning and Damping of Turbine and Compressor Impellers

→ **FVV Publication:** R592 | Engineering Guide

→ **FVV proceedings:** R588 | 2019 Spring Conference, R591 | 2019 Autumn Conference and R594 | 2020 Spring Conference

PGT DATABASE

THEMIS

PG T | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
836 II	Alternative bearing metals for plain bearings II	
M2419	Fuel Cell Compressor Design	**Dr. Thomas Hildebrandt,** NUMECA
T0118	Flexible HP-Turbines	**Christoph Lyko,** Rolls-Royce Deutschland
T0119	Bidirectional Aeromechanical Coupling II	**Dr. Andreas Hartung,** MTU Aero Engines
T0120	Multiscale-based HCF-Properties Ni-Base	**Dr. Andreas Fischersworring-Bunk,** MTU Aero Engines
T0218	W14 Concepts / FKM Guideline	**Dr. Shilun Sheng,** Siemens
T0219	Thermal Effects and Rotor Stability for Foil Bearings	**Dr. Joachim Schmied,** Delta JS
T0220	Sensitivity and Probabilistic (ComDynA_SP)	**Dr. Andreas Hartung,** MTU Aero Engines
T0317	Fill Factor Influence	**Dr. Christoph Weißbacher,** GTW
T0320	Heat Transfer Reduction at Turbine Casing Parts	**Norbert Pieper,** Siemens
T0419	Thermo-mechanically Induced Stress Gradients	**Frank Vöse,** MTU Aero Engines
T0420	Modelling of Primary Atomisation Using SPH	**Dr. Ruud L.G.M. Eggels,** Rolls-Royce Deutschland
T0520	Particle Transport in Compressor Casing Channels	**Prof. Dr. Marius Swoboda,** Rolls-Royce Deutschland
T0620	Constraint Effect in Component Design	**Dr. Christian Amann,** Siemens
T0719	Industrial Application of Usteady Fow Solvers	**Stephan Behre,** MTU Aero Engines
T0720	Squeeze Film Dampers II: Optimised Bearing Support	**Thomas Klimpel,** ABB Turbo Systems
T0818	Oil Supply Model for Axial Plain Bearings	**Michael Bottenschein,** Voith Hydro
T0819	Centrifugal Compressor in Flexible Operation	**Dr. Matthias Schleer,** Howden Turbo
T0820	Inverse Dynamic Analysis	**Dr. Andreas Hartung,** MTU Aero Engines
T0919	AI-based Material Data Analysis	**Alexander Schult,** Rolls-Royce Deutschland
T1119	Thermal TC Bearing Interaction	**Uwe Tomm, BorgWarner** Turbo Systems
T1219	Dynamic of Swirl and Jet Flames II II	**Dr. Bruno Schuermans,** GE Power
T1318	Extended Operation Range of YSZ	**Dr. Arturo Flores Renteria,** Siemens
T1419	Mixing Processes of Jet in Crossflow Configurations in Gas Turbine Combustors	**Dr. Marco Konle,** MTU Aero Engines
T1510	Plain bearing-Lubricant qualification	**Cornelia Recker,** Klüber Lubrication
T1519	Calculation Model for Wet Compression	**Christoph Biela,** Siemens
T1603	Qualification of lead-free multilayer plain bearings	**Marc Witte,** Rickmeier
T1618	Intelligent hybrid plain bearings	**Sebastian Wolking,** SAINT-GOBAIN

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
T1619	Correlation-Framework for NDE Data with Defects	**Dr. Christian Amann,** Siemens
T1621	KI applications on plain bearing systems	**Klaus Steff,** Siemens **Dr. Marc ter Beek,** Siemens
T1629	Process media lubricated plain bearings	**Dr. Christoph Weißbacher,** GTW
T1818	Combined Dynamical Analyses (ComDynA): Analytics	**Dr. Andreas Hartung,** MTU Aero Engines
T1918	Combined Dynamical Analyses (ComDynA): Validation	**Dr. Andreas Hartung,** MTU Aero Engines

