FVV ANNUAL MAGAZINE

PrimeMovers.

2022 | »Make it new«

Science for a moving society

Photo: Lindner & Steffen

FVV ANNUAL MAGAZINE | 2022

»Make it **new**«

Dear FVV members,
Dear readers,

The turning tide towards sustainable powertrains and energy sources has long been in motion. Industrial Collective Research that wants to do justice to its role in society must therefore contribute to both climate neutrality as well as a resilient and globally competitive national economy. As is so often the case in life, it is much easier to set a goal than to actually work towards it step by step, especially if there are still steep hills to climb. Nevertheless, FVV set out on this path years ago because we were (and still are) firmly convinced that the monumental task of transformation can only be achieved through innovation within the discussed social and political framework conditions. Technologies are developed by researchers, engineers, technicians and scientists who are passionate not only about continuously improving what already exists, but also about constantly creating something new. Networks that are constantly expanding are crucial for success. FVV offers just such a network of companies, research centres and associations – and this creates the breeding ground from which something new can emerge. As a research association, which future technologies we wanted to work on was a crucial question for us.

Against this backdrop, the board, the research committee and the management of FVV actively initiated a fundamental discussion on how we want to realign our research programme, oriented towards current social, societal and political discussions and decisions. Representatives from many member companies played a constructive role in this process, which came to its conclusion in mid-2022. The results are summarised in a V-model, which will be familiar to all engineers. You can find this on → page 14. At the start of the process, represented by the model, are major questions about a sustainable energy supply, especially for the field of mobility, in which technical and macroeconomic aspects have to be taken into account. The orientation studies initiated by the board have already been able to make a significant contribution to a fact-based debate in the past and will continue to do so.

At the underlying system level, the aim is to investigate the potential of new energy sources and energy converters based on regenerative resources. On the other hand, it is important to make the development of the relevant powertrain systems more sustainable and efficient. As the actual design of powertrain systems cannot be the subject of precompetitive collective research, this point requires explanation. The increasing complexity of powertrain systems, which often combine several energy sources and converters (such as electricity and hydrogen in a hybrid fuel cell system), requires new development methods that can also be used by small- and medium-sized enterprises. By providing appropriate methods, FVV contributes significantly to collective understanding and, above all, to a competitive SME sector.

We develop scientific facts which are used as the basis for creating innovations for continuous change and societal progress.

Of course, the various energy converters – from engines and turbo machines to fuel cells and electrical machines – are and will remain part of the research programme. Work on electrical machines is part of the E-MOTIVE programme, which is carried out in collaboration with VDMA and FVA. The highest energy efficiency and pollutant-free operation in the sense of zero-impact emissions are what motivate us to continue our research. Other facets of sustainability are addressed by the work on materials and operating supplies and their properties. Among other things, this lays the foundations for long-term durability, as well as recyclability in a circular economy.

In order to create new knowledge in all these areas, which our member companies can use to develop innovative solutions and bring them to market, a structure in which research projects are primarily initiated by member companies has proven successful in the past. After intensive discussion within various committees, we are now certain that FVV should maintain its character as a ›collaborative association‹. It is precisely due to the fact that the research

Photo: Uwe Nölke

we initiate is stoked by members' ideas that the likelihood of industrial application increases considerably. It also remains important to support and nurture young engineering scientists, who get to know the views of industrial companies with regard to research results at an early stage through their work in FVV projects.

Our name should also signal the dawn of a new era and must cover the entire breadth of our research, which has long since grown beyond the combustion engine. At the same time, it is intended to signal continuity in our scientific approach, which is renowned throughout the energy and mobility world. And last but not least, it must illustrate the societal relevance of our work. After an intensive discussion process involving many stakeholders, we decided to keep the name FVV and to clarify the new orientation with an additional claim.

The new claim is a promise that we also personally stand for: We develop scientific facts which are used as the basis for creating innovations for continuous change and societal progress. We want to take this opportunity to make this clear in our external communication as well, especially at a time when more and more non-factual or at least unverifiable information is circulating.

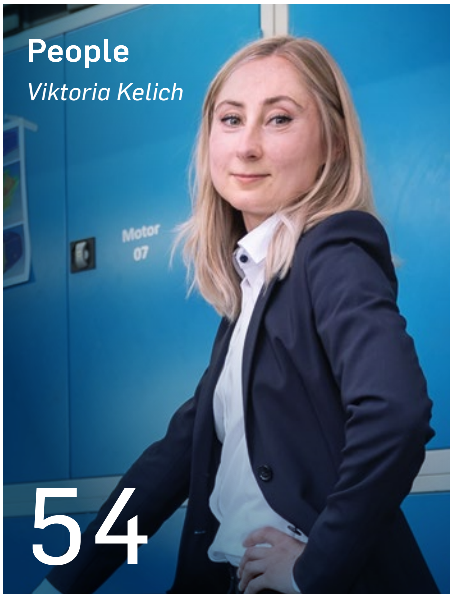
Our following pages in our annual magazine clearly demonstrate how the work of the FVV results in useful – and also extremely fascinating – technology. //

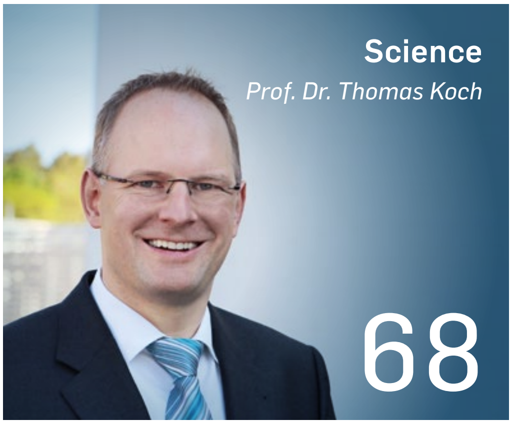
We look forward to continuing to work and collaborate with you!

PROF. DR. PETER GUTZMER
President

DIETMAR GOERICKE
Managing Director

fvv//
Science for a moving society



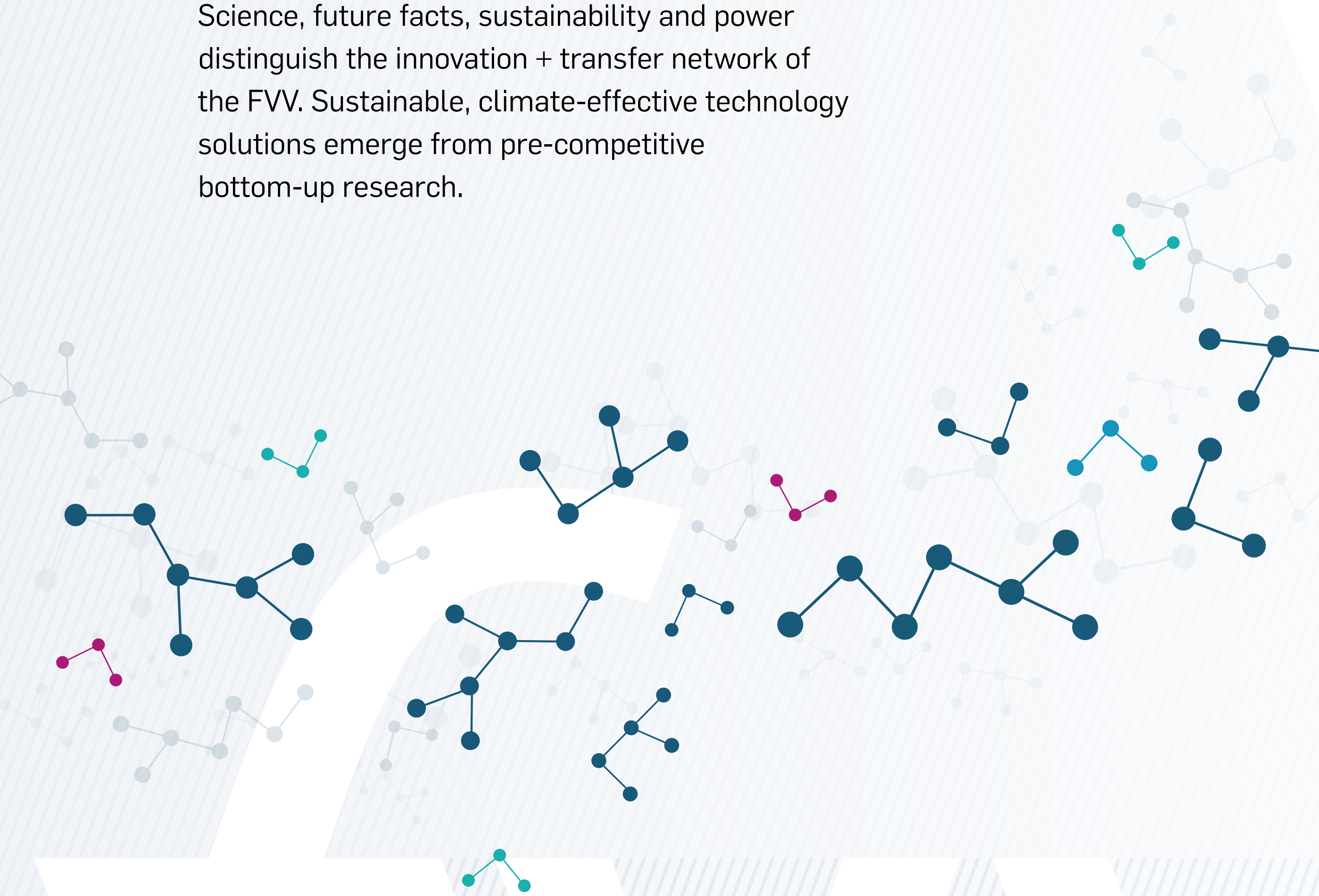
Who is driving our future?

*You can find a detailed list of our members at → **www.fvv-net.de/en***

NOVA SWISS
SEG AUTOMOTIVE
MAN
WOODWARD L'orange
GLEITLAGERTECHNIK ESSEN GmbH
CATERPILLAR
MAHLE
Kingsbury GmbH
RHEINMETALL AUTOMOTIVE
MAIN METALL
Hengst AUTOMOTIVE
KISTLER measure. analyze. innovate.
GTW Gleitlagertechnik Weißbacher GmbH
bertrandt
DAIMLER
PORSCHE
HITACHI Inspire the Next
automotive engineering iav
Ford
DELTA JS AG
Innovation in Motion Miba
pankl TURBOSYSTEMS
PILLER Blowers & Compressors
aramco
HONDA The Power of Dreams
arteco ENGENIOUS COOLANTS
NUMECA INGENIEURBÜRO
MET Motoren- und Energietechnik GmbH
HATZ DIESEL
GRAEBENER MASCHINENTECHNIK
TOTAL
nexiss
IBIDEN
CORNING
NGK
KBB Kompressorenbau Bannewitz GmbH
exothermia EFFICIENCY. PREDICTED.
Haltermann Carless
BOSCH Technik fürs Leben
JM Johnson Matthey
Howden
Audi
TOYOTA
Tec4 Fuels
RICARDO
MTU Aero Engines
DAF A PACCAR COMPANY
aalberts surface technologies
DEUTZ
Atlas Copco
AM METALS
EMISSION PARTNER
AtlantIng
DERC Development - Engineering Research Combustion engines
AeroDesignWorks
BorgWarner
CONVERGENT SCIENCE
ABB
Bosch Mahle TurboSystems

Make it **new**

Science, future facts, sustainability and power distinguish the innovation + transfer network of the FVV. Sustainable, climate-effective technology solutions emerge from pre-competitive bottom-up research.



FUTURE FACTS → *SUSTAINABLE SOLUTIONS* → *SCIENCE*

FORSCHUNG VERANTWORTUNG WISSENSCHAFT

We are the power behind all drives

In our innovation network, globally operating manufacturers of energy carriers, power systems, sustainable powertrains and prime movers such as vehicle/aircraft/industrial engines, fuel cells and turbo machines, as well as their suppliers and development service providers, conduct together with universities and other research institutions pre-competitive, collective research on future technologies. The goal is to operate energy converters – engines, hybrid powertrains, turbines, compressors, turbochargers and fuel cells – with renewable energy sources in new, (partly) electrified, integrated and digitalised conversion systems in a more efficient, cleaner and sustainable way – to the benefit of society, climate, environment and industry.

Our task is to keep the future open

The FVV is globally networked to create science-based insights into forward technologies for climate neutrality and zero-impact emissions from sustainable energy conversion systems. We have a clear fact-based compass and we are always open to the best solution from a technical, economic and environmental point of view. In doing so, we organise open-topic research along the value chains, bringing together companies with the same interests regardless of size and economic power. We network bright minds and benefit from their knowledge and experience. We think ahead and open up paths to the world of tomorrow for young talents. This is how inner drive and passion give rise to science for a moving society.

Science for a moving society

The FVV-Model

The V-model is a well-established engineering process model that the FVV has adopted for IGF project planning: Society's demands and the associated technological requirements for sustainable energy conversion systems are specified from the system level down to the component level and implemented in research projects.

SOCIETY'S EXPECTATIONS

The United Nations in its 2030 Agenda has set out global goals for sustainable development – the **UN Sustainable Development Goals** (SDGs).

SUSTAINABLE DEVELOPMENT

The FVV researches sustainable energy conversion systems. To this end, we always keep an eye on society's expectations and technological **megatrends**.

SOCIAL RESPONSIBILITY

The FVV **Board** directs the dialogue with the science community on future technologies by means of orientation studies.

COMPETITIVE STRATEGY IMPLEMENTATION

The development of innovative products that stand out from the competition on the **market** is the natural system limit of pre-competitive IGF.

PRE-COMPETITIVE RESEARCH TOPICS

In order to create new knowledge companies can use to develop innovative solutions and bring them to market, a structure in which research projects are primarily initiated by representatives of member companies in **expert groups** has proven to be most effective.

KNOWLEDGE TRANSFER

Industrial Collective Research provides access to a continuous stream of new knowledge that **members** can use effectively for the development of their own products and methods.

TOMORROW'S RESEARCH

TOMORROW'S INDUSTRY

Social Responsibility

In its Agenda 2030, the UN set out seventeen global Sustainable Development Goals. The FVV bases its work around six UN Sustainable Development Goals, each of which is given equal weighting.

SOCIETY'S EXPECTATIONS

7

Affordable and clean energy

Ensure access to affordable, reliable, sustainable and modern energy for all.

8

Climate action

Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

9

Industry, Innovation and infrastructure

Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.

12

Responsible consumption and production

Ensure sustainable consumption and production patterns.

13

Decent work and economic growth

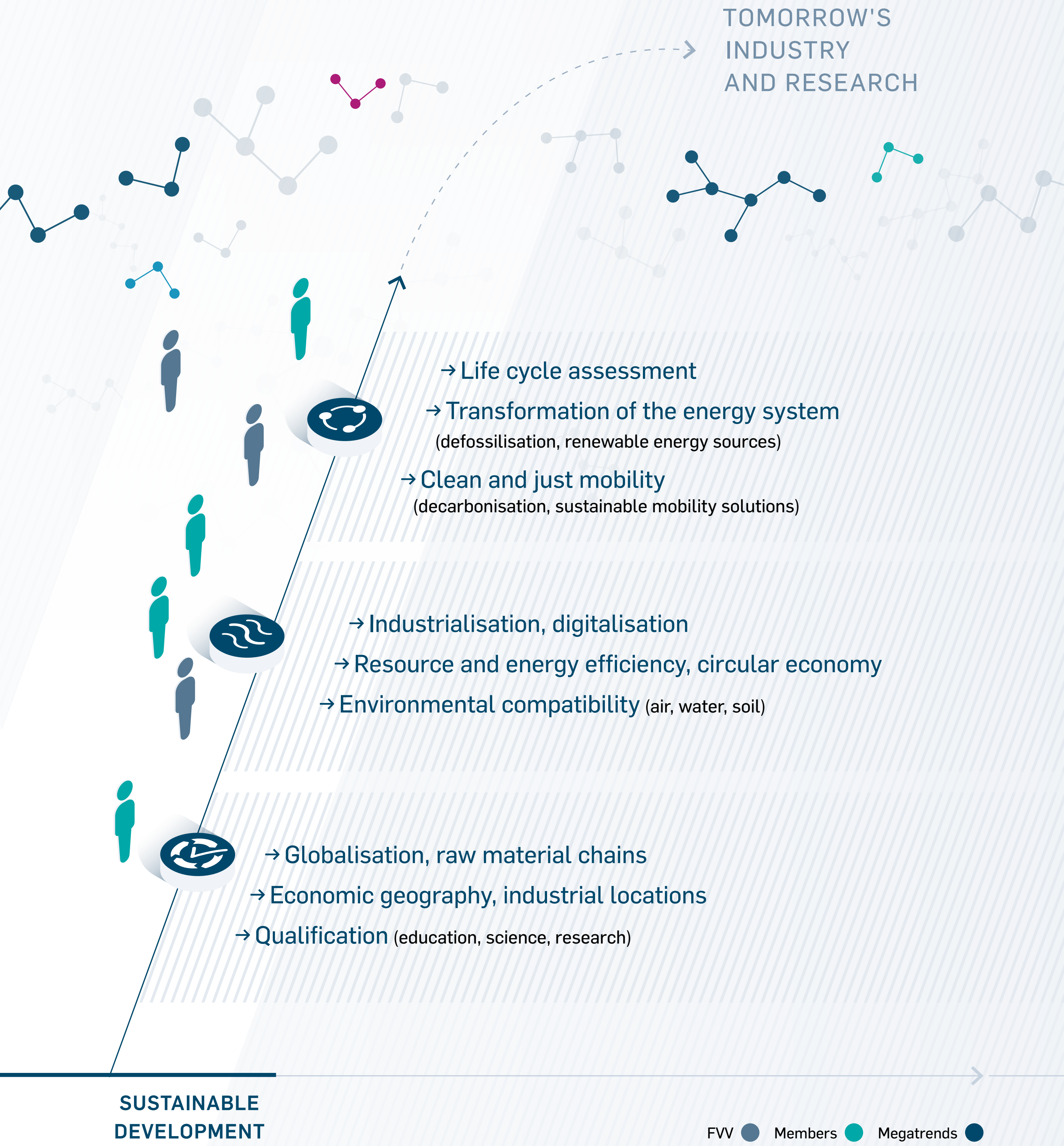
Take urgent action to combat climate change and its impacts.

17

Partnership for the goals

Strengthen the means of implementation and revitalise the global partnership for sustainable development.

SUSTAINABLE DEVELOPMENT GOALS
https://sdgs.un.org/goals


TOMORROW'S
INDUSTRY
AND RESEARCH
→ Life cycle assessment
→ Transformation of the energy system
(defossilisation, renewable energy sources)
→ Clean and just mobility
(decarbonisation, sustainable mobility solutions)
→ Industrialisation, digitalisation
→ Resource and energy efficiency, circular economy
→ Environmental compatibility (air, water, soil)
→ Globalisation, raw material chains
→ Economic geography, industrial locations
→ Qualification (education, science, research)
SUSTAINABLE
DEVELOPMENT
FVV
Members
Megatrends

Tomorrow's Research

Pre-competitive research as organised by the FVV empowers companies to solve common research and technology problems about life cycle assessment, materials or circular economy on a science-based approach.

SUSTAINABILITY | SOCIETY

FVV organises science-based, forward-looking research. We think ahead and open up paths to the world of tomorrow for young talents.
→ Future facts, orientation studies → Academic research, qualification of young engineers

PRE-COMPETITIVE RESEARCH TOPICS

SYSTEM

METHODS AND TOOLS

→ Development tools
→ Artificial intelligence
→ Emission control / EMC

Energy infrastructure and storage

Interaction of energy sources and system components, energy infrastructure and external storage.
→ Chemical energy carriers and alternative fuels beyond application → Standardisation → Life cycle analyses

Sustainable powertrain systems

Road / rail vehicles: classic powertrains (ICEV), hybrid / electrified powertrains (PHEV, BEV, FCEV), aircraft engines, marine propulsion, mobile machinery, power systems. **→ Energy storage within the application → System efficiency → Air pollution, global warming, noise, sound, radiation → E-machine combined with battery**

SUBSYSTEMS

Energy conversion systems

IInnovative and / or optimised energy conversion systems minimising environmental impact and maximising process efficiency and engine performance.
→ Engines → Electric motors → Fuel cells → Turbo machines → Zero-impact emissions

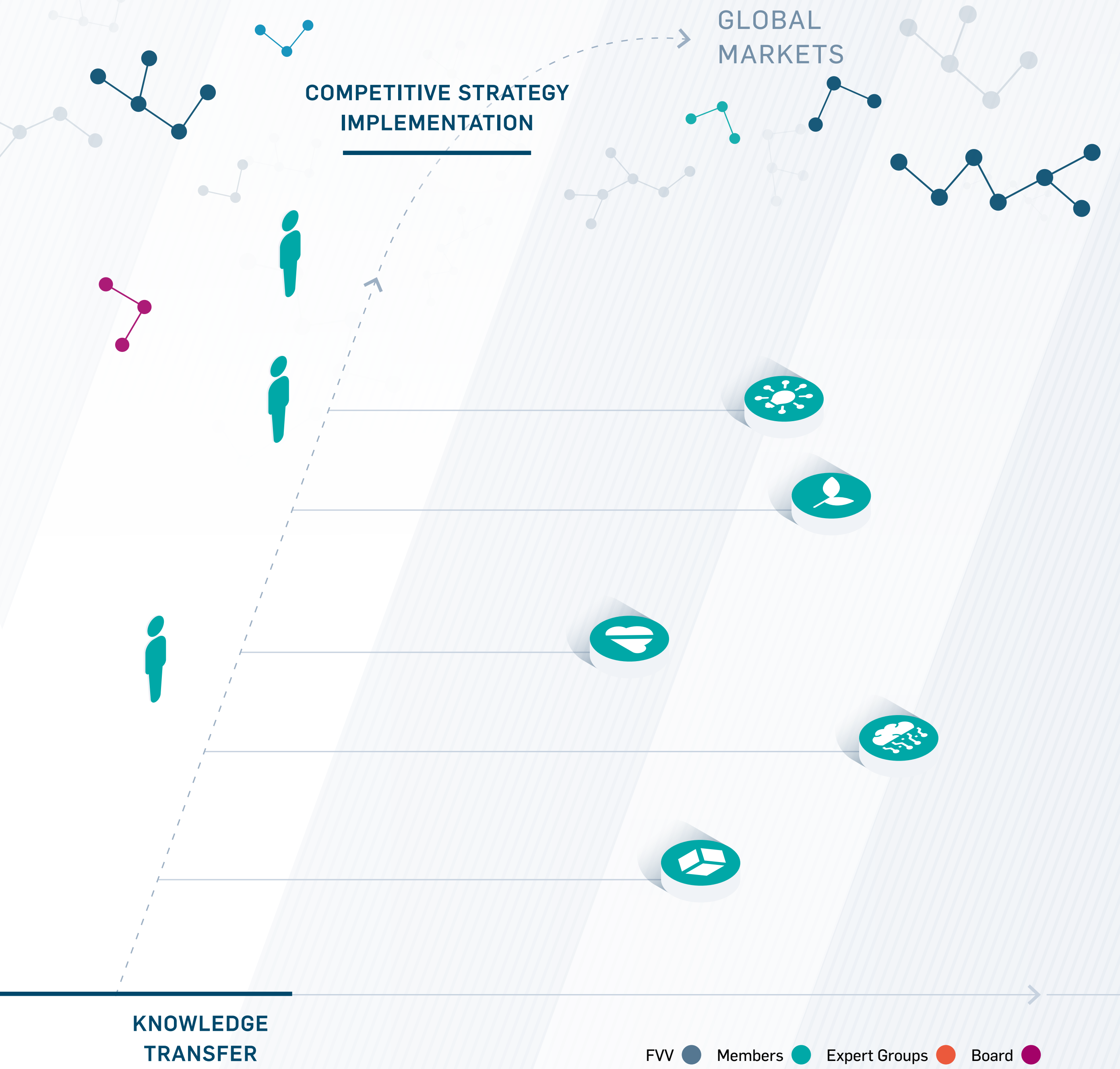
COMPONENTS

Materials science and recycling

All conventional topics on materials research in connection with new energy sources, production methods and recycled materials. **→ Strength → Tribology → Recycling**

Tomorrow's Industry

Industrial Collective Research (IGF) is both trend-setting and open-topic.
Its core element is the transfer of knowledge, which reaches its natural system boundary with the competitive implementation of the research results.
From here on, companies use the new knowledge to develop their own products, processes and services.



Scientific Coordination

The FVV follows a ›hands on‹ approach in which members shape and conduct pre-competitive applied research collectively. In the expert groups, under the leadership of experienced members, the common research needs are identified and projects are designed accordingly.

SYSTEM

Energy infrastructure and storage

NN

Sustainable powertrain systems

Thorsten Oberpenning, Rolls-Royce Solutions

SUBSYSTEMS

Energy conversion systems

→ **Engines** | Dr. Christian Weiskirch, MAN Truck & Bus

→ **Electric motors** | Carsten Weber, Ford-Werke

→ **Fuel cells** | Dr. Volker Formanski, BMW Group

→ **Turbo machines** | Dr. Dirk Hilberg, Rolls-Royce Deutschland

→ **Zero-impact emissions** | Dr. Volker Schmeißer, Daimler Truck

COMPONENTS

Materials science and recycling

Dr. Dieter Eppinger, SEG Automotive Germany

Cooperation

E-machines, fuel cells, climate-neutral energy sources – the transformation in mobility is anything but one-dimensional. To ensure that there will be alternative solutions for sustainable powertrain systems in the future, we organise cooperation projects with our network partners.

MAKE IT NEW (ToR)

E-MOTIVE BY FVA

»A new **self-image**«

In the midst of transformation, making good decisions in the face of diverse technology options requires not only courage but also a profound depth of knowledge. Five voices from our member companies on the new FVV claim ›**Science** for a moving society‹.

Science for a moving society

Building bridges to a climate-neutral society

Natalia Cochin,
Powertrain Specialist,
Toyota Motor Europe

More than anything, we all want to achieve the goal of a climate-neutral society. That's why the world of industry, led by the automotive sector, has initiated an unprecedented transformation process. Public policy and civil society have used numerous activities to help drive this process forwards. But individual measures don't always clearly reveal the full picture. FVV is an important forum for cooperation in the automotive industry – this is where optimised, comprehensive solutions can be found through reciprocal exchange which are always based on scientific facts and intensive research. FVV, initially founded as a research association for combustion engines, has itself undergone a considerable transformation in recent years to be able to meet the need for basic research as we strive to become a society free of reliance on fossil fuels. In fuel studies, in particular, we were able to clearly work out that the climate-neutral transportation solutions we want cannot be achieved with a single technology. I see FVV as an opportunity to continuously expand our knowledge regarding the bridges and pathways towards a climate-neutral society.

Photo: Toyota

Demonstrating the potential of technology

Mats Hultman,
Head of OEM Partnerships, R&D, Products and Applications, Neste

It is important always to keep the goal of reducing greenhouse gases with a technology-neutral approach in mind. None of the alternatives such as electrification or renewable fuels will be sufficient on their own, especially given the limited time we have to achieve this goal. Focusing on just a single solution would be a grave error. The technical solutions already exist or are at least on the verge of a breakthrough. All we need to do is create a working environment and a culture that allows us to make the best use of climate change technologies. FVV and its member companies play an important role in demonstrating the potential of both existing and future technologies such as renewable fuels. For us at Neste, creating something new means developing solutions that enable us to replace fossil fuels and energy sources by combining them with efficient powertrains. FVV is a fantastic forum for this, as it brings together knowledge from many different sectors to create new potential.

Photo: Neste

Science generates knowledge

Marc Sens,
Senior Vice President, Research & Technology, Sustainable Mobility, Future Powertrains, IAV

›Knowledge is power.‹ This statement is as true now as it was in Francis Bacon's time. It may be even more relevant today than it was then, especially when far-reaching decisions have to be made in the context of complex issues such as climate change. There are so many influencing factors and different things interacting that it is almost impossible to make the right decisions without in-depth knowledge. And what generates knowledge? Science! This is precisely where FVV enters the limelight. Since it was founded in 1956, a huge wealth of knowledge has been generated and made available to all interested parties in the field of energy converters and, for some years now, energy systems in the mobility sector. If this knowledge is now used to make decisions on the energy and mobility transition, for example, rather than making them based solely on gut feeling and ideology, the value of FVV's pre-competitive research for society cannot be overestimated.

Photo: IAV

We need drivers of innovation

Prof. Dr. Gunnar Stiesch,
Senior Vice President Research and Development / Engineering, MAN Energy Solutions

Our society is facing its greatest challenge: by 2050 at the latest, almost all areas of our lives must become climate-neutral. But this also opens up opportunities. A global market for climate-neutral energy conversion and powertrain systems will emerge – with promising economic and industrial policy prospects. We are already at a good starting point. However, in order to consolidate this, we need innovation drivers like FVV who are researching sustainable and climate-neutral technologies in a science-based, politically neutral and technology-neutral manner. These crucially important innovations can only emerge with the help of cross-sector networking of industrial companies and technology providers with universities and research institutions. With its consistent promotion of academic research and thus also of prospective top engineers, FVV plays a key role in securing both Germany's and Europe's technological leadership in the future and positioning mechanical engineering as an attractive employer.

 Photo: MAN Energy Solutions

Technology as lever for climate protection

Dr. Marco Warth,
Vice President Development, Engine Systems and Components, MAHLE

Without question, the transport sector has to contribute to climate protection and this is the goal for all of us – until we have achieved carbon neutrality. Further market penetration with battery-powered electric powertrains and the establishment of hydrogen technology and infrastructure, especially for heavy goods transport, are therefore extremely important. From a global perspective, however, internal combustion engines will continue to play a major role for quite some time. And that's why expertise, as collated and developed within FVV, continues to be crucial in making these engines even cleaner and more efficient. For us at MAHLE, an important key to globally sustainable mobility – and therefore to the necessary contribution to climate protection – lies not in moving away from internal combustion engines, but in switching from fossil fuels to climate-neutral e-fuels. Depending on regional market specifics and infrastructure conditions, as well as vehicle class and intended use, they can be an extremely effective approach within the framework of real-life technology neutrality. //

Photo: MAHLE

Photos: Dirk Lässig
Text: Matthias Heerwagen

The **time is ripe**

Thomas Korn has been working on hydrogen engines for many years. As the founder of Keyou, he now believes the breakthrough is on the horizon.

Sun and water everywhere // The sun shines 5000 times more energy onto the earth than humans use. And 71 per cent of the earth's surface is covered with water. For Thomas Korn, the solution to many of the energy and environmental problems facing the world is plain to see. He gained a formative experience in this regard when he studied physical engineering at Munich University of Applied Sciences after first training as an IT technician. While there, he investigated how dirty water can be made clean again. »Even back then, I thought that we were working at the wrong end. We need to start where the contamination first arises,« says Korn. That's why, for Thomas Korn, hydrogen represents the ultimate fuel for combustion engines, because it doesn't contain any carbon and burns without creating any CO_2.

This energy-rich gas has followed him along every step of his career. During his studies, Korn completed an internship at utility company Bayernwerk, which operates a hydrogen test plant together with BMW and industrial gas producer Linde. While completing his internship, the lead engineer offered him the opportunity to work for the BMW R&D team, allowing him to take his first step into the automotive industry. He wrote his dissertation on remote diagnostics for a hydrogen vehicle. And at a time when no one was yet talking about an energy transition, Korn was already convinced that hydrogen would be a key element of the mobility of the future. He played a major role in developing a BMW 7 Series with a hydrogen engine before moving to the USA with the company in 2005 to build its hydrogen vehicle programme in California. However, statutory regulations thwarted the project's success and, a few years later, BMW withdrew from its hydrogen combustion engine plans completely. It wasn't yet the right time. »But for me, it was clear that there was potential in hydrogen and that I wanted to stick with it. So I left BMW and gained experience on how to build a company at Alset,« says Korn. For Alset, a spin-off from Graz University of Technology, he developed dual-fuel engines and converted an Aston Martin to hydrogen combustion; the vehicle then went on to successfully complete the 24-hour

race at the Nürburgring. But while the technology was solid, the financing was fragile – Alset filed for bankruptcy in 2014.

One year later, Korn founded Keyou to make his vision of emission-free mobility a reality. In a commercial vehicle, where robustness and cost efficiency are all important, Korn maintains that the hydrogen combustion engine is superior to the fuel cell, or the electric powertrain in any case. Korn built up contacts and convinced investors of the technology's value – no easy task given that battery electric powertrains were initially seen as the only technology of the future. Engine manufacturer Deutz provided an engine for test bench runs and the initial results were

At a time when no one was yet talking about an energy transition, Korn was already convinced that hydrogen would be a key element for the mobility of the future.

surprisingly good. And things progressed from there: a hydrogen engine co-developed by Korn based on the Deutz unit has an efficiency of 44.5 per cent and holds the world record for being the most efficient combustion engine in the commercial vehicle sector. »But there's more to come!« says Korn with a mischievous smile – 50 per cent is possible, he claims. His engineers are developing components and combustion processes that are capable of achieving the Euro 6 emission standard without the need for expensive exhaust gas aftertreatment systems.

The time is ripe. Bit by bit, interest in this alternative fuel is growing. The CO_2 legislation and the hydrogen strategy of the German government are playing into Keyou's hands. The company has acquired several millions of euros from investors and Korn now has 70 employees. When and where they work isn't important to this CEO, as long as the agreed milestones are reached and the quality is there. Flat hierarchies, agility and short decision-making processes are what define start-ups. The CEO's door is always open.

In Bad Dürkheim, Keyou runs several engine test benches together with its partner KST Motorenversuch; yet its design and simulation teams are based in Munich. Keyou joined FVV at the start of 2020: »FVV offers a very interesting network for our developers,« says Korn. »There are a number of topics on which my colleagues share their thoughts and experiences with others. And we are certainly in a position to make a contribution too.« The greatest challenge halting the hydrogen combustion engine's breakthrough is the expensive storage technology involved. However, Korn has established another company that is working on new types of storage which would enable the costs to be reduced significantly. The concept is based on changing stations and exchange tanks that are filled centrally so that a region doesn't have to have lots of expensive hydrogen filling stations; instead, it would just have one filling station that is used to full capacity and quickly pays for itself. However, it's not the time for that just yet.

The first two prototype vehicles using Keyou engines hit the road in the summer of 2022 – an 18-tonne truck and a public bus. Next year, eight vehicles are set to be put into service with customers, and 48 a year later. Keyou is targeting 2025 for its general market launch. However, there isn't yet a market or the infrastructure – everything needs to be established first. Yet Korn is confident: »There will quickly be

THOMAS KORN,
born in 1968, studied physical engineering at Munich University of Applied Sciences. After working at BMW for many years, followed by a stint at Alset, Korn established Keyou in 2015 together with his partners Alvaro Sousa and Markus Schneider. Their objective is to develop an emission-free and cost-effective hydrogen powertrain for commercial vehicles.

a business case for hauliers and transport companies, as we are a competitive alternative to the diesel engine. Toll exemptions will more than offset the costs of converting the vehicles.«

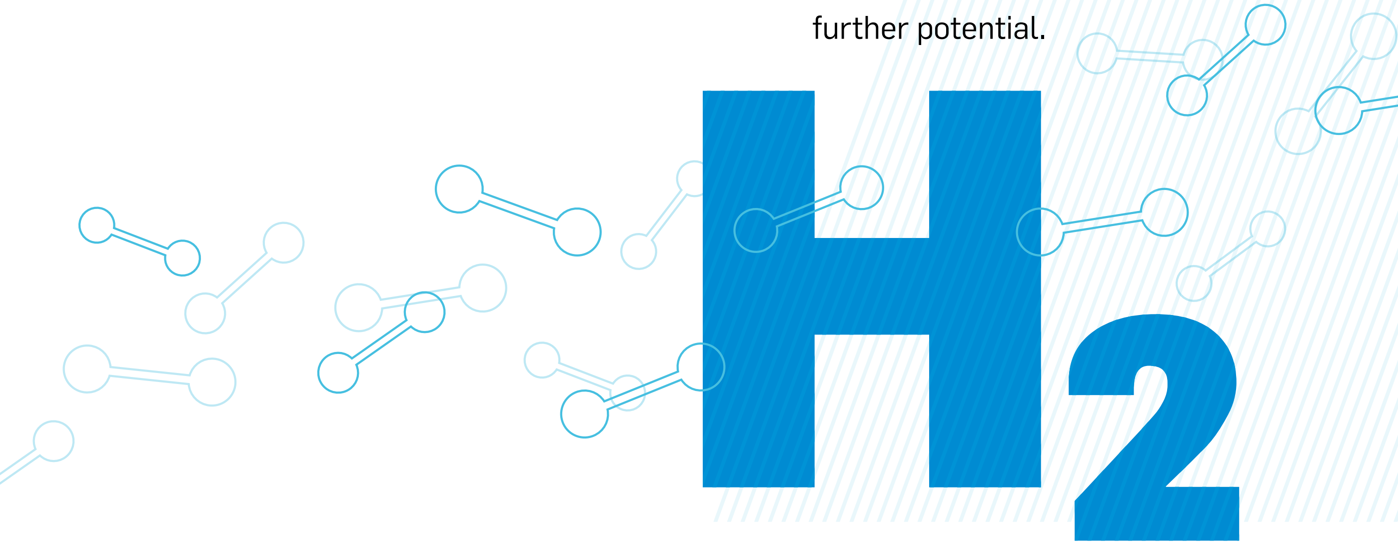
The engineer set out with the conviction that it is possible to make a difference and contribute to the energy transition even as a small company. »Every generation can make the world a little bit better. We're doing it with hydrogen,« says Thomas Korn. The 54-year-old is working hard to make his vision a reality, as well as to secure the future of his two children. Yet every now and then, he treats himself to a little peace and quiet. After heading to a small mountain stream, he casts his fly rod and concentrates only on the bait. No stress. No street noise. Just the here and now. //

As the first hydrogen specialist company worldwide, KEYOU presents **an 18-ton truck and a 12-meter city bus** with a hydrogen engine. Since summer 2022 the two prototype vehicles have been in test operation. The market launch is planned for 2025.