Ongoing projects

1232	Secondary Flow Influence // FVV-EM // 01-10-2016 to 30-06-2021	**Stephan Behre,** MTU Aero Engines
1252	Failure Criteria for Plain Bearings II // DFG, FVV-EM // 01-12-2016 to 31-08-2020	**Dr. Ümit Mermertas,** Siemens
1259	Thick-walled Castings II // AVIF // 01-01-2017 to 31-12-2020	**Dr. Martin Reigl,** GE Power
1270	Self-excited Combustion Dynamics in Multiburner Systems (ROLEX) // FVV-EM // 01-05-2017 to 30-04-2021	**Dr. Michael Huth,** Siemens
1272	Structural Deformation with Fluid Film Bearings // BMWi/AiF // 01-04-2017 to 30-09-2020	**Michael Bottenschein,** Voith Hydro
1273	Radial Turbine Temperature Field II // BMWi/AiF // 01-04-2017 to 31-12-2020	**Dr. Tom Heuer,** BorgWarner
1279	Design and Implementation of the FVV Industrial Compressor // FVV-EM // 01-07-2017 to 30-09-2020	**Dr. Matthias Schleer,** Howden Turbo
1288	Lifing Methods, Multiaxial and Anisothermal (LEBEMAN) // BMWi/AiF // 01-09-2017 to 31-05-2021	**Dr. Hartmut Schlums,** Rolls-Royce Deutschland
1291	Squeeze Film Dampers – Elements of an Optimised Outer Bearing Support // BMWi/AiF // 01-09-2017 to 31-10-2020	**Thomas Klimpel,** ABB Turbo Systems
1299	Notch Support Cast Steel // AVIF // 01-01-2018 to 31-12-2020	**Henning Almstedt,** Siemens
1325	Crack Behaviour Multiaxial (ARIMA) // BMWi/AiF // 01-10-2018 to 31-03-2021	**Dr. Andreas Fischersworring-Bunk,** MTU Aero Engines
1326	Stress Relaxation Behaviour II // BMWi/AiF // 01-04-2018 to 31-03-2021	**Dr. Martin Reigl,** GE Power
1329	BHT-Threshold Calculation Methods // BMWi/AiF // 01-10-2018 to 31-03-2021	**Frank Vöse,** MTU Aero Engines
1330	Metal-graphite Composites for Plain Bearings (MeGraV) // BMWi/AiF // 01-09-2018 to 31-12-2020	**Dan Roth-Fagaraseanu,** Rolls-Royce Deutschland
1331	Aeroelastic Cascade DELTA // CORNET // 01-06-2018 to 31-01-2021	**Dr. Sabine Schneider,** Rolls-Royce Deutschland