Photo: KEYOU

Career **potential**

Hydrogen engines can facilitate climate-neutral mobility or form part of a secure energy supply. And current FVV research projects are highlighting further potential.



Ideal characteristics // Many thermodynamicists believe that hydrogen is the ideal energy carrier. Its gravimetric calorific value is around three times higher than that of petrol. Hydrogen is readily combustible and does not contain any carbon, which can form carbon dioxide or lead to combustion residues such as particles. And above all, when used as a storage medium for solar and wind power, hydrogen offers the option of decoupling energy generation and demand in terms of both geographical location and time. Prime movers that are operated directly with hydrogen can use the green electricity harvested and chemically stored elsewhere, thus facilitating climate-neutral mobility or forming part of a secure energy supply. In particular, heavy goods vehicles deployed in long-distance transport or mobile machinery used around the clock can be made climate-neutral quickly with hydrogen engines.

And although this model student is already celebrating its first successes, the hydrogen engine still needs to excel in a few more tests to reach the zenith of its career. FVV's pre-competitive collective research is making a contribution here, as evidenced by the ›Acoustics of Hydrogen Piston Engines‹ project to name but one example. This project is addressing an area where the hydrogen engine actually has a major advantage: the fact that its conversion process during combustion is very rapid. The flame front moves through the cylinder several times faster than is the case with fuels containing carbon. Although this is highly efficient, the resulting high pressure gradients pose a challenge for the acoustics experts.

To assess the acoustic properties of an engine from an early development stage, sophisticated simulation models have already been created

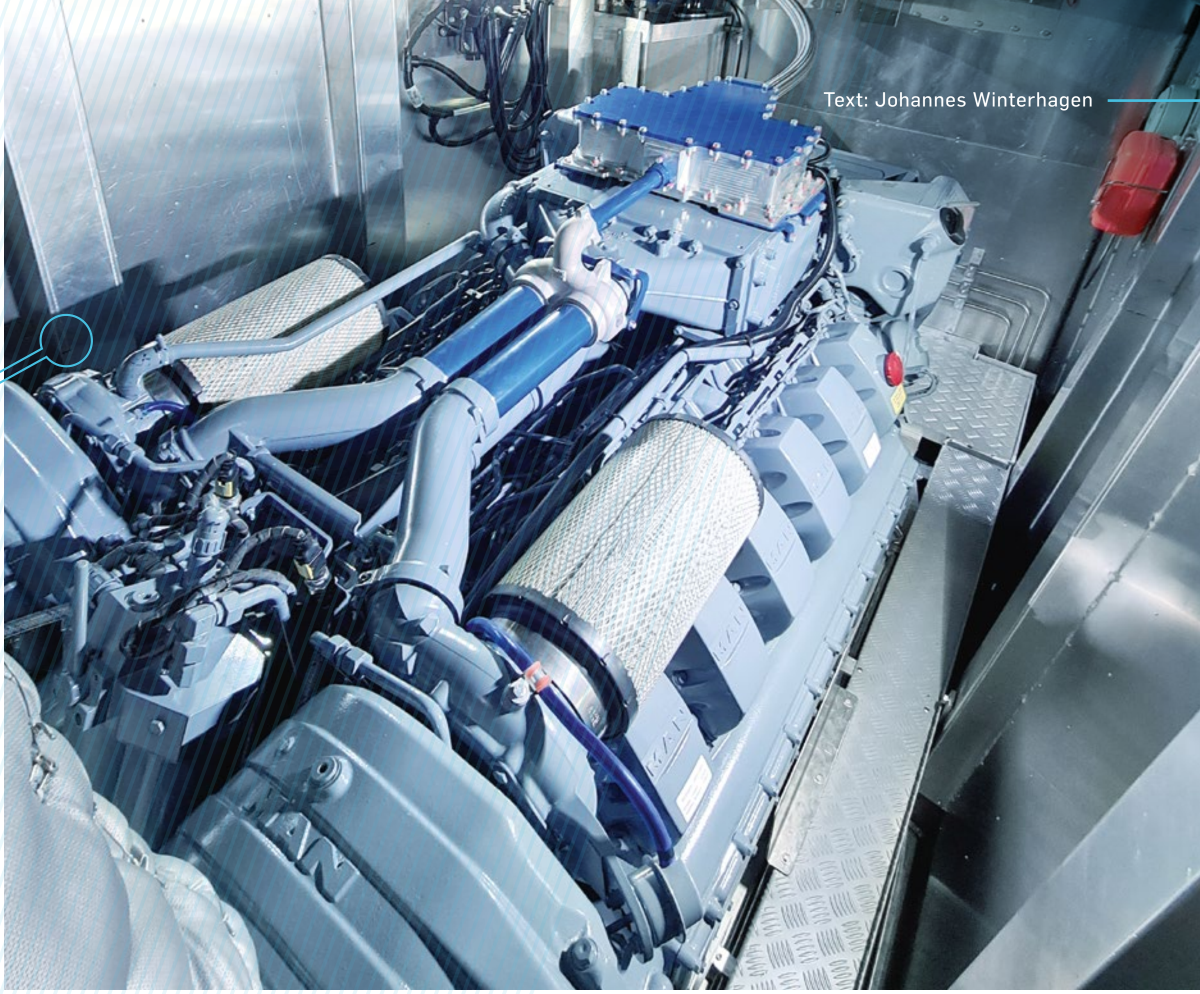

Text: Johannes Winterhagen

Photo: MAN Truck & Bus

in previous FVV projects. Dr. Stefan Heuer, who is responsible for acoustics and vibrations in the development team at MAN Truck & Bus, completed a doctorate on the subject around 25 years ago as part of an FVV project. In his role as project manager, he is now coordinating the new project, which began in mid-2022 and is expanding the existing simulation models to include hydrogen combustion. »We need to better understand how cause and effect are linked,« explains Heuer. »We need to have a precise understanding of the variables for specific acoustic phenomena in order to optimise the noise emissions.«

One peculiarity in this project is the fact that the data used by the RTD performer at RWTH Aachen University isn't actually collected in the project itself. Instead, the researchers are drawing on test bench data that is being generated in five other FVV hydrogen projects. »Otherwise, it simply wouldn't be possible to achieve valid results in a project lasting just twelve months,« says Heuer. He is confident that networked, cross-institute research in FVV can achieve added value, especially with respect to the study of new combustion processes. »This is how we can reach our goal with a relatively small amount of money and in a shorter period of time.«

Nevertheless, hydrogen engines need to do more than simply demonstrate acceptable acoustic properties – they also need to comply with all current and future emissions limits. While this is something that is relatively straightforward for pollutants containing carbon, nitrogen oxides present more of a challenge. The high combustion rates and the high peak temperatures in particular cause oxygen not only to combine with the hydrogen, but – depending on the air-fuel ratio – to also bond with the nitrogen present in the ambient intake air. »Nothing comes from nothing,« as the saying goes, and this prompted the idea of substituting the ambient air with a carrier gas that does not take part in the combustion process. Pure oxygen and hydrogen are then supplied to the engine, while the carrier gas is circulated – which is why it is referred to as a ›closed-cycle engine‹.

In an FVV project that was completed at the end of 2021, researchers at Otto von Guericke University Magdeburg investigated the potential of a self-igniting closed-cycle hydrogen engine. One key question that needed to be answered was whether there is a substance that would be suitable as a carrier gas. With the aid of a simulation model calibrated on a real hydrogen engine, three potential gases were examined: argon, helium and neon. Once all the characteristics had been combined, it soon became clear to the researchers that argon best met the requirements of the thermodynamicists. What's more, the noble gas is also completely safe from an environmental perspective: it already accounts for almost one per cent of the atmosphere and is the third most abundant element in the air that we breathe.

Project coordinator Dr. Markus Wenig, a department head at the large engine developer WinGD, points out the following: »In addition, argon is the most cost-effective solution, as it has a positive impact on overall efficiency.« However, the costs of the noble gas do need to be considered. Even though it is not involved in the combustion process, it has to be replaced after around 60 days of operation. This is because it gradually becomes contaminated with carbon dioxide that arises from the combustion of lubricating oil. Overall, the university's cost-benefit analyses, which were based on a period of 20 years, revealed a cost advantage of ten per cent for the closed-cycle mode of operation, as it cuts out the need for exhaust gas aftertreatment.

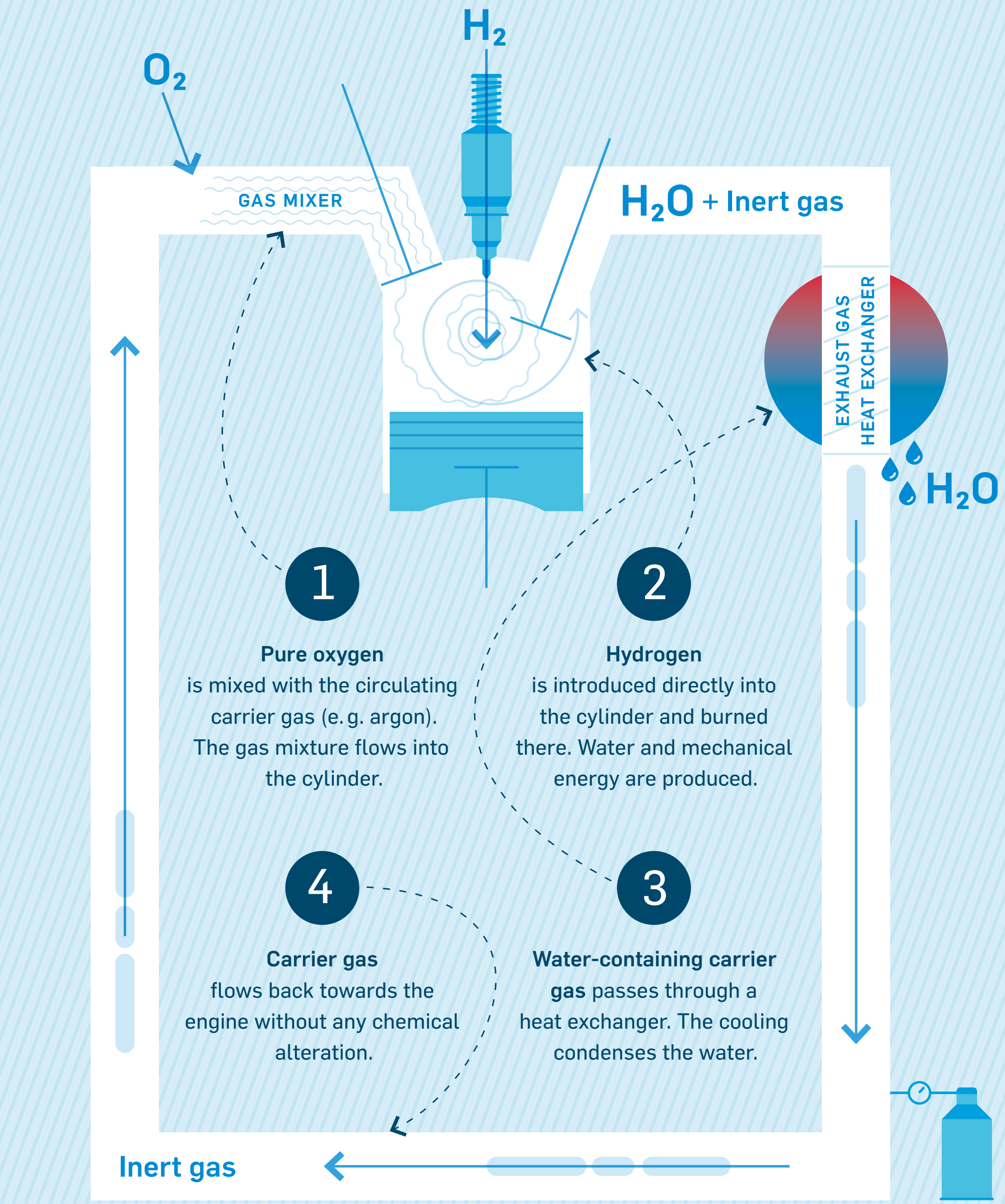
»The closed-cycle principle is less suited to mobile applications,« says Wenig. »Stationary modes of operation, such as applications to stabilise electricity grids, are a more interesting prospect.« He adds that direct coupling with electrolysers is conceivable, as they don't just generate hydrogen from green electricity, but also produce the pure oxygen as a by-product. The efficiency calculated by the researchers stands at around 53 per cent for an energy recovery system of this nature. »It is certainly worth pursuing the matter further,« says Wenig. »It's fantastic that – as a small company with fewer than 500 employees – FVV gives us the opportunity to investigate such vital topics.« //

Sample projects on
FVV's research priority ›Hydrogen‹:

- → » Acoustic of Hydrogen Piston Engines [1457]«
  FUNDING: FVV // **PROJECT MANAGEMENT:** Dr. Stefan Heuer (MAN Truck & Bus) // **RTD PERFORMER:** Chair of Thermodynamics of Mobile Energy Conversion Systems (tme), RWTH Aachen University
- → » Closed-cycle Hydrogen CI Engine [1405]«
  FUNDING: FVV // **PROJECT MANAGEMENT:** Dr. Markus Wenig (Winterthur Gas & Diesel) // **RTD PERFORMER:** Institute of Mobile Systems (IMS-EMA), Otto von Guericke University Magdeburg

This is how a closed-cycle engine works

Since a closed-cycle engine does not work on ambient air, there is no nitrogen entering the combustion chamber. This prevents nitrogen oxide emissions at the source.

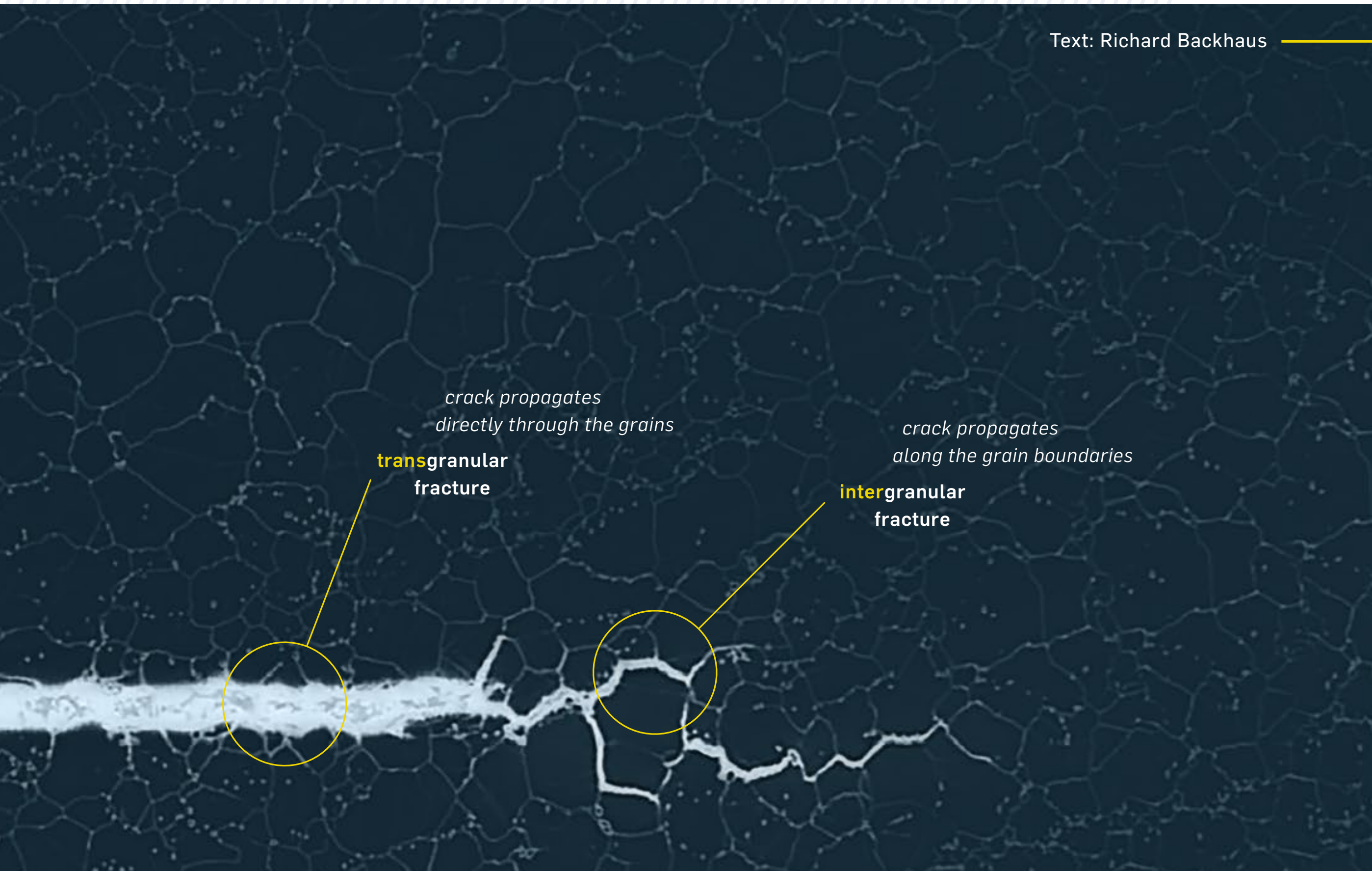


All things energy transition

With the energy transition, thermal machines and plants such as turbines are increasingly running cyclically instead of in continuous operation. The resulting alternating loads and additional stresses due to temperature changes can cause cracks in the material. The growth of such cracks must be closely monitored and evaluated to rule out failures. The development of the necessary methods is one of the diverse tasks of project group W14 ›High-Temperature Creep-Crack Behaviour‹ of the Research Association for High-Temperature Steels and Materials (FVWHT) and the FVV, which has been working for 40 years.

Photo: MPA Stuttgart

Text: Richard Backhaus



A little-known pillar of the energy transition // The share of renewable energies from sources such as hydropower, solar power or wind power in the German energy mix is growing continuously. Something that receives less public attention is the fact that conventional power plant technology with turbines is also a supporting pillar of this strategy. This is because the amount of energy generated by solar and wind power depends on weather conditions and solar radiation, making it subject to a high degree of fluctuation. If wind farms and solar plants produce less electricity than required, conventional thermal power plants supplement the energy generation. If more electricity from solar and wind power is available than can be taken, the surplus energy is to be temporarily stored in future. To do this, gaseous or liquid substances are generated from electric current, which can be converted back into electrical energy as required. This conversion back into electricity also takes place in thermal power plants. »As a result of the feed-in of renewable energies associated with the energy transition, conventional power plants are increasingly being operated cyclically, which also changes the loads on the thermally stressed components; for example, in the turbines. This requires a post-evaluation of power plant components to determine the remaining service life in terms of defect tolerance, crack initiation and crack propagation,« explains Dr. Shilun Sheng, head of project group W14 ›High-Temperature Creep-Crack Behaviour‹ of the Research Association for High-Temperature Steels and Materials (FVWHT) and the FVV.

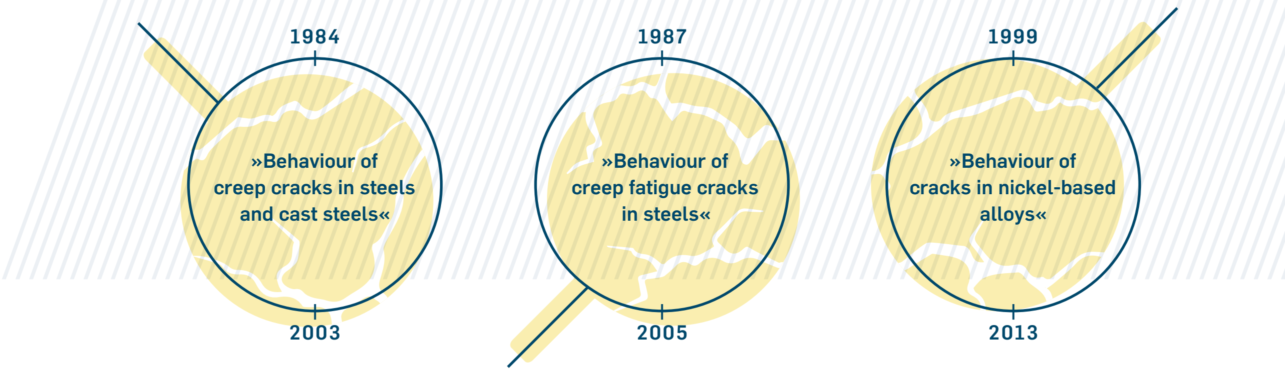
For 40 years, the project group has been working on the development and validation of methods for describing crack initiation and crack growth under high-temperature stress in materials for thermal machine and plant construction. To date, the project group has completed 19 funded research projects, and two projects are currently ongoing. »The tasks varied over time, but were always oriented towards the needs of the industry, because for us, user-oriented research is the primary focus,« says Sheng. The cooperation between the Materials Testing Institute of the University of Stuttgart (MPA), the Institute for Materials Science (IfW) of the TU Darmstadt and industry has resulted in a broad basis of calculation methods and valuable long-term data for a wide range of materials. These include modern steels and nickel-based alloys with a coarse grain structure.

Another aspect of the project group involves international collaboration; for example, through joint research activities and comparisons within the framework of the European Creep Collaborative Committee (ECCC). Based on collected expertise, the project group produced technical guidelines for the assessment of creep cracks in structural components in 2019. »In this way, we are enabling operators, manufacturers and, in particular, national calculation and service providers to carry out studies such as the post-evaluation of the now greater cyclical load in the event of changed conditions of use due to the energy transition in a competitive manner without restricting the safety of continued operation,« explains Dr. Andreas Klenk, Deputy Director of MPA.

Currently, the project group is working on an extension of the ›Fracture Mechanics Proof of Strength‹ guidelines for the Forschungskuratorium Maschinenbau (FKM), which were developed with the cooperation of IfW in 2001. The guidelines have been established for fracture mechanical analyses and evaluations for years, but have so far been limited exclusively to room temperature applications. »In German-speaking countries, there are currently no guidelines that enable a reliable assessment of the cracking behaviour under creep or creep fatigue loads. A recommended course of action for calculating the service life of components would open up potential for improvement across the entire field of mechanical and plant engineering,« states Dr. Falk Müller, Deputy Head of the High-Temperature Materials competence area at IfW.

One target group of the FKM guideline is small and medium-sized engineering service providers that take on tasks in the design and monitoring of thermal plants, but cannot undertake

40 years of research – The key working areas of the project group W14



their own research and development due to their size. In order to evaluate defects, both during development and commissioning as well as at the end of the component's service life, they must be able to access guidelines that define and map the state of the art. The FKM recommendation provides these companies with scientific expertise that can be implemented directly, even if only a limited amount of experience in fracture mechanics assessment has been accumulated. In order to ensure that this knowledge transfer takes place without difficulties, the plan is to evaluate calculations of SMEs in exchange for a fee. Possible difficulties in the transfer to practical application can therefore be eliminated even before the project is implemented. However, large companies also benefit from the FKM guideline; for example, in the further development of their machines and systems for the thermal use of alternative energy sources. »Hydrogen, for example, places its own specific demands on the components. The extension of the FKM guideline would increase the efficiency of the development work based on them and help to speed up and safeguard the market launch of the plants and systems,« says Sheng. //

Designing components safely and efficiently

Together with the FVWHT (Research Association for High-Temperature Steels and Materials), the FVV is conducting research on long-term material tests in the temperature range from 450 °C to 1200 °C. Material manufacturers cooperate with material users, manufacturers of power generation plants and research institutes to investigate the long-term behaviour of creep-resistant materials and their welded joints. The research programme managed by the FVV focuses on high-temperature fatigue (W 10), relaxation behaviour (W 11) and creep-crack behaviour (W 14).

In the expert group ›Component Strength‹ of the Mechanical Engineering Research Federation (FKM), guidelines are being developed that describe procedures for strength verifications for mechanical engineering components. The research results of ›W 14‹ are incorporated into the guideline. By using standardised procedures in everyday design, components can be designed according to the current state of the art both safely and efficiently.

»Still **room** for research«

Gas power plants are to be converted to green hydrogen in the long term, which will contribute to security of supply in an energy system based primarily on solar and wind power. FVV board member **Dr. Michael Ladwig** from GE Gas Power explains what still needs to be done to achieve this.

Replacing natural gas with hydrogen is now the talk of the town. Is this technically feasible?
Gas turbines have some intrinsic advantages for a country's energy supply. Manufacturers have therefore been working for some time to also exploit these advantages in a completely climate-neutral environment. That is why the members in EU Turbines have committed to a defined roadmap. By 2030, turbines will be available that can run completely on hydrogen. Since the outbreak of the war in Ukraine, the question has been raised to what extent we can accelerate this process to ensure security of supply.

Gas turbines are known for extremely high efficiencies, especially in combined heat and power plants. Will this remain the case with hydrogen operation?
Today, we have an electrical efficiency of 64 per cent. If heat extraction is added, a gas-fired power plant achieves an energy utilisation rate of over 90 per cent. The conversion to hydrogen has a marginal effect on efficiency. There are differences when it comes down to the details – for example, in the heat transfer of steam – but these will not significantly affect the results.

And the gas turbines can also cope with hydrogen?
There are still a few points that need to be clarified with the aid of intensified research efforts. Hydrogen combustion is free of CO_2, but the higher combustion temperatures increase the likelihood that nitrogen oxides will form. This can be overcome through technical means – for example, by lowering the combustion temperature. However, this would decrease efficiency. All this to say that there is still room for research here.

But aren't turbines already available that are marketed as ›H_2 ready‹?
These products do exist, and they can run on up to 100 per cent hydrogen. However, we are talking about turbines that have not been ›cultivated‹ to the extreme for maximum efficiency and that are usually also somewhat smaller. In the case of the very large turbines, we have now reached the point where a hydrogen content of 50 per cent is unproblematic.

What about the retrofitting capability of existing power plants?
Everyone looking to invest in a gas power plant today is asking about the ability to someday running it on hydrogen. The manufacturers must be able to prove the retrofitting capability now.

Text: Johannes Winterhagen

There is also a lot of discussion about adding hydrogen to fossil natural gas. What proportion of hydrogen is ideal from a technical point of view?
Today, most gas turbines can easily cope with low hydrogen contents of up to 20 per cent. But that is more cosmetic. In order to noticeably reduce CO_2 emissions, we need to achieve significantly higher percentages. A CO_2 reduction of 50 per cent is only achieved with 70 per cent hydrogen. The reason for this is the higher energy content of natural gas in relation to its volume.

In turn, this poses the problem of the availability of green hydrogen.
That's exactly what we are talking about. From a technological perspective, there are no longer any major obstacles. But if you think of a combined cycle gas and steam power plant with a combined output of 800 megawatts, you need a considerable amount of hydrogen. And such a solution simply isn't available, at least not one that is not based on natural gas anyway.

In most scenarios, gas-fired power plants are not operated continuously, but in a highly cyclical manner. Wouldn't that lead to building smaller and more flexible turbines again?
Not necessarily. The solutions are highly dependent on the energy mix in individual countries. One example: if a gas power plant is to replace a nuclear power plant, then there is the grid structure on site to distribute one gigawatt of electrical power. In that case it makes sense to use a large, highly efficient turbine there. However, there are also scenarios where we would prefer smaller gas turbines.

Thank you very much for the interview, Dr. Ladwig! //

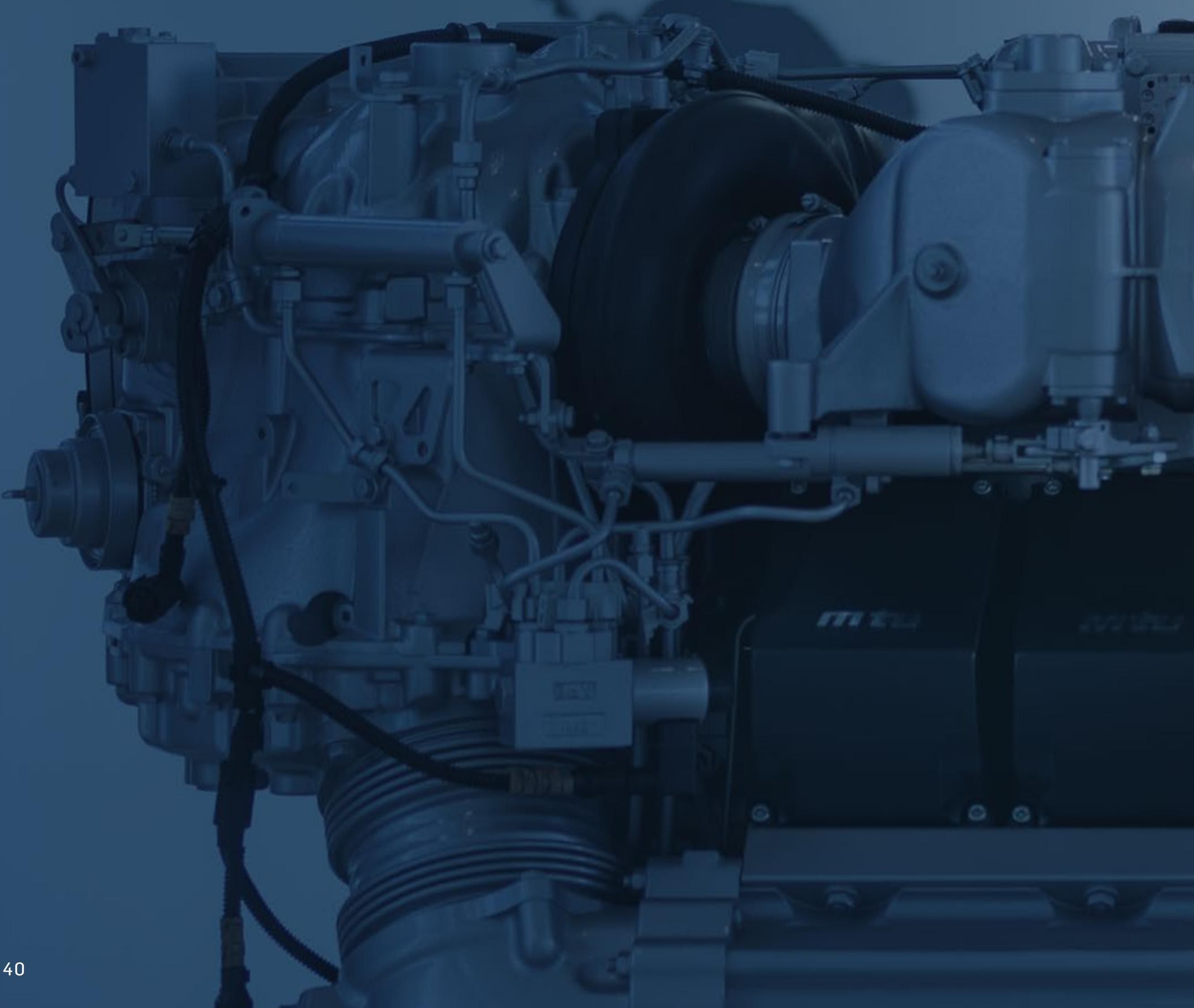
DR.-ING. MICHAEL LADWIG

is responsible for scientific cooperation at GE Gas Power in Switzerland and has therefore also been involved with FVV for a long time, currently as a member of the board. As President of the European Association of Gas and Steam Turbine Manufacturers ›EU Turbines‹, he drove the development of a cross-manufacturer commitment to switch to renewable gases.

Photos: General Electric (Switzerland) GmbH

The power **lies in the system**

Martin Urban, who describes himself as an ›engineer with a wallet‹, works on economic solutions for a climate-neutral energy system. For the head of development at Rolls-Royce Power Systems, the focus is not on individual components, but on the system as a whole.



Photos: Dirk Lässig
Text: Johannes Winterhagen

It works! // Sunday evenings were always craft time. Martin Urban's father, a humanities scholar with craftsman's skills, shared his passion for model aircraft construction with Martin and his siblings. Martin was twelve years old when he built his very first airplane – not from a kit, but from a construction drawing. »There were moments of frustration when everything wasn't working as it should right away,« Urban recalls today. »But that didn't stop me from always trying something new.« The first model flew with a small single-cylinder combustion engine. Later, he upgraded to an electric drive and realised that this worked, too; however, the battery didn't hold up very long. When Urban was asked as a teenager what he wanted to do for a living, he answered: »I want to build airplanes.«

So it's hardly surprising that Urban went on to study aerospace engineering in Aachen and chose particularly demanding subjects to specialise in: rotary wing aircraft and aircraft propulsion systems. In addition to his main studies, he worked as an intern and student trainee in flight testing at DASA's Manching site. Urban not only gained technical knowledge here, but also developed his own personal ›energy conservation law‹: »I can put a lot of energy into something if I get at least as much out of it.« And so, despite the part-time job, Urban completed his studies in almost the standard period of study.

The fact that his path did not immediately lead him to aircraft construction, but to stationary gas turbines, was due to a chain of various circumstances – but most importantly due to the fact that Urban proved himself in a number of very different positions at Siemens, his first employer after graduating. After two years as a test engineer at the Mülheim site, he was allowed to go out into the world and take measurements on customer plants. His first accolade followed in 2000, when Urban was given responsibility for the large

»If we as engineers develop technical solutions, they must have an economic value for society.«

gas turbine test bench in Berlin. At the historic site built in the middle of the Moabit district, Urban supported the electrical company in developing a gas turbine with 43 per cent efficiency – the world's highest efficiency rating at the time. But the energy world is always changing rapidly, and more and more combined cycle gas and steam power plants were being built. The system efficiency counts for more than the absolute best value for the gas turbine. In order to increase the system efficiency, higher exhaust gas temperatures were necessary – which meant that a new combustion process was required. Urban started developing just such a process with a team in Orlando, Florida in 2003. A few years earlier, Siemens had bought Westinghouse's non-nuclear power plant business, and now the task was to develop common technical standards.