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NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1337	Circumferentially Inhomogeneous Centrifugal Compressor Flow // BMWi/AiF // 01-12-2018 to 31-05-2021	**Dr. Thomas Hildebrandt,** NUMECA
1345	Hot Gas Ingestion into Wheel Cavities in Gas Turbines – Test Turbine // FVV-EM // 01-02-2019 to 31-10-2021	**Dr. Marco Konle,** MTU Aero Engines
1351	TMF Crack Path Calculation for Turbocharger Hot Parts // BMWi/AiF // 01-02-2019 to 31-01-2022	**Dr. Andreas Koch,** Rolls-Royce Solutions
1353	Wheel-space Sealing II// BMWi/AiF // 01-04-2019 to 30-09-2021	**Dr. Karsten Kusterer,** B&B-AGEMA
1354	Radial Compressor with Wide Operating Range // BMWi/AiF // 01-02-2019 to 31-07-2021	**Dr. Matthias Schleer,** Howden Turbo
1356	Tilting Pad Bearing Dynamics // BMWi/AiF, FVV-EM // 01-03-2019 to 31-08-2021	**Klaus Steff,** Siemens
1358	Dynamic of Swirl and Jet Flames // FVV-EM // 01-04-2019 to 31-03-2022	**Lukasz Panek,** Siemens
1360	Unsteady Tandem Flow // DFG, FVV-EM // 01-10-2019 to 30-09-2021	**Dr. Henner Schrapp,** Rolls-Royce Deutschland
1371	Robust Fracture Deformation Parameters // FVV-EM, AVIF // 01-07-2019 to 30-06-2022	**Dr. Torsten-Ulf Kern,** Siemens
1373	Dynamics of TC rotors with coupled bearings // BMWi/AiF // 01-10-2019 to 31-03-2022	**Thomas Klimpel,** ABB
1375	Brush Seals – Statistical Approach// FVV-EM // 01-12-2019 to 31-05-2022	**Joris Versluis,** MTU Aero Engines
1376	Rotordynamic Casing Models and Model Update // BMWi/AiF // 01-11-2019 to 30-04-2022	**Dr. Joachim Schmied,** Delta JS
1380	Probabilistic Lifetime Model Comparison – Creep-Fatigue // AVIF // 01-01-2020 to 31-12-2022	**Henning Almstedt,** Siemens
1383	Acoustic Emission into Discharge Pipes II // FVV-EM, DFG // 01-02-2020 to 31-07-2022	**Dr. Irhad Buljina,** MAN
1386	Turbo High Temperature Steel // BMWi/AiF // 01-02-2020 to 31-01-2023	**Dr. Markus Dinkel,** Schaeffler
1388	Blade Forces and System Damping // BMWi/AiF // 01-01-2020 to 30-06-2022	**Dr. Thomas Hildebrandt,** NUMECA
1389	Intentional Mistuning // BMWi/AiF // 01-01-2020 to 30-06-2022	**Thomas Winter,** PBS Turbo
1390	Aluminum High Temperature Fatigue // BMWi/AiF // 01-01-2020 to 30-06-2022	**Dr. Reiner Böschen,** Rolls-Royce Deutschland
1392	Material Applications FeAl (WAFEAL) // BMWi/AiF // 01-01-2020 to 31-12-2021	**Dan Roth-Fagaraseanu,** Rolls-Royce Deutschland
1397	Prediction of Gas Turbine Emissions // DFG, FVV-EM // 01-04-2020 to 31-03-2022	**Dr. Ruud L.G.M. Eggels,** Rolls-Royce Deutschland
1399	Validation TISG // FVV-EM // 01-04-2020 to 31-08-2020	**Frank Vöse,** MTU Aero Engines