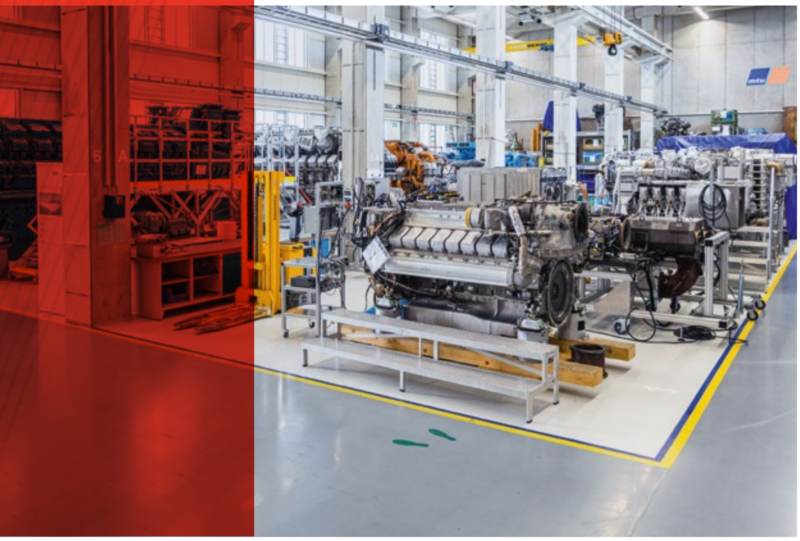
When Urban assumed responsibility for the product line development of Siemens gas turbines in 2006, work began on the Irsching combined cycle gas and steam power plant, which held the world efficiency record from the time of commissioning until 2016. Accordingly, the CO_2 emissions per kilowatt hour were low. However, due to the electricity market structure and the associated rapid changes, the power plant was only able to achieve a few full-load hours. As an ›engineer with a wallet‹, as he describes himself, Urban takes a sober-analytical look at the past and tries to learn from it for the future. »If we as engineers develop technical solutions, they must have an economic value for society.«

MARTIN URBAN,
born in 1971, studied aerospace engineering at RWTH Aachen University. After graduating, however, he spent 21 years at Siemens – most recently with development responsibility for the distributed power generation business. In 2017, he joined Rolls-Royce Power Systems. Since January 2022, he has been responsible for all aspects of development at the propulsion and energy solutions provider.

Martin Urban volunteers as a member of the board of FVV.

After holding a few more positions, in 2014 Urban took over development responsibility for the recently established Siemens business unit ›Distributed Power Generation‹, which focuses on small, distributed power generation plants. At the centre of this kind of plant there is still a gas turbine, with a maximum of 65 megawatts. However, Urban instantly recognised that »Individual components do not count in a business like this. It always comes down to system performance.«

Three years later, Andreas Schell, whose term as CEO of Rolls-Royce Power Systems had just begun, knocked on Urban's door – and he took over responsibility for system development. »At that time, not everyone had realised the tremendous impact of the pending change. We were able to work ahead and put ourselves in a situation where our customers have a choice today.« The expanded spectrum of the supplier, which still uses the Motoren- und Turbinenunion logo for its products, is illustrated by a ›Validation Center‹, which realistically and vividly reproduces a complete system consisting of the new products. It consists of a battery storage system that stores the solar power generated on the roofs of the factory, a power generation module in which four fuel cells are used, and the complete automation for this micro grid. In addition, combined heat and power plants and diesel gensets are integrated. A module with a hydrogen combustion engine is nearing completion during the visit, and an electrolysis module is to be added later, using technology from the Wismar-based start-up Hoeller, in which Rolls-Royce Power Systems has just acquired a 51 per cent stake. Urban makes it clear that, as well as being the most important source of revenue at the moment, the



combustion engine will continue to play an important role in the future. »It is the very heart of our business. With our engine expertise, we have proven to customers that we are worthy of their trust.«

The power lies in the system – this is also the message Urban brings to the team, where conventional engine developers are increasingly interacting with employees from acquired start-ups. According to Urban, the different cultures can be successfully bridged through one thing in particular: collaborative working, encouraged in part by the fact that project teams physically move into shared spaces. Besides scientific results, Urban considers the opportunity for exchange as the most valuable advantage created by FVV. »There are so many open questions – for example, which combinations of energy converters and energy sources make sense for which applications. FVV is an important forum where these issues can be discussed in a scientifically substantiated manner.«

As far as model aircraft building is concerned, the issue of the ideal propulsion system also remains open. Martin Urban is regularly making time for crafts again – this time with his 13-year-old godson. //

Accelerated progress

Modern IT processes can accelerate the development of innovative energy converters and complete powertrains. With this in mind, researchers working on FVV projects are investigating the applicability of innovative methods such as object-oriented architectures and machine learning.

Managing variant diversity //

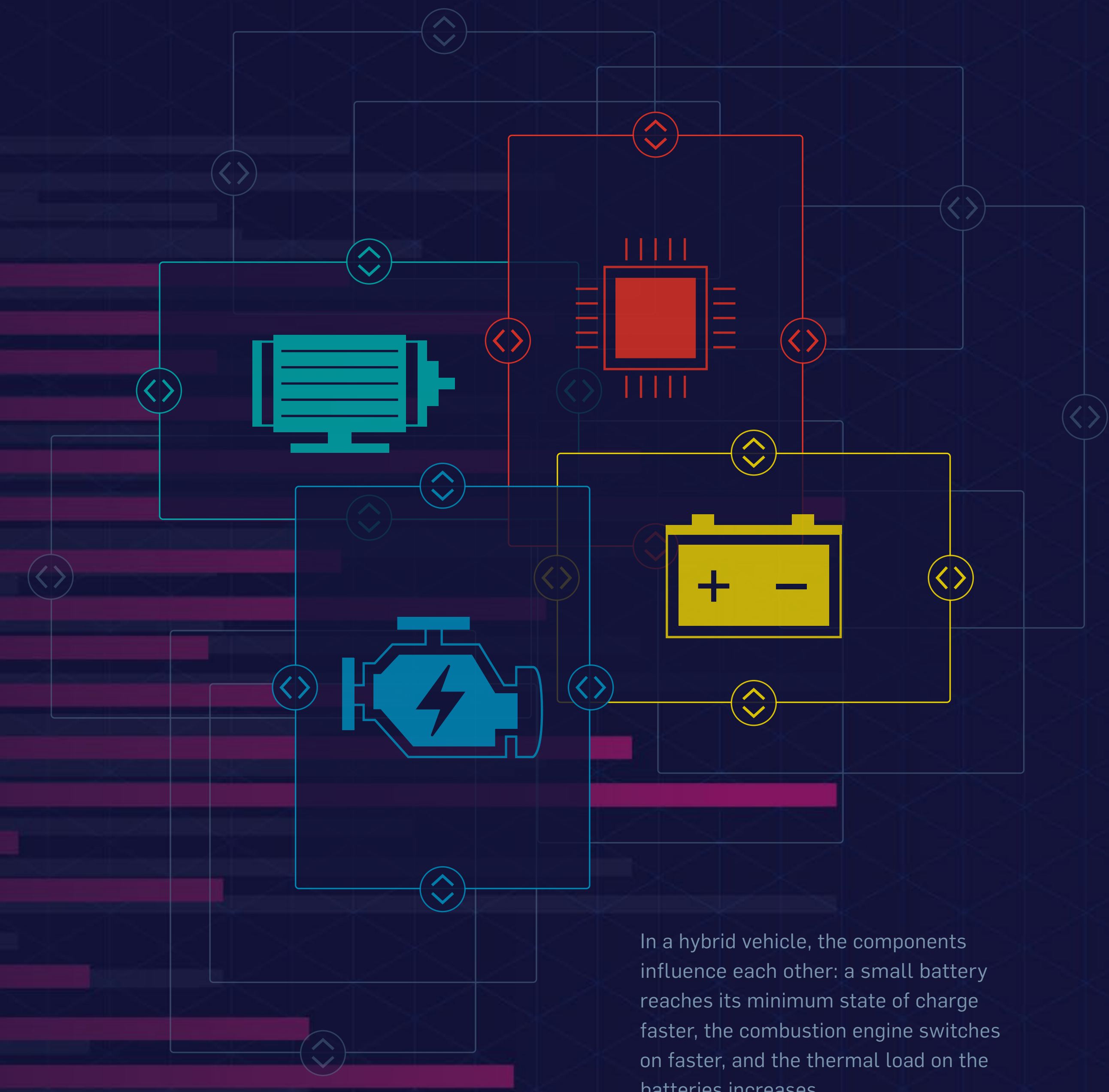
The development of hybrid powertrains presents engineers with huge challenges. Complex architectures, different powertrains, multiple energy conversion processes, interactions between subsystems and the interdependence of components increase complexity. And variant diversity is set to rise further in future, as it will be possible to combine various combustion engines, batteries and electric motors. Taking all of this into account during development requires an increased degree of modularity and an object-oriented architecture.

In FVV's ›Modular Hybrid Powertrain‹ project, researchers from the Technical University of Darmstadt are developing an integrated approach to efficiently meet different market requirements. In the concept phase, it is a question of finding a database for object-oriented designs and transferring this to modular structures for hybrid powertrain systems and the individual powertrain components. »You can picture this as a computer, where individual components such as the mouse, monitor, keyboard and printer form a complete system. Each component is an object that is networked and communicates with the others,« explains Prof. Dr. Christian Beidl, head of the Institute for Internal Combustion Engines and Powertrain Systems (VKM) at the Technical University of Darmstadt.

Transferred to a hybrid vehicle, the principle can be represented by a traction battery, for example. Its capacity has a decisive influence on the operating strategy of the vehicle. A small battery will reach the minimum charge level faster, the combustion engine will kick in earlier and the thermal load of the battery will increase. In a nutshell, the load profile will be completely different to that of a larger battery. In the object-oriented architecture, the researchers need to consider electrical, mechanical and software-based properties and dependencies. This requires further standardisation of the interfaces, which will provide great flexibility when it comes to adding, removing and scaling components.

Text: Matthias Heerwagen

Object-oriented architectures in powertrain development



In a hybrid vehicle, the components influence each other: a small battery reaches its minimum state of charge faster, the combustion engine switches on faster, and the thermal load on the batteries increases.

Thus, an object-oriented architecture takes into account the electrical, mechanical and software-based properties and correlations.

From FVV's perspective, the advantage of an object-oriented component definition is that it will also improve opportunities for suppliers in terms of how they interact with OEMs. »If we are working with a common description basis, every supplier will know what properties the component has to have. And every integrator will then be able to integrate this component,« explains Professor Beidl. The investigations will be based on the VKM's existing simulation structures, which already have a flexible and modular design. Two sample hybrid configurations are being used to validate the devised approach and the team is devising a matrix for evaluating the suitability of architectures.

Another project is also dealing with the challenge of growing variant diversity, as the number of parameters is also increasing in classic engine development. Stroke/bore, valve control, charging strategy or number of cylinders – every detail can vary and each change results in a completely different engine design. During the basic design of a new engine, the zero- or one-dimensional simulation is an indispensable development tool.

»The advantage of these methods is that they have relatively short computing times. However, here too, multi-dimensional optimisation problems in the calculation can be very time-consuming,« explains Dr. Christian Schnapp, development engineer at Toyota Gazoo Racing Europe. This takes up valuable time that could be spent elsewhere in the development phase. In the Heuristic Search and Deep Learning research project, Schnapp and his colleagues from the Chair of Thermodynamics of Mobile Energy Conversion Systems at RWTH Aachen University and the Institute of Automotive Engineering at the University of Stuttgart are looking for ways to reduce the computing time. This special project aims to simulate the high-pressure curve in the combustion chamber.

»We want to investigate how artificial intelligence can help in the development process by mapping the simulation via neural networks. We are pursuing two approaches to do this,« explains project coordinator Schnapp. In the first approach, deep learning is used and, as a first step, requires the researchers to generate many millions of data sets with a detailed model that they will then use to train a neural network – a form of artificial intelligence. The AI algorithm is based on libraries that are freely accessible in the Python programming language and that the engineers can make use of. »This is a common standard and means that other researchers or companies can also use the algorithm,« says Schnapp.

Sample projects on
FVV's research priority ›Digitalisation‹

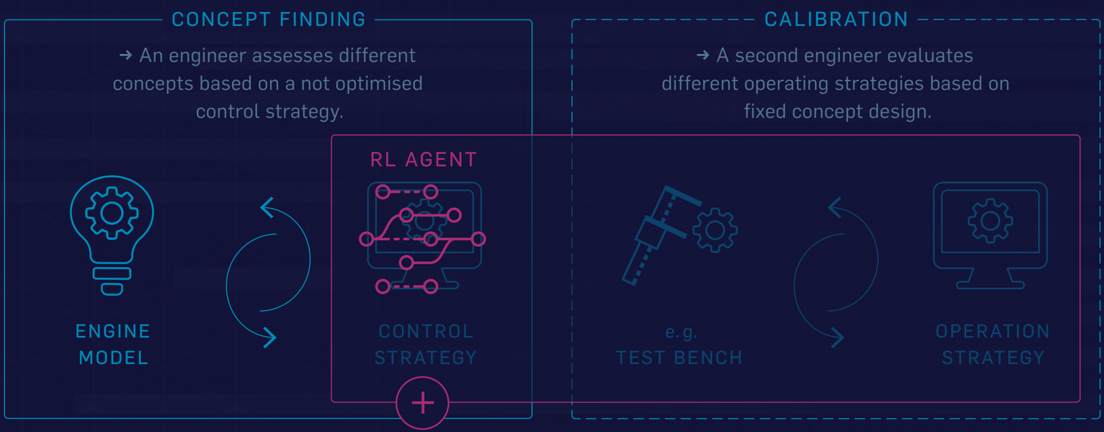
- » Modular Hybrid Powertrain [1428]« // **FUNDING:** FVV // **PROJECT MANAGEMENT:** Dr. Veit Held (Stellantis Opel Automobile) // **RTD PERFORMER:** Institute for Internal Combustion Engines and Powertrain Systems (vkm), TU Darmstadt
- » Heuristic Search and Deep Learning [1426]« // **FUNDING:** BMWK/AiF (21407 N) // **PROJECT MANAGEMENT:** Dr. Christian Schnapp (TOYOTA GAZOO Racing Europe) // **RTD PERFORMERS:** Teaching and Research Area Mechatronics in Mobile Propulsion (MMP), RWTH Aachen University / Chair of Thermodynamics of Mobile Energy Conversion Systems (tme), RWTH Aachen University / Institute of Automotive Engineering (IFS), University of Stuttgart

The initial data is impressive: the AI produces a result 50 times faster, and without jeopardising accuracy. The models can therefore be integrated into real-time applications in future or even used to solve higher-dimensional optimisation problems – for example, if several components in the overall system need to be optimised.

The other approach concerns what is known as reinforcement learning. So far, a simulation engineer has been working in the development phase and studying various engine concepts which do not yet have an optimum control strategy. Another engineer then develops this strategy on the test bench. The idea is then to hand this task – whether it be the control of an e-booster, waste gate or the setting of the ignition time, for example – over to a reinforcement learning agent. »By carrying out lots of simulations, the agent attempts to teach itself the best control strategy,« explains Schnapp, who adds: »This is performed by rewarding the agent for a success, so that it always learns more.« A time-consuming undertaking it may be, but the calculation time can be shortened by running parallel simulations. It is conceivable that the trained strategy will be implemented directly into the ECU in the future.

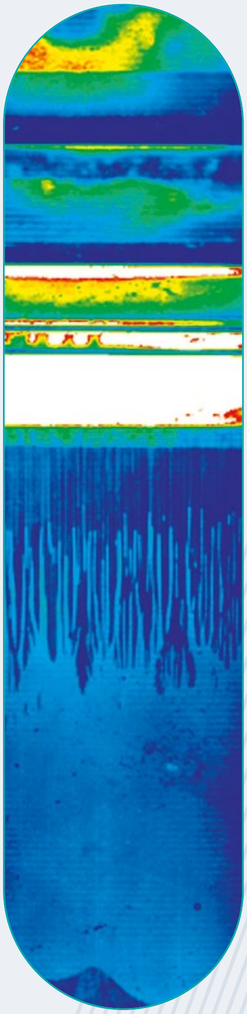
The project is set to run until 30 April 2023, but FVV members will soon be able to benefit from the initial results and rapid knowledge transfer: »There is certainly interest in the code, so we are going to hold a workshop in which the code from the first work package will be made available,« says Schnapp. The final documentation and a simulation tool for immediate use will be provided at the end of the project. //

Reinforcement learning for the concept design of SI engines



→ Today's ENGINE DEVELOPMENT PROCESS consists of two distinct steps. This approach leads to suboptimal layouts, because the transient engine behaviour should already be taken into account during the concept finding phase.

→ A reinforcement learning agent finds the optimal control strategy for each engine design. By integrating the RL AGENT into the concept finding process, an appropriate evaluation of a control strategy can already be carried out in the first step.



On the hunt for **molecules**

Work on the test bench is still indispensable to engine development, despite the fact that simulation options are constantly improving. Against this backdrop, researchers in a joint German-Japanese project are making the oil movements in the piston assembly of an engine visible.

Several paths lead towards the destination // One path towards climate-neutral mobility involves hydrogen as an energy carrier. As hydrogen does not contain any carbon, no CO_2 is produced during combustion. Classic combustion processes in the piston engine are suitable for the rapid deployment of hydrogen, but one challenge is to minimise the emissions from the lubricating oil. To do this, the amount of oil that is transported out of the crankcase and into the combustion chamber needs to be reduced. »Oil consumption has been halved over the past 20 years. A further 30 to 40 per cent reduction is certainly possible,« says Dr. Marcus Gohl, development engineer at APL Automobil-Prüftechnik Landau, stating one ambitious goal. He adds: »Although research has been conducted into the system for years, the individual mechanisms are still not understood in detail due to the highly dynamic movements.«

When it comes to sealing the combustion chamber, the proven combination of pistons and piston rings is still the system of choice, as it represents a cost-effective and efficient solution. However, if the piston rings are not completely tight, oil can enter the combustion chamber from the crankcase and fuel can ingress into the oil from above, for example due to incomplete combustion. The engineers are faced with conflicting goals: »The entry of lubricating oil into the combustion chamber has the unpleasant consequence that lots of tiny particles are generated, even if the volumes of oil are small,« explains Gohl. Even if these are then filtered out again during exhaust gas aftertreatment, the raw emis-

Text: Matthias Heerwagen

→ Through the **sapphire glass window embedded in the cylinder**, the researchers use a laser beam to excite a marker which has been applied to the engine oil. The thicker the oil film in one spot, the higher the luminous intensity.

Photos: TU München

sions need to be kept as low as possible. At the same time, an oil film with a layer thickness of just a few micrometres is needed on the cylinder barrel to prevent wear. During engine operation, however, some molecule layers can evaporate during each working cycle. If the remaining oil film is too thin, the piston rings come into contact with the cylinder barrel, posing a risk of engine damage.

In the joint German-Japanese Fuel Oil Flow Measurement project (1396), researchers from Tokai University, Tokyo City University, the Technical University of Munich and the Institute for Analytical Measurement Technology Hamburg are investigating oil transport processes in the piston assembly. To do this, a single-cylinder spark-ignition engine was built in Munich, with an oblong sapphire glass window embedded in its cylinder barrel for the tests. Through this window, the researchers are able to observe how the oil accumulates and moves using two optical processes. With laser-induced fluorescence, the researchers apply a marker to the oil, which is excited by the laser and then lights up. The light intensity changes depending on the amount of oil at a certain point – a thicker oil film will glow more brightly. Marcus Gohl is full of enthusiasm for the technique: »On the film images, we can even observe the oil transport mechanisms when the engine is fired under full load and, in parallel, use the mass spectrometer to measure individual hydrocarbons such as evaporating oil molecules.«

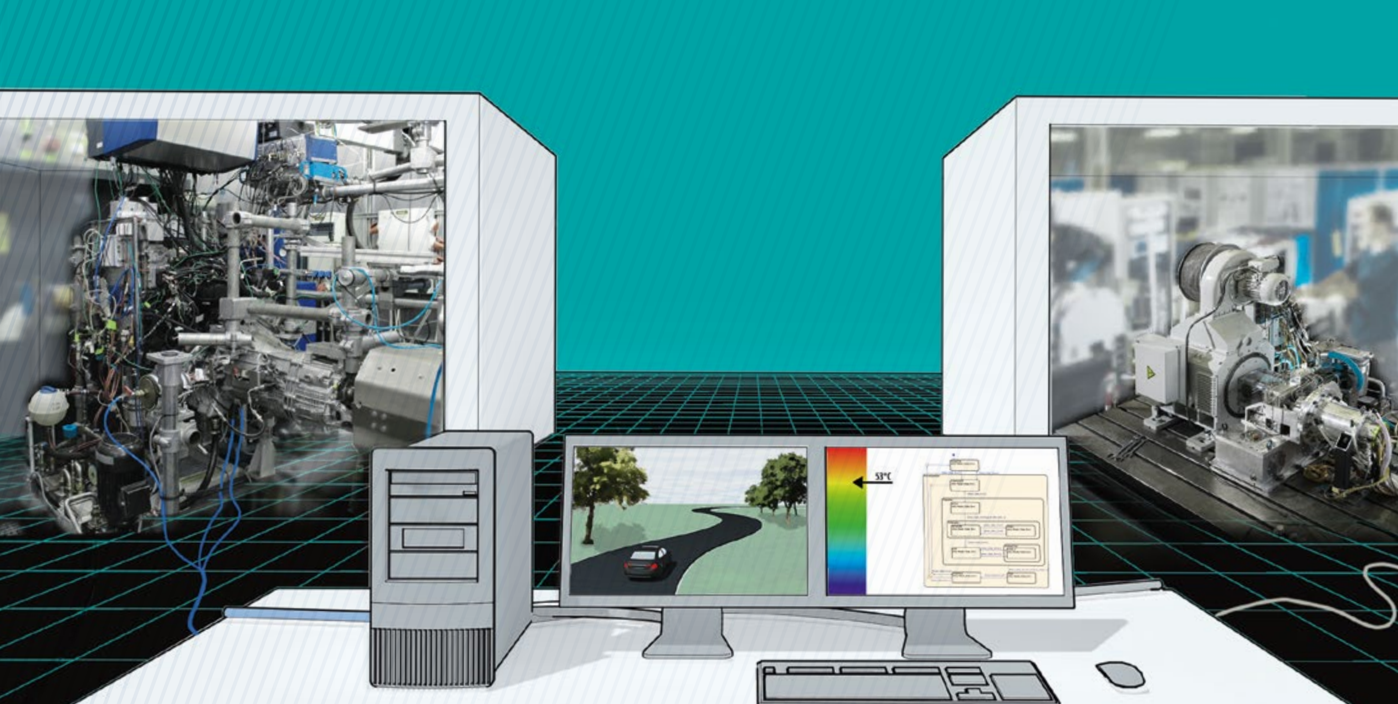
The engineers in Japan have used photochromism to develop the second optical measurement technique, which is also based on a marker in the oil. »Photochromism is suitable for determining the oil and fuel film flow and making movement visible,« explains project coordinator Dr. Motoichi Murakami from Toyota. »To do this, the laser generates a small and relatively long-lasting colour marker at any point on the oil film and at any time. This allows us to observe how the oil moves – for example, from the top to the bottom or through the impacts of the piston rings,« says Murakami. He adds that, in addition to measuring the oil film, the option to measure the fuel film both on spark-ignition and diesel engines is an important result, as this has never been done before with this technique.

Engineers also worked on new development methods in the broader, recently completed FVV project entitled ›Method Hybrid Testing‹. More and more often, cars have hybrid powertrains where development and testing involve huge complexity. However, test benches for complete powertrains are expensive, generally already being used to full capacity and – compared to component test benches – can only be equipped with limited measurement technology. Researchers from various departments at the Karlsruhe Institute of Technology (KIT) have now developed a methodology which connects different component test benches in order to map hybrid powertrains virtually. This enables the influence of different components on the overall system to be examined even at early development phases. In addition, the use of appropriate measurement techniques allows detailed statements to be made regarding loads, emissions and the consumption of fuel and electrical energy. Benefitting from this are small and medium-sized automotive suppliers which can now also adapt their products at an early stage.

Sample projects on FVV's research priority ›Development tools‹

- » Fuel Oil Flow Measurement [1396]« // **FUNDING:** CORNET // **PROJECT MANAGEMENT:** Dr. Motoichi Murakami (Toyota Motor Corporation) / Dr. Marcus Gohl (APL Automobil-Prüftechnik Landau) // **RTD PERFORMERS:** Tokai University / Faculty of Engineering, Tokyo City University / Institute of Analytical Measurement Hamburg – IAM-Hamburg e V / Institute of Sustainable Mobile Drivetrains, TU München

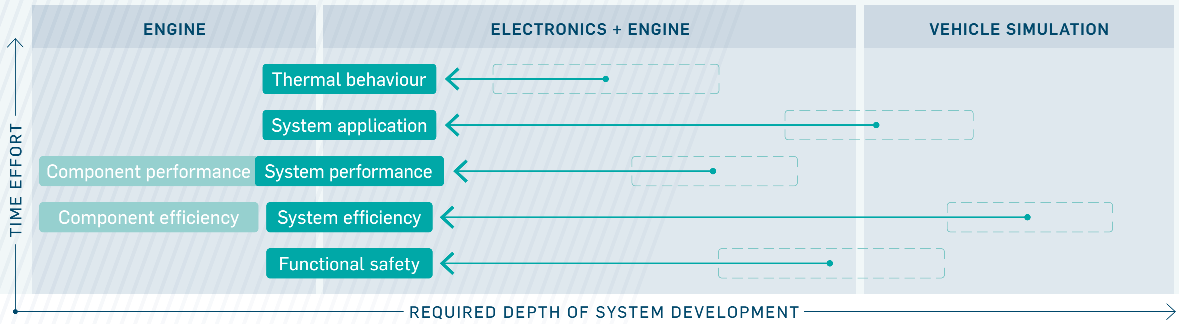
- » Method Hybrid Testing [1363]« // **FUNDING:** FVV // **PROJECT MANAGEMENT:** Dr. Marcus Gohl (APL Automobil-Prüftechnik Landau) // **RTD PERFORMERS:** Institute of Electrical Engineering (ETI), KIT Karlsruhe / Institute of Vehicle Systems Technology (FAST), KIT Karlsruhe / Institute for Internal Combustion Engines (IFKM), KIT Karlsruhe



Potentials of coupled test benches

Photo: KIT

→ Schematic representation of the temporal shift of individual complete vehicle test cases into the component test phase. Networked test rigs result in **significant time and cost savings**.



A special focus was placed on the mapping of the thermal systems in a manner that replicated real-life vehicle conditions, with the aim of testing new thermal management concepts early on. The follow-up project makes direct reference to this and focuses on meeting significantly stricter emission standards that have yet to be defined. In particular, the extended temperature range from –10 to +40°C represents a major challenge for hybrid vehicles, as both the exhaust gas aftertreatment system and the battery need to be brought to operating temperature within a short period of time. When it comes to developing the powertrain, this requires development and test methods that are as flexible as possible.

To meet this requirement, the project is pursuing an approach featuring coupled test benches. The test benches for the combustion engines and electric motors, which have already been connected, are supplemented by a battery test bench that KIT is integrating into the existing network. The test benches are equipped with an automatic start/stop system, dynamically adjustable conditioning systems and rapid exhaust gas measurement technology to enable the replication of realistic Euro 7 cold start conditions. Subject to the powertrain topology, the operating strategy and the resulting temperatures, efficiencies and emissions, this then allows the most energy-efficient cooling concept to be determined. //

Coordinating expertise

At the Institute of Automotive Engineering at the University of Stuttgart, **Viktoria Kelich** is responsible for coordinating the research projects – a role that combines her love of engineering with business knowledge and a talent for organisation.

Photos: Dirk Lässig
Text: Matthias Heerwagen

Partners are essential // Good research doesn't achieve anything all by itself – it needs to be shared among experts with complementary expertise. Viktoria Kelich has made it her mission to link the right people together to develop state-of-the-art vehicle powertrains. The passion for engineering that she gets to live out in her job was inspired in her as a child. Her father, an electrical engineer, used to repair friends' and acquaintances' television sets and video recorders during the evenings from his kitchen table. His six-year-old daughter sat next to him, watching with interest. As a teenager, the pair of them built a stereo system together, and she still uses it regularly to this day.

This affinity for engineering and science stayed with her, and while her fellow students at her specialist business college chose to drop subjects like physics and chemistry, she decided to only study science subjects. »After taking my final leaving exams, I knew I wanted to study business administration, but I also wanted to do something with engineering. That's why the technically oriented business administration programme at Stuttgart was perfect for me,« says Kelich. This combines the basic technical study programme of an engineer with classic business administration. Materials science, manufacturing and strength of materials form part of the curriculum alongside marketing, macroeconomics or mathematics for economists. Kelich chose to study two engineering-focused electives – automotive and production engineering – even though she only needed to pick one. »I was interested in both subjects and they enabled me to broaden my technical profile.« To inspire more girls and young women to study engineering, she is a dedicated VDI ambassador and visits schools and careers events.

Kelich was in charge of organising the University of Stuttgart's Formula Student race team from 2016 to 2018. She decided who did what, where and when they did it, coordinated processes during the race season and organised sponsorship and PR. Everything had to go to plan and the preparations were complex and took weeks to complete. The roll-out of the 2017 race car in front of 1000 guests at the Carl Benz Arena in Stuttgart, which she was responsible for organising, remains a very special memory. And the teams in the years that followed regularly asked her for advice. During this time, Kelich acquired skills that still help her on a daily basis: she learnt how to maintain an overview of the big picture, not to get bogged down in the tiny details and to delegate tasks to the right people. She says: »Each person needs to be deployed where their strengths lie, and my strengths lie in juggling lots of things at the same time.«

»Each person needs to be deployed where their strengths lie, and my strengths lie in juggling lots of things at the same time.«

Her coordination skills had to be put to the test right at the beginning when she started her role as a research assistant at the Institute of Automotive Engineering (IFS) at the University of Stuttgart. Her boss, Prof. Dr. Michael Bargende, had a particular job for her straight away: a week after joining the team, the FVV autumn conference was taking place and Kelich was required not only to take part but also to co-organise the IFS's reporting of the event. Over the months and years that followed, she has learnt the ropes, familiarised herself with the structures and established good relationships with FVV. This wouldn't have been possible without her technical knowledge. Kelich has that in spades, and she is able to explain complex matters in layperson's terms – a skill that served her well during her master's degree when she tutored student practicals. Kelich has decided not to pursue an envisaged doctorate in marketing, as she would prefer to remain involved with engineering.

As research manager at the IFS, Viktoria Kelich is responsible for coordinating around 30 publicly funded research projects and takes on tasks in each individual phase – from project acquisition to completion. After drafting presentations and application documents, she searches for new funding opportunities and project managers, looks after doctoral candidates, organises events and takes care of external communications. Her work also involves coordinating international FVV research projects, such as the CORNET programme which was established by the German Federation of Industrial Research Associations (AiF) with the aim of bolstering international collaboration.

Kelich is currently working on the application for a joint research project on hydrogen combustion processes involving water injection between the IFS, RWTH Aachen University and Politecnico di Torino. »The project aims to use direct injection to improve knock behaviour and to reduce the NO emissions formed with hydrogen engines. To do this, both experimental and simulative studies need to be conducted, and water evaporation, carburation, spray geometry and combustion processes need to be investigated in order to derive injection strategies,« says Kelich, explaining the complex research approach. This can only succeed with teamwork: the test engine is set to be based in Aachen, the 3D simulation is likely to be processed in Stuttgart, while the 0D/1D simulation will take place in Turin. Kelich is coordinating the expertise.

And the young woman has no complaints in terms of the variety of her job – the wide range of tasks that her role entails is something she enjoys. But does the call of industry sometimes tempt her? »Research and development is really exciting, but motor sport too has never loosened its grip on me. Working as a team and putting all your effort and energy into achieving something that seemed almost impossible – and then winning – is a great feeling!«

enthuses Kelich. But perhaps she would miss the conferences, organisation, communication, contacts and everything else that goes into research management. To clear her head, the 34-year-old jumps in her bright yellow Mercedes and drives to her ballet class for a 90-minute workout three times a week after work. How does she find the time? »It's all a question of self-management.« //

VIKTORIA KELICH,
MSc, born in 1987, studied technically oriented business administration at the University of Stuttgart. After her master's degree, she enrolled on the electrical engineering programme and attended various lectures for three semesters. She was in charge of organising the University of Stuttgart's race team for two years. Since 2018, Kelich has been coordinating the research projects at the Institute of Automotive Engineering at the University of Stuttgart (IFS); as part of FVV's CORNET programme, she champions international collaboration between various universities.

The **common thread**

Regardless of which energy converters and energy carriers are used in the future, the efficiency of energy conversion processes is one of FVV's most important research areas.

Every kilowatt-hour counts // This is true not only for electricity and gas and not only in the here and now. Efficiency has always been a central development goal for prime movers. A more efficient use of fuel helped the steam engine of a certain James Watt to achieve his breakthrough, just as it did for Rudolf Diesel's self-igniting piston engine. And this certainly applies to the energy converters in a climate-neutral future, where renewable gases and synthetic fuels will be used as energy carriers. Against this backdrop, projects on increasing efficiency are a common thread running through the research programme of FVV and range from increasing the system efficiency of hybrid powertrains all the way up to optimising components for fuel cells.

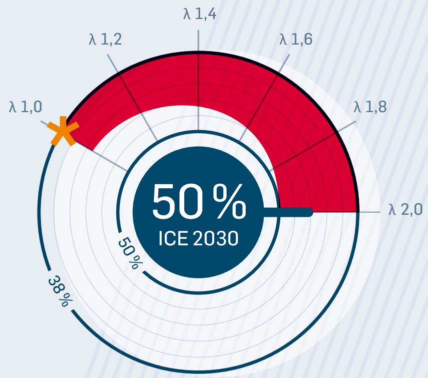
The journey towards higher efficiency has been taking in new terrain for a number of years, as Prof. Dr. Stefan Pischinger explains: »In the past, the main focus was on improving the efficiency of the operating ranges in which specific fuel consumption is particularly high. In modern hybrid powertrains, the combustion engine can generally be operated close to its optimum point – so it's primarily a question of improving consumption in this range.« As the holder of the Chair of Thermodynamics of Mobile Energy Conversion Systems at RWTH Aachen University, Pischinger, along with three other RTD performers at the universities of Braunschweig, Darmstadt and Stuttgart, is conducting research into exactly this subject on behalf of FVV. The ICE 2030 project aims to develop the technical concept for a combustion engine for a car that will achieve an efficiency of at least 50 per cent at its optimum point.

Pischinger is certain that this can be achieved – after all, there are already commercial vehicle engines and large engines that exceed the 50 per cent mark. »However, with smaller engines, the proportion of tribological and thermal losses is higher,« he says, explaining the scale of the challenge. As in the ICE 2025+ predecessor project, the four institutes are not simply examining the engine technology in isolation, but are also considering the influence of the fuel on efficiency. For example, the targeted admixing of hydrogen is being investigated. Hydrogen is extremely combustible and therefore allows combustion even if there is a high excess of air. »It's a case of exploring the boundaries,« says Pischinger. As a secondary benefit, he believes that hydrogen engines could also be designed for flexible operation. If piston engines operating with hydrogen achieve an efficiency of 50 per cent, they would come pretty close to the fuel cell, he explains.

Text: Johannes Winterhagen

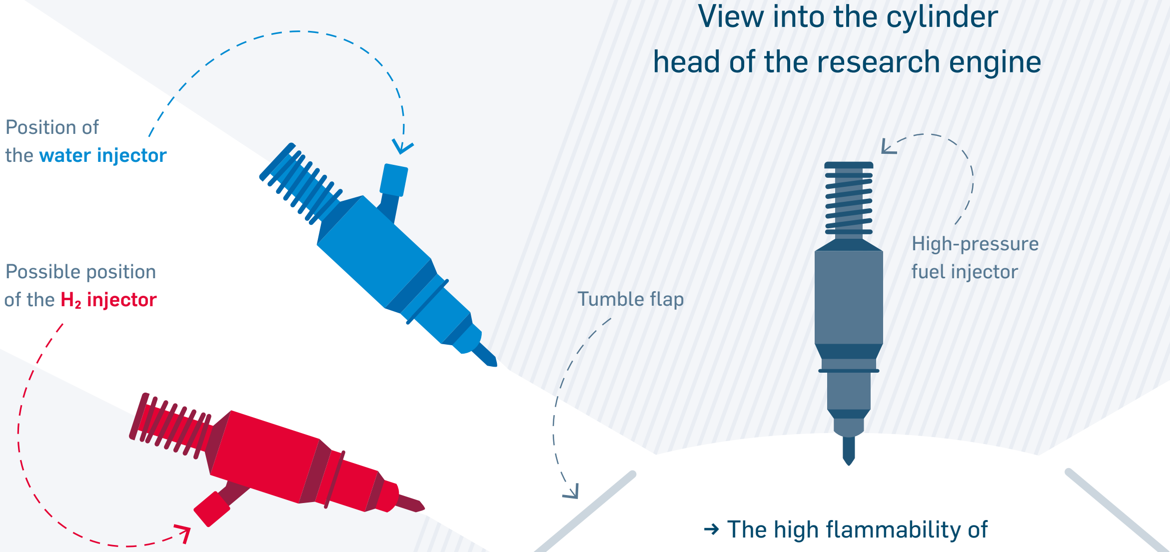
Financed from FVV's own funds, the project will continue to run until the start of 2023. But will the results still be relevant given that European manufacturers will be bringing the last generation of car combustion engines onto the market in 2025 or 2026? »Absolutely,« says Pischinger emphatically. »Even in 2035, 40 to 50 per cent of all new cars worldwide will have a combustion engine. And if these vehicles consume 20 per cent less fuel on the road, that is definitely relevant!«

Efficiency of at least 50 % at the best point is the target



* The starting point is a modern SI engine with an efficiency of 38.5 percent at a fuel-air ratio of lambda = 1.