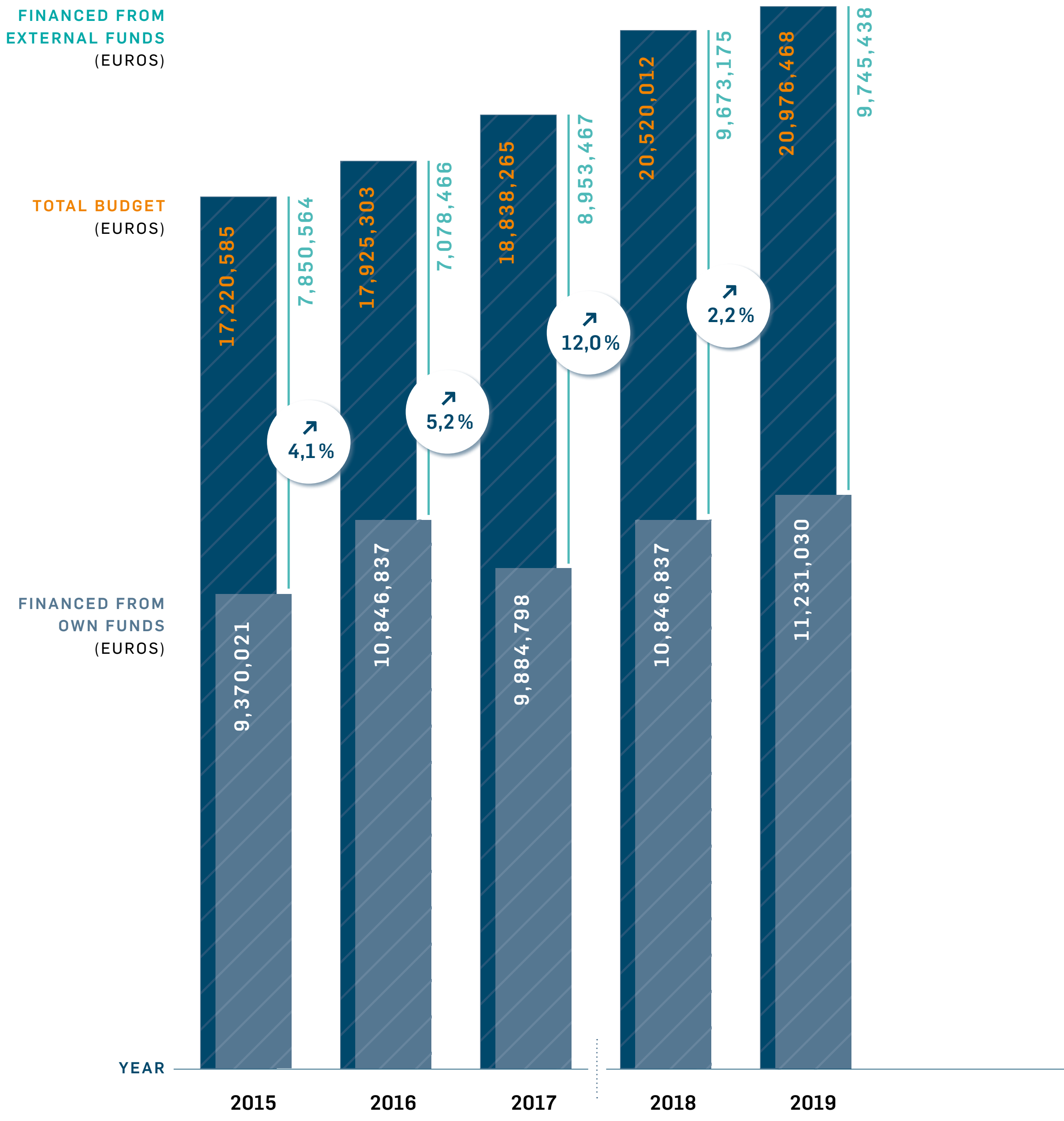
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1401	LPBF High-Temperature Lifetime// BMWi/AiF // 01-05-2020 to 30-04-2023	**Dr. Roland Herzog,** MAN
836 I	Alternative bearing metals for plain bearings // BMWi/AiF // 01-06-2018 to 30-11-2020	**Martin Limmer,** RENK
847 I	Micro-Structuring of plain bearing surfaces // BMWi/AiF // 01-11-2018 to 31-01-2021	**Dr. Oliver Alber,** MAN
880 I	Material qualification // BMWi/AiF // 01-11-2019 to 30-04-2022	**Martin Limmer,** RENK
T0318	Robuste Bruchverformungskennwerte (3D-Messsystems) // FVV-EM // 01-07-2019 to 30-06-2022	**Dr. Torsten-Ulf Kern,** Siemens