View into the cylinder head of the research engine



→ The high flammability of hydrogen allows combustion even with high excess air.

»Every kilowatt counts.«

For fuel cells based on polymer electrolyte membranes (PEM), an efficiency of 50 per cent represents the lower end of the scale. But developments mustn't stop there. In addition to the continuous improvement of the cells and cell stack, there is a second optimisation field: the ›peripherals‹, which primarily concern the supply of air and hydrogen as well as the removal of water. The problem in practice is that the components that are important for conveying media are generally based on components which were actually developed for combustion engines (due to the low volumes currently required). This is the case, for example, with respect to the compression of air, which has a direct influence on the efficiency of the fuel cell and the system.

Currently, centrifugal compressors are mainly used, which are derived from exhaust gas turbochargers. »This works in principle. But instead of the exhaust gas mass flow, a small electric motor is then used to power the compressor,« explains project manager Thomas Hildebrandt, founder of Numeca, an engineering firm specialising in turbomachinery. »For the electric motor, around twelve kilowatts of power are required for a 100-kilowatt stack.« Each saving made here would be entirely to the benefit of the system efficiency. The FVV project, which is sponsored by the German Federal Ministry for Economic Affairs and Climate Action, is working on exactly this. It is investigating what a compressor would look like if it were specially designed for use in the air system of a fuel cell. »The geometric design determines the efficiency,« says Hildebrandt with conviction.

A suitable design does not exist yet, which is why the first task is to select a few options from the thousands of theoretical variants with the aid of a numerical optimisation method. These compressors then have to prove themselves in two stages: firstly, they are sent in their original size to a small test bench where their basic function is confirmed. The problem is that, in their original size, the compressors are far too small to be equipped with extensive

Photo: MAHLE

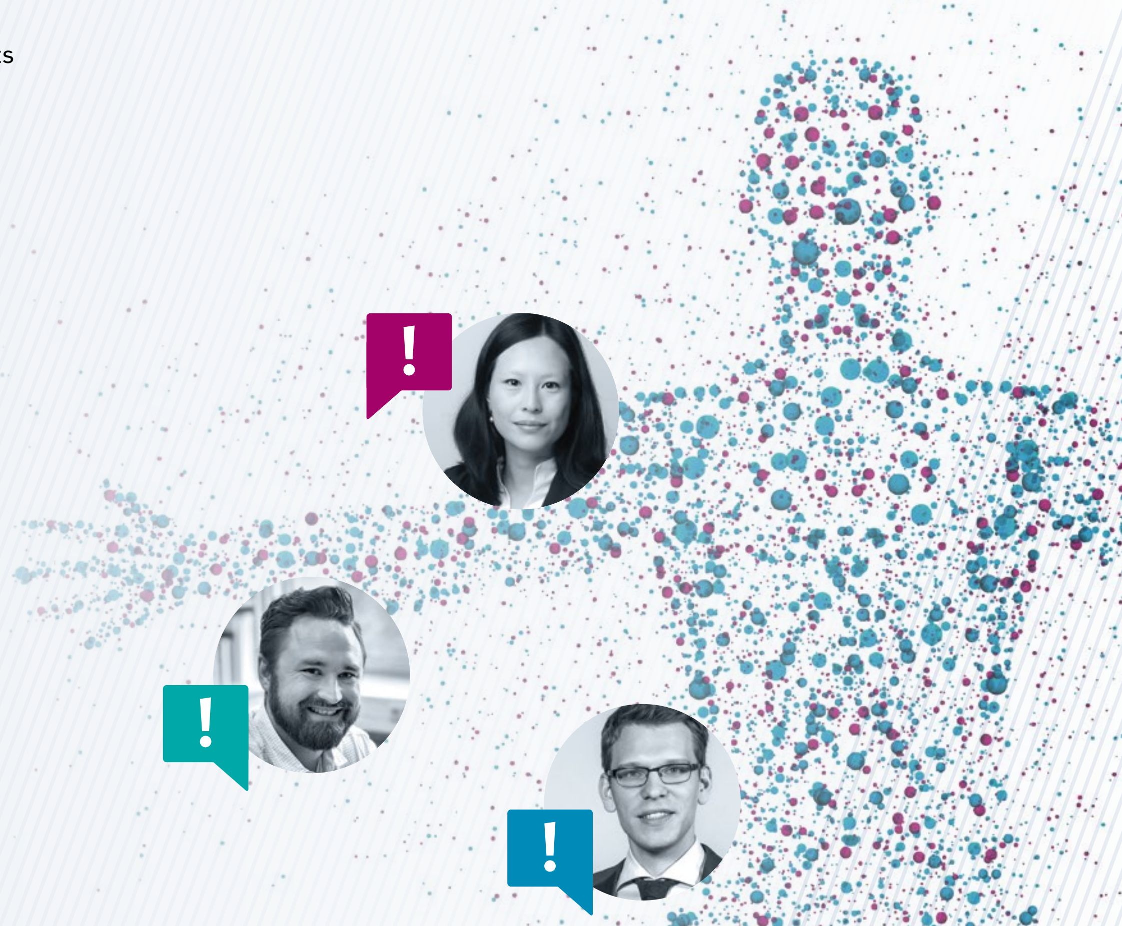
Test rig for fuel cell components at Mahle: For optimum development of cell components, a perfectly adapted test environment is a key factor.

measurement technology – especially if you want to avoid distorting the measurement result. This being the case, a prototype that is three times larger than the original and which has the ideal geometry is being tested on a large centrifugal compressor test bench at RWTH Aachen University. This test bench was co-financed by FVV (see PrimeMovers 2021, p. 60 onwards) and is now being used for a fuel cell project for the first time. At the end of the project, which is set to run until summer 2023, a chain of development tools will be available. Small and medium-sized companies will then be able to use these tools to get involved in the design of compressors for fuel cells.

»Every kilowatt counts,« says Thomas Hildebrandt, who has been designing turbomachinery for decades. This sentence could also form the common thread that connects the research of FVV across all energy converters and energy carriers. //

Sample projects on FVV's research priority ›Efficiency‹

- → »ICE2030 [1434]« // **FUNDING:** FVV // **PROJECT MANAGEMENT:** Arndt Döhler (Stellantis Opel Automobil) // **RTD PERFORMERS:** Chair of Thermodynamics of Mobile Energy Conversion Systems (tme), RWTH Aachen University / Institute for Internal Combustion Engines (ivb), TU Braunschweig / Institute for Internal Combustion Engines and Powertrain Systems (vkm), TU Darmstadt / Institute of Automotive Engineering (IFS), University of Stuttgart
- → »Fuel Cell Compressor Design [1439]« // **FUNDING:** BMWK/AiF (21644 N) // **PROJECT MANAGEMENT:** Dr. Thomas Hildebrandt (NUMECA Ingenieurbüro) // **RTD PERFORMERS:** Chair of Thermodynamics of Mobile Energy Conversion Systems (tme), RWTH Aachen University / Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University



»No one makes it alone«

FVV has been presenting the Young Researchers Award for outstanding scientific achievements by students since 2006. The prize winners **Dr. Denise Chan**, **Bastian Lehrheuer** and **Marcus Wiens** speak here about their experience with FVV projects and what is expected of engineers and scientists.

During your studies, you all worked on FVV research projects. What were you able to take away from this time for your later careers?

! For me there were three points besides the professional insights: Firstly, I was able to gain an insight into industrial research, which was incredibly valuable. Secondly, I was able to gain my first experience in project management. And I found the interdisciplinary collaboration particularly enriching. In the working group, I had to make the chemical structures understandable to many mechanical engineers. This taught me how important it is to find common ground when it comes to communication. If you can do that, you can combine expertise from different disciplines, which is the best way of solving complex problems. In fact, this has accompanied me throughout my entire professional career.

! From a technical point of view, I've not really moved too far from the issues I focussed on during my studies. I first learned the methodology needed to answer such questions through the coursework in an FVV research project. The structured approach of creating a model and then testing it in an experiment is still helpful today. I also loved the fact that I wasn't just handing in written coursework that gets marked and then disappears into a drawer. I found it very motivating to produce a piece of work that others could build on and which found its way into the final report.

! I can only agree with all of that. My Bachelor's thesis within the FVV project was the first topic I worked on independently as a junior researcher. This also showed me that not everything always works out the way you imagined it would right away. Going on to try something new, something that no one has ever done before, is what still intrigues me about science to this day. There's something else I also took away: my fuel conversion topic had some chemical aspects that were completely new to me at the time. Not to be put off by this, but to ask experts for explanations is something that has proved invaluable time and again later in my life.

How do you view the social responsibility of engineers and scientists today?

! You always have to look at the bigger picture. I am currently researching electricity generation from wind power. But there are still many questions to be answered about the use of this electricity. And there probably won't be just one answer either. For example, in the future we perhaps could electrify all small cars, but run heavier vehicles, especially in goods transport, on hydrogen and synthetic fuels. I definitely still see potential for the combustion engine.

! The most important thing is that engineers and scientists remain curious and keep searching for new answers – and in a way that is as interdisciplinary and open-ended as possible. We learned how to do this systematically in our studies.

! This is especially true for the transformation to a sustainable world. We have the knowledge to look for new answers in a targeted manner; for example, switching to renewable energies and effective storage technologies. Another example is that there is still a great deal of research needed in chemical recycling, both in terms of catalysts and process technology. Ultimately, we are heading towards a world where carbon from fossil sources is no longer available.

Beyond the technology, what else do you think is important for achieving this transformation?

! Interdisciplinary collaboration! No Company and no industry can manage the transformation to a circular economy on its own. Everyone needs to pull together because we need the entire supply chain to achieve this and we have to look at the entire life cycle of the products. This also requires policymakers to create the right framework conditions. There are numerous good approaches, but implementation is subject to so many things. For example, permits take far too long even for the conversion of existing plants. Planning certainty would be very helpful.

! Policymakers must set framework conditions that address the fundamental problems instead of prescribing technology decisions. At the moment, these policymakers are oversimplifying things. They work with prohibitions without these having a sound scientific background. We're talking about the house being on fire. And we have three fire extinguishers: electromobility, hydrogen and synthetic fuels. Instead of using all three fire extinguishers, policymakers are discussing which fire extinguisher we are allowed to use.

! Policymakers are also responsible for the expansion of wind energy. We have a tremendously big goal, after all. And to achieve it, we have to solve enormous tasks. However, if we merely focus on small problems, we will not be successful. But this should not distract from the fact that we as engineers are responsible for tackling many new things and constantly scrutinise the status quo.

DR. DENISE CHAN
studied chemistry at the Karlsruhe Institute of Technology. She completed her dissertation as part of an FVV project on the simulation of exhaust gas catalysts and received the FVV Young Researcher Award for it in 2010. After completing her doctorate – also on exhaust gas catalysis – Chan began her career as a laboratory manager at Covestro (Bayer at that time) in 2014. After another role with global technology responsibility, she assumed her current position as Executive Assistant to the Chief Technology Officer of Covestro at the beginning of 2021.

BASTIAN LEHRHEUER
studied mechanical engineering in Aachen. In 2010, his student research project on a real-time gas exchange model, which was developed as part of an FVV project, was honoured with the Young Researcher Award. After completing his studies, he initially worked as a research assistant at what is now the Chair of Thermodynamics of Mobile Energy Conversion Systems at RWTH Aachen University, coordinating FVV projects among other things. Lehrheuer became chief engineer in 2018 and took over the management of the ›The Fuel Science Center‹ excellence cluster in 2019.

MARCUS WIENS
first studied mechanical engineering at RWTH Aachen and completed his Bachelor's thesis, which was awarded the Young Researcher Award, on modelling reduced reaction mechanisms for gasoline fuels as part of an FVV project. He then switched to energy technology for his Master's degree, which he completed with a thesis on the control of wind turbines. Since 2019, he has worked as a research associate at the Fraunhofer Institute for Wind Energy Systems, where his primary focus is on simulation issues.

With your experience today, what do you recommend when it comes to the training of future scientists?

! At our university today, interdisciplinarity is at the top of the agenda. There are more and more degree programmes that cross over into several faculties. In FVV projects, too, different disciplines are working together more often. When you're sitting together over a beer after a working group meeting, it doesn't matter what discipline you work in.

! We take great care to ensure that young people who come to us not only achieve good results working alone behind closed doors, but can also work together with others. A great wish of mine is for there to be greater diversity in professional technical fields and in FVV projects.

! It is good that Germany offers Bachelor's and Master's theses are often carried out in industrial companies or within the framework of Industrial Collective Research. This ensures that young researchers are working on topics with industrial relevance. This is something we need to continue at all costs! //

Photos: Covestro (Chan), RWTH (Lehrheuer), FVV (Wiens)

»Knowledge is generated at **interfaces**«

Training specialists in efficient prime movers and engines – in combination with climate-neutral energy sources – remains an important task. **Prof. Dr. Thomas Koch**, Head of the Scientific Society for Automotive and Engine Technology, explains what young engineers should be learning today.

Text: Johannes Winterhagen

Professor Koch, why should a young person choose to study mechanical engineering with a focus on combustion engines?
Engines power countless machines, from hand-held chainsaws to agricultural machinery and ships. In many applications, there is no chance of the combustion engine being replaced in the coming decades. And even in the automotive sector, combustion engines still have a future in many regions of the world and possibly also in Europe.

Young people usually want to make the world a better place. Can they do that with a scientific education as specialists in motor vehicle and engine technology?
Whether it's electric powertrains, fuel cells or combustion engines, much remains to be done; for example, when it comes to raw materials, costs or the sustainability balance. At the same time, we have to make sure that we can produce the solutions in this country so that we can also generate prosperity here.

Please be a bit more specific – what will be the most exciting tasks for research and development in the future?
First, the new tasks are the same as they were 30 years ago: improving efficiency and thus reducing energy demand remains an important engineering task. The same applies with regard to further increasing the durability and with it the sustainability of machines. Added to this is the new task of operating with carbon-neutral fuels. The conventional piston engine is also usually part of a hybrid powertrain, which raises new control engineering questions.

How much knowledge is there already out there regarding the interaction between piston engines and renewable fuels?
The biggest challenge is that we have to dovetail the development of energy sources and energy converters better than we have managed to in the past. After all, the investment costs for fuel production plants are very high. We have to achieve an overall optimum, which is not possible if we only consider the engine or the hybrid powertrain individually. At present, no one can say whether a holistic optimum will ultimately be found in the use of hydrogen, methanol or another hydrocarbon.

At the same time, methodological development seems to be taking a big leap forward.
In the last 15 years, the focus has been on optimisation in n-dimensional space, i. e. the search for the optimum with simultaneous variation of injection timing, exhaust gas recirculation rate, boost pressure or Adblue dosing, for which the design of experiments has been continuously developed further. But it still takes us far too long to get from an initial application solution to a drivable prototype. That is why new methods, such as artificial intelligence processes, are playing an increasingly important role in engine development.

How is teaching changing as a result of the increasing electrification of combustion engine powertrains?
We have to incorporate everything, but also need the courage to hand over, at the right time, to neighbouring institutes which are working on batteries or fuel cells, for example. But teaching also needs to dovetail better. For example, I will present a lecture on hybrid powertrains together with a head of the Electrotechnical Institute at my university. Close collaboration is important because knowledge is generated at interfaces.

PROF. DR.-ING. THOMAS KOCH
has headed the Institute for Internal Combustion Engines at the Karlsruhe Institute of Technology (KIT) since 2013. Before his appointment, the mechanical engineer with a doctorate from ETH Zurich worked in engine development at Daimler AG for ten years. His numerous voluntary activities include involvement in the Scientific Society for Automotive and Engine Technology (WKM).

Photo: KIT

What role does Industrial Collective Research play in this?
Even if the application process has become somewhat cumbersome and bureaucratic, I consider Industrial Collective Research, as organised by FVV, to be extremely valuable. In the past, it has significantly strengthened the competitiveness of German companies – especially in the SME sector – as well as environmental protection. One example is research into exhaust gas purification. I see no reason why such a successful instrument should be less profitable in the future – especially as working in FVV projects prepares young engineers well for their work in the industry later on.

What are the current job prospects for young engineers?
The pandemic initially cut quite a swathe through the personnel market, but our graduates are now experiencing increased demand again – including from the automotive industry.

Thank you very much for the interview, Professor Koch! //

»Make it new«

Science for a
moving society

Background: monsitj, Adobe Stock

FVV PrimeMovers.
Transfer + Networking Event.

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 fantastic network!

Nothing can replace face-to-face meetings! Please save the dates of the FVV Spring & Autumn Conferences:

Spring – 30 / 31 March 2023

Autumn – 05 / 06 October 2023

See you there!

FVV PrimeMovers.
Publications.