Completed projects

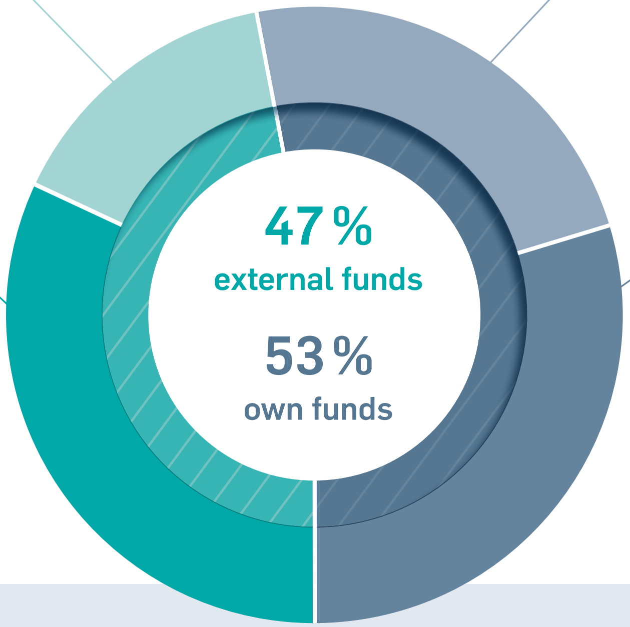
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1217	Crack Behaviour of Welded Joints // AVIF // 01-01-2016 to 30-09-2019	**Dr. Shilun Sheng,** Siemens
1218	Thermally-induced Stress Gradients (TISG) // FVV-EM // 01-05-2016 to 30-04-2019	**Dr. Kathrin Anita Fischer,** Siemens
1238	Thermally influenced TC Bearing Friction // FVV-EM // 01-07-2016 to 30-06-2019	**Uwe Tomm,** BorgWarner Turbo Systems
1240	Wheel-space Sealing // BMWi/AiF // 01-10-2016 to 31-03-2019	**Dr. Karsten Kusterer,** B&B-AGEMA
1251	Simulation-Crack Behaviour-Coarse Grain // BMWi/AiF // 01-11-2016 to 31-10-2020	**Markus Fried,** MTU Aero Engines
1255	Brush Seals – Material Combinations // FVV-EM // 01-04-2017 to 30-04-2019	**Joris Versluis,** MTU Aero Engines
1258	Thermally Extended Rotordynamic of Turbochargers // BMWi/AiF // 01-01-2017 to 30-09-2019	**Thomas Klimpel,** ABB Turbo Systems
1261	Aerodynamics of Tandem Stators II // BMWi/AiF // 01-01-2017 to 30-06-2020	**Dr. Henner Schrapp,** Rolls-Royce
1267	Foil Bearings II // BMWi/AiF // 01-03-2017 to 31-08-2019	**Dr. Joachim Schmied,** Delta JS
1269	Mistuning with Aerodynamic Coupling II // DFG, FVV-EM // 01-07-2017 to 31-12-2019	**Dr. Harald Schönenborn,** MTU Aero Engines
1308	Bidirectional Aeromechanical Coupling // DFG, FVV-EM // 01-06-2018 to 31-05-2020	**Dr. Andreas Hartung,** MTU Aero Engines
1334	Model-based Rotor Monitoring (Literature Study) // FVV-EM // 01-10-2018 to 31-03-2019	**Dr. Joachim Schmied,** Delta JS
314 V	Damage Tolerance on Plain Bearings // BMWi/AiF // 01-10-2016 to 30-06-2019	**Michael Lutz,** MAN

Research funding

EXPENDITURE FOR RESEARCH



DISTRIBUTION OF INVESTED FUNDS



* We can rely on strong partners and committed funding organisations. For more information on our most important sponsors, see **page 104.**

YEAR-OVER-YEAR ANALYSIS

	2018	2019	Change
MEMBERSHIP CONTRIBUTIONS	6,112,837	6,429,950	↗ 5.2 %
IN-KIND CONTRIBUTIONS	4,734,000	4,801,080	↗ 1.4 %
TOTAL OWN FUNDS	**10,846,837**	**11,231,030**	↗ **3.5 %**
BMWi/AiF	6,304,806	6,658,718	↗ 5.6 %
OTHER SPONSORS	3,368,369	3,086,720	↘ - 8.4 %
TOTAL EXTERNAL FUNDS	**9,673,175**	**9,745,438**	↗ **0.7 %**

Research support

SPONSORS

Innovative and sustainable research cooperations need a stable funding framework. Our projects are funded through contributions from member companies, cooperations (such as AICE, DVGW, FVA) and from public research funds. We would like to thank all of our research partners for their fantastic support!

A SELECTION OF OUR SPONSORS

BMWi / AiF –

Federal Ministry for Economic Affairs and Energy / German Federation of Industrial Research Associations

The pre-competitive Industrial Collective Research (IGF) programme is conducted in close cooperation with the German Federal Ministry for Economic Affairs and Energy (BMWi). Within the scope of Industrial Collective Research, the BMWi currently provides around € 180 million for outstanding research projects and networking between small and medium-sized enterprises and research institutions. As the agency in charge of Industrial Collective Research and other funding programmes of the federal government and the federal states, AiF is committed to the performance of small and medium-sized enterprises. It links business, science and state funding to form an innovation network and offers practical advice on innovation.

www.aif.de/english

DFG –

German Research Foundation

The German Research Foundation is the central, self-governing research funding organisation for science that promotes research at universities and publicly financed research institutions in Germany.

www.dfg.de/en

CORNET –

COllective Research NETworking

CORNET is an international network of ministries and funding agencies that combine their existing funding schemes to increase the competitiveness of small and medium-sized enterprises (SMEs). In this way, CORNET supports new funding organisations worldwide in introducing pilot actions and schemes for pre-competitive Industrial Collective Research.

www.cornet.online

AVIF –

Research Association of the Working Group of the Iron- and Metal-Processing Industry

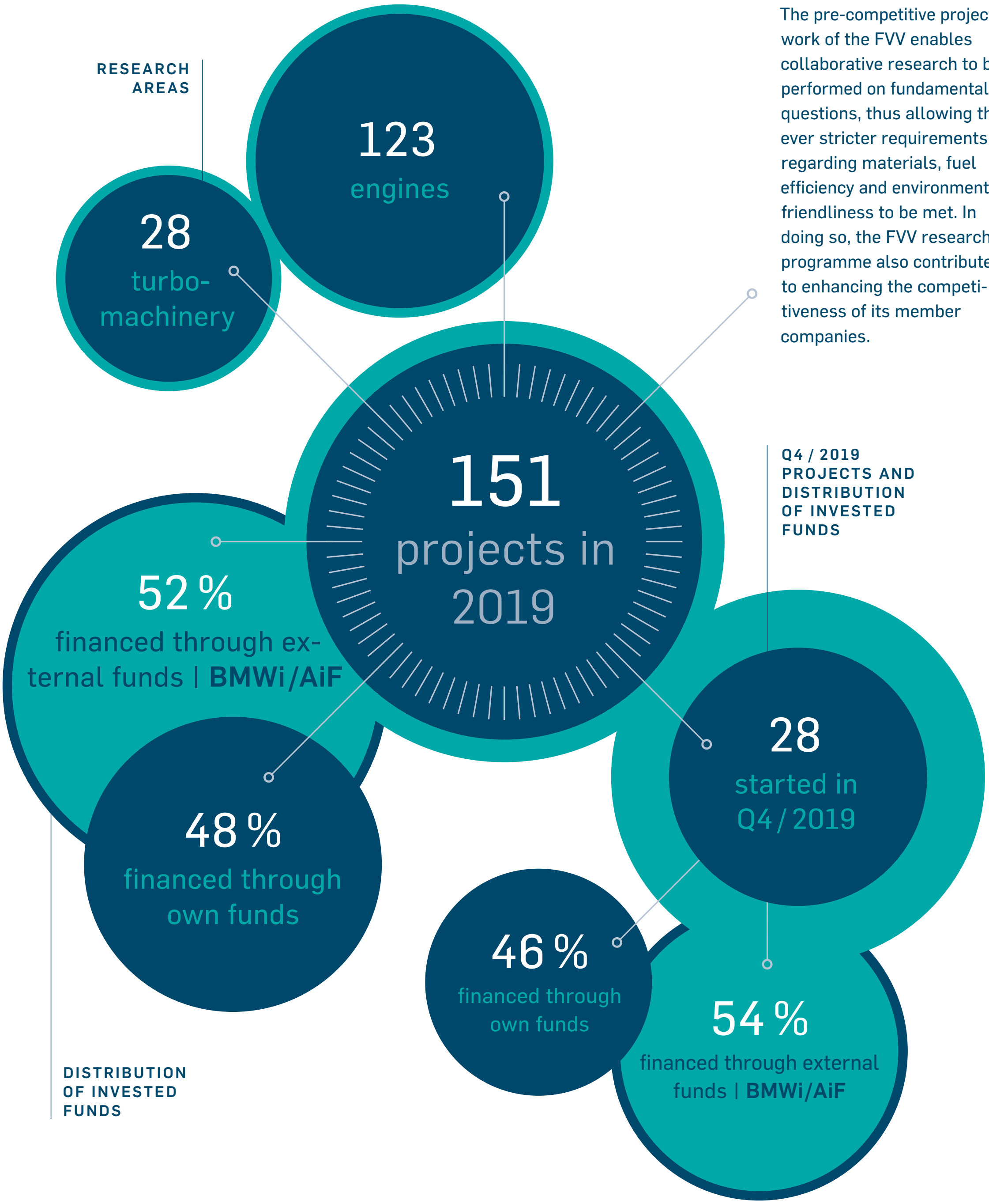
The objective of the AVIF is to fund research in the area of steel processing and application in Germany. Since its foundation, the AVIF has funded around 240 research projects with a funding volume of € 55 million. It plays a significant role in raising knowledge of the possible applications of steel in the steel processing industry. This makes it easier to meet growing demands while also boosting competitiveness.

www.avif-forschung.de

Realised projects

BREAKDOWN

The pre-competitive project work of the FVV enables collaborative research to be performed on fundamental questions, thus allowing the ever stricter requirements regarding materials, fuel efficiency and environmental friendliness to be met. In doing so, the FVV research programme also contributes to enhancing the competitiveness of its member companies.



Research partners Engines

DISTRIBUTION OF FUNDS | BMWI/AIF AND OWN FUNDS

LOCATION	EUROS	%
Stuttgart	1,827,660	19.8 %
Karlsruhe	1,132,089	12.3 %
Aachen	1,127,446	12.2 %
Braunschweig	789,484	8.5 %
Darmstadt	643,640	7.0 %
Berlin	474,772	5.1 %
Hamburg	346,127	3.7 %
Nuremberg	278,958	3.0 %
Magdeburg	264,850	2.9 %
Hanover	262,790	2.8 %
Wuppertal	239,790	2.6 %
Cottbus	220,715	2.4 %
Freiberg	195,772	2.1 %
Dresden	177,630	1.9 %
Zurich (CH)	143,437	1.6 %
Vienna (AT)	135,000	1.5 %
Graz (AT)	99,340	1.1 %
Kassel	91,140	1.0 %
Duisburg	90,922	1.0 %
Munich	81,311	0.9 %
Jülich	79,240	0.9 %
Oldenburg	70,322	0.8 %
Dortmund	59,540	0.6 %
Rostock	59,134	0.6 %
Others < € 50,000	346,946	3.8 %
	9,238,055	

*A detailed list of our research partners can be found at → **www.fvv-net.de/en | Research***

Status: 31.12.2019

RTD PERFORMERS

Research partners Turbomachinery

DISTRIBUTION OF FUNDS | BMWI/AIF AND OWN FUNDS

LOCATION	EUROS	%
Aachen	573,420	24.7 %
Magdeburg	252,810	10.9 %
Darmstadt	228,168	9.8 %
Berlin	222,831	9.6 %
Dresden	168,320	7.2 %
Clausthal	153,005	6.6 %
Hanover	124,882	5.4 %
Freiberg	123,286	5.3 %
Freiburg	120,000	5.2 %
Stuttgart	106,050	4.6 %
Bremen	65,350	2.8 %
Munich	61,045	2.6 %
Cottbus	60,879	2.6 %
Braunschweig	44,320	1.9 %
Karlsruhe	17,492	0.8 %
	2,321,858	

A detailed list of our research partners can be found at → ***www.fvv-net.de/en | Research***

Status: 31.12.2019

RTD PERFORMERS

Annual statement of accounts

BALANCE SHEET

	31 DECEMBER 2019		31 DECEMBER 2018	
ASSETS SIDE	EUROS	EUROS	EUROS	EUROS
A. Current assets				
I. Receivables and other assets				
01. Advance payments	2,765,042.77		2,324,585.42	
02. Other assets	35,860.25		203,058.50	
		2,800,903.02		2,527,643.92
II. Cash on hand and bank balances		7,375,920.50		6,600,399.62
B. Non-current assets				
I. Securities		81,386.13		65,004.88
		10,258,209.65		**9,193,048.42**

	31 DECEMBER 2019		31 DECEMBER 2018	
LIABILITIES SIDE	EUROS	EUROS	EUROS	EUROS
A. Amount carried forward for research activities				
01.a Own funds	7,204,300.19		6,475,825.23	
01.b Reserves of own funds	224,000.00		224,000.00	
02. External funds	17,658.97		761,283.21	
		7,445,959.16		7,461,108.44
B. Provisions				
01. Provisions for pensions and similar obligations	281,820.00		258,164.00	
02. Other provisions	123,963.94		114,474.33	
		405,783.94		372,638.33
C. Liabilities				
01. Liabilities to research institutes	2,363,231.85		1,327,413.25	
02. Other liabilities	43,234.70		31,888.40	
		2,406,466.55		1,359,301.65
		10,258,209.65		**9,193,048.42**

CONFIRMATION OF AUDITOR

GG✓

Wirtschaftsprüfungsgesellschaft
Steuerberatungsgesellschaft

- 9 -

4. Schlussbemerkung und Bescheinigung

Wir haben die Jahresrechnung unter Einbeziehung der Buchführung des Forschungsvereinigung Verbrennungskraftmaschinen e.V., Frankfurt am Main, bestehend aus der Vermögensübersicht zum 31. Dezember 2019 und der Ertrags- und Aufwandsrechnung für die Zeit vom 1. Januar bis 31. Dezember 2019, mit Ausnahme der zu statistischen Zwecken erfassten Sachleistungen der Mitglieder, geprüft.

Wir haben unsere Prüfung unter analoger Anwendung von §§ 317 ff. HGB und Beachtung der vom Institut der Wirtschaftsprüfer (IDW) festgestellten deutschen Grundsätze ordnungsmäßiger Abschlussprüfung sowie unter Beachtung des IDW Prüfungsstandards: Prüfung von Vereinen (IDW PS 750) durchgeführt.

Nach dem Ergebnis unserer Arbeiten erteilen wir der als Anlagen I und II beigefügten Jahresrechnung des Forschungsvereinigung Verbrennungskraftmaschinen e.V., Frankfurt am Main, für das Rechnungsjahr vom 1. Januar bis zum 31. Dezember 2019 die folgende Bescheinigung:

Die Buchführung und die Jahresrechnung entsprechen nach unserer pflichtgemäßen Prüfung den Grundsätzen einer ordnungsmäßigen Rechnungslegung. Die zu statistischen Zwecken erfassten Sachleistungen der Mitglieder haben wir nicht beurteilt.

Frankfurt am Main, den 22. April 2020

GGV GMBH
WIRTSCHAFTSPRÜFUNGSGESELLSCHAFT STEUERBERATUNGSGESELLSCHAFT
WIRTSCHAFTS-PRÜFUNGS-GESELLSCHAFT
SIEGEL
FRANKFURT AM MAIN

GGV GmbH
Wirtschaftsprüfungsgesellschaft
Steuerberatunggesellschaft

Gäbler
Wirtschaftsprüfer

31. Dezember 2019 FVV

Achim Königstein, Opel Automobile GmbH, and Prof. Dr. Christoph Brands, Schaeffler Technologies AG & Co. KG, performed the internal audit for the 2019 financial year on 5 August 2020. The audits revealed no grounds for objections: the auditors appointed by the Annual Meeting of Members agree with the auditor's report with regard to the use of funds.

The ›Prime**Movers.**‹ annual magazine is included in the FVV membership fee.

You may use the QR code to download an electronic copy of the FVV 2020 Annual Magazine or order the print version at kommunikation@fvv-net.de.

The ›Prime**Movers.**‹ annual magazine is available online:

→ www.fvv-net.de/en | Media

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Prime**Movers.** is an annual research magazine on Industrial Collective Research (IGF) on emerging technologies for internal combustion engines, hybrids, turbomachines and fuel cells, published by the Research Association for Combustion Engines (FVV). The magazine features a number of selected articles on relevant research topics from throughout the year. Additionally, representatives from business and science share their perspectives on questions around clean energy and mobility. Prime**Movers.** is completed by FVV's annual report.

Forschungsvereinigung Verbrennungskraftmaschinen e.V.
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