MTZ / ATZ – PROJECT REPORTS

- **MTZ 09/2022:** Investigation double-flow turbines // Project: Investigations into double-flow turbines [1264] // System › PG1 › Developmet Tools
- **MTZ 07-08/2022:** Ash behaviour in wall-flow filters // Project: Ash behaviour in wall-flow filters [1292] // Engines › PG6 › Emission
- **MTZ 05/2022:** Test rig configuration for the investigation of an industrial-type centrifugal compressor stage // Project: Design and implementation of the FVV industrial compressor [1279] // Turbo machines › PGT › Development Tools
- **MTZ 01/2022:** Potentials of coupled test benches // Project: Method hybrid testing [1363] // System › PG1 › Hybrid powertrains
- **MTZ 12/2021:** Influence of thermally induced stress gradients on fatigue life // Project: Thermally Induced Stress Gradients (TISG) [1218] // Turbo machines › PGT › Development tools
- **MTZ 11/2021:** Optimised modelling of gas exchange and turbulence in engine process calculation // Project: Modeling of turbulence II [1233] // Turbo machines › PGT › Development tools
- **MTZ 10/2021:** Modelling and investigation of particle formation in DI gasoline engines in transient driving conditions // Project: Systemic analysis of particle formation on gasoline engines [1282] // Engines › PG2 › Emissions
- **MTZ 07-08/2021:** Oil Entry via Piston Top Land // Project: Fuel in Oil II – Sources of oil in the combustion chamber of SI engines [1225] // Engines › PG2 › Emissions

MTZ / ATZ – RESEARCH PRIORITIES

- **MTZ 06/2022:** Mastering complexity – Pre-competitive Collective Research in hybrid powertrains // Research priority: Hybrid powertrains
- **MTZ 04/2022:** Pathways to climate-neutral mobility in the post-fossil age // Research priority: Fuels
- **MTZ 09/2021:** Industrial engines as power systems – research for optimum system design // Research priority: Efficiency

OTHER PUBLICATIONS

- **FVV 03/2022:** Zero-Impact Vehicle Emissions (Conceptual Study) – Definition and requirements of vehicle »zero-impact emission levels« based on ambient air quality // Final report issue no. H1295 // Research priority: Emissions
- **FVV 11/2021:** Centrifugal compressor research – Research projects of the past ten years// Issue no. R601 // Research priority: Development tools
- **FVV 11/2021:** Future Fuels Study IV – Six theories on climate neutrality in the European transport sector // Summary report issue no. R600 // Research priority: Fuels
- **FVV 11/2021:** Future Fuels Study IV – The Transformation of Mobility to the GHG-neutral Post-fossil Age // Final report issue no. H1269 // Research priority: Fuels

MTZ Articles

MTZ is the international technical-scientific trade magazine for engineers in powertrain development with a special focus on the development of electrified and internal combustion engine powertrains. In addition, it also reports on classic topics such as friction, turbocharging or charge cycle and valve control.

www.MTZ-magazine.com

ATZ Articles

ATZ is the must-read international technology magazine for decision-makers in the automotive industry. For more than 120 years, it has been presenting forward-looking technology solutions in automotive research and the latest information for the daily work of engineers on the entire vehicle - chassis or bodyshell, lighting technology or air conditioning.

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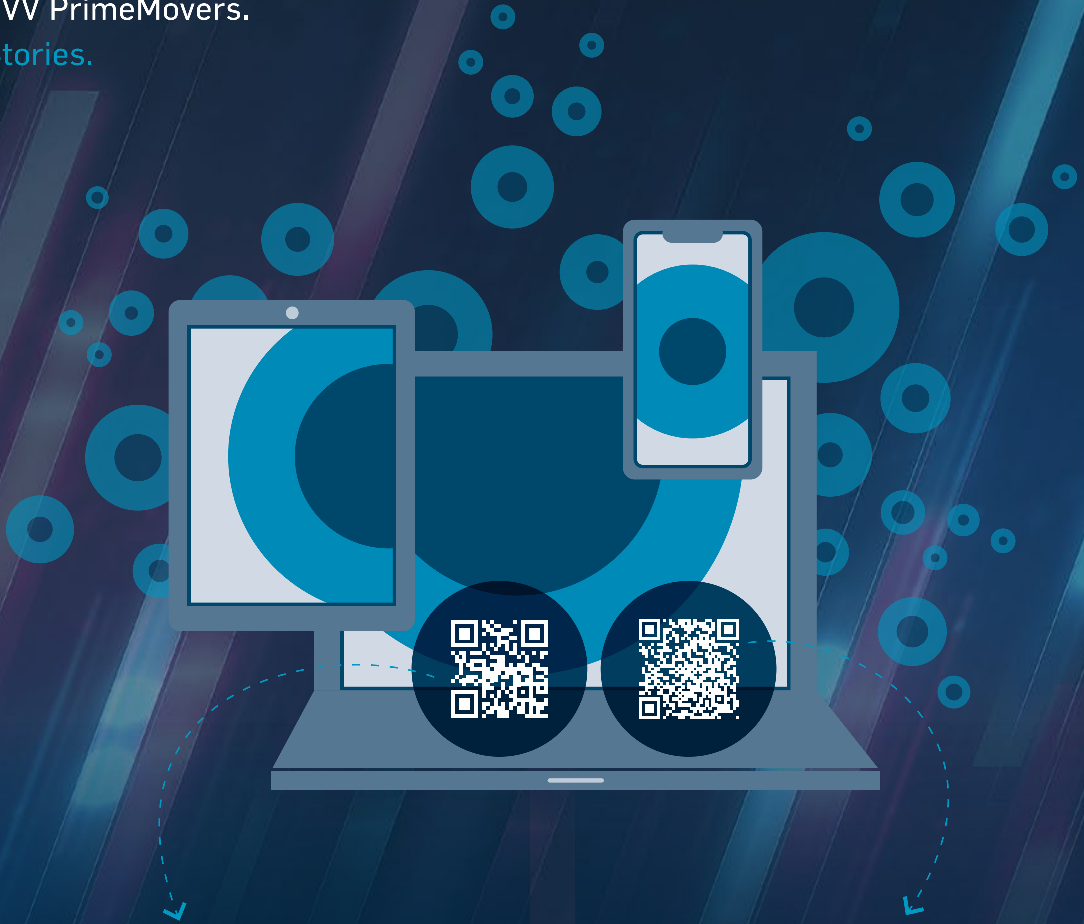
FVV PrimeMovers.
Stories.



Science

The FVV Website informs about research findings on important technological challenges and identifies future research needs. Discover the work of scientists and engineers who are researching the best available technologies of the future together with us!

www.fvv-net.de/en

Newsletter

For members and friends of the FVV we issue an electronic newsletter. It informs you regularly about news from our innovation network and interesting facts about Industrial Collective Research (IGF) as well as technology funding and promotion. Sign up now! The subscription is free and can be stopped at any time.

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FVV ANNUAL REPORT

2021/2022

Science for a moving society

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	Garrett Advancing Motion Inc.	Rolle (CH)	Jean-Sebastien Roux
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SCIENCE AND RESEARCH

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For the list of members of the Scientific Advisory Committee, please refer to Members (pp. 78 to 83).

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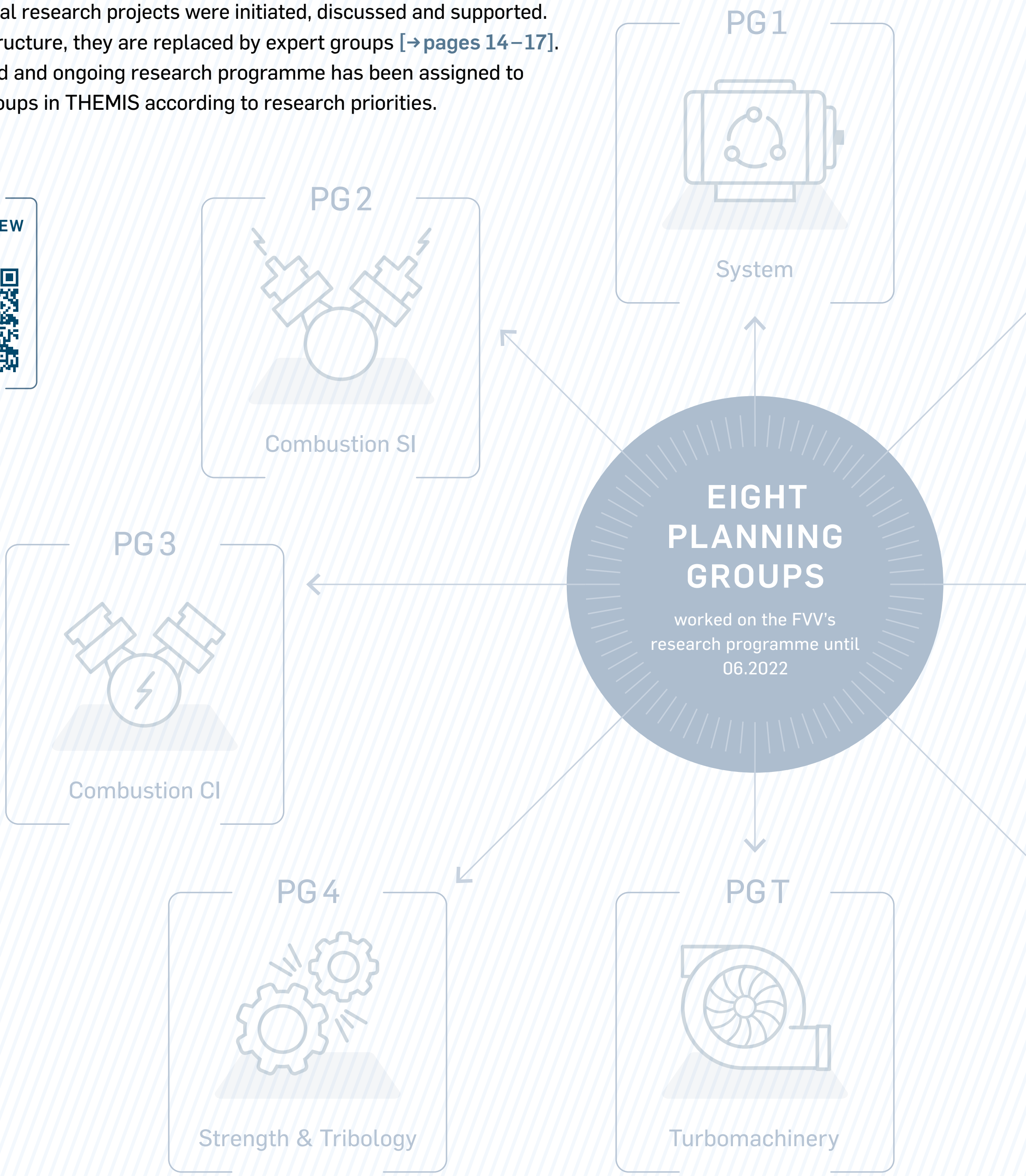
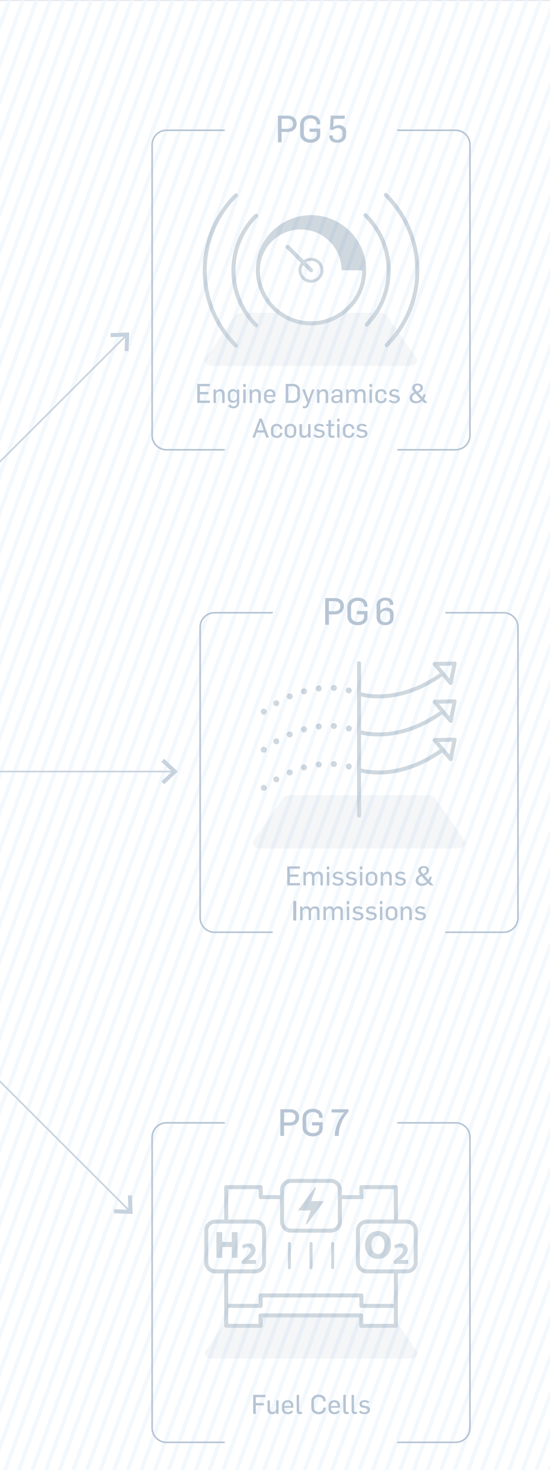
Coordination and knowledge transfer

PLANNING GROUPS (PG) | **Since 01.07.2022 new group structure**

The planning groups were the FVV's engine room: this is where the individual research projects were initiated, discussed and supported. In a new structure, they are replaced by expert groups [→ pages 14–17]. The planned and ongoing research programme has been assigned to the new groups in THEMIS according to research priorities.

MAKE IT NEW (ToR)





THEMIS DATABASE

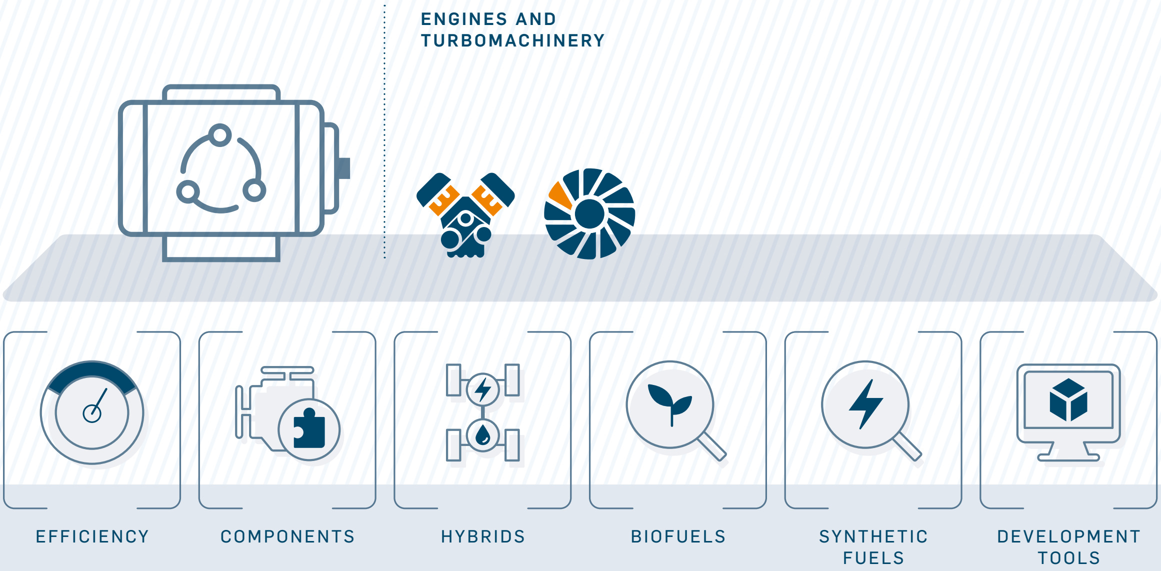
THEMIS is the communication and knowledge platform for Industrial Collective Research (Industrielle Gemeinschaftsforschung – IGF) in the mechanical engineering industry. It contains the collected research knowledge from six research associations on the topics of mechanical and plant engineering / automation and micro-electronics / Industrie 4.0 (FKM), drive technology (FVA), construction equipment and plant engineering (FVB), energy conversion systems (FVV), industrial furnace construction (FOGI) and air and drying technology (FLT).

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‹, was dedicated to the following topics:

- → Future engine concepts, hybridisation
- → Alternative fuels
- → Digitalisation in the powertrain
- → Life-cycle analyses

And tackled 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

PG 1 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0521	PIFPGE Pre-ignited Flame Propagation Gas Engines // CORNET	**Dr. Markus Wenig,** Winterthur Gas & Diesel
M0522	Lubrication Large Bore Engines III	**Hans-Peter Böhm,** ELGAN Diamantwerkzeuge
M1021	Predictive Powertrain Health Care // BMWK/AiF	**Dr. Christian Jörg,** Hitachi Automotive Systems Europe
M1022	Light-duty CI-ICE 2027	**Dr. Frank Bunar,** IAV
M1321	Condensate Formation in Exhaust Systems	**Thorsten Reimers,** Rheinmetall
M1422	Erosion in Injection Systems with Alternative Fuel	**Dr. Johann Wloka,** MAN Energy Solutions
M1521	Distributed Thermal Hybrid Powertrain Testing // FVV-EM	**Dr. Marcus Gohl,** APL
M1522	Powertrain 2040 Truck // FVV-EM	**Dr. Hagen Wegner,** FEV
M1621	AI4Fuels // FVV-EM, CORNET	**Dr. Michael Bippes,** Volkswagen
M1922	Real Driving Data for Automotive Application // BMWK/AiF	**Dr. Jochen Schwarzer,** Robert Bosch
M2022	Simulation of Hybrid Powertrains // BMWK/AiF	**Marc Sens,** IAV
M3320	New Hydrogen Storage Concept // BMWK/AiF	**Kathrin Giefer,** Ford-Werke
	Ongoing projects	
1312	48V Mild Hybrid with Semi-Homogeneous Diesel Combustion // BMWK/AiF // 01-01-2018 to 31-05-2022	**Dr. Achim Lechmann,** IAV
1321	Working Cycle Dissolved Turbine Efficiency in Turbochargers // DFG, FVV-EM // 01-10-2018 to 30-09-2022	**Dr. Mathias Vogt,** IAV
1339	Calibration and Validation of Self-learning System Controllers // FVV-EM // 01-03-2019 to 30-09-2022	**Prof. Dr. Peter Prenninger,** AVL List
1342	Sensor Concept for E-Fuels // FVV-EM, FVV-EM // 01-02-2019 to 31-08-2022	**Dr. Bernd Becker,** IAV
1382	Lubrication Large Bore Engines II // FVV-EM // 01-05-2020 to 31-10-2022	**Dr. Udo Schlemmer-Kelling,** FEV Europe **Dr. Tobias C. Wesnigk,** M. JÜRGENSEN
1394	Modelling of Pre-ignition in Gas Engines // FVV-EM, CORNET // 01-04-2020 to 30-09-2022	**Dr. Markus Wenig,** Winterthur Gas & Diesel
1428	Modular Hybrid Powertrain // FVV-EM // 01-01-2021 to 31-12-2022	**Dr. Veit Held,** Stellantis Opel Automobile

↓ Continue on the next page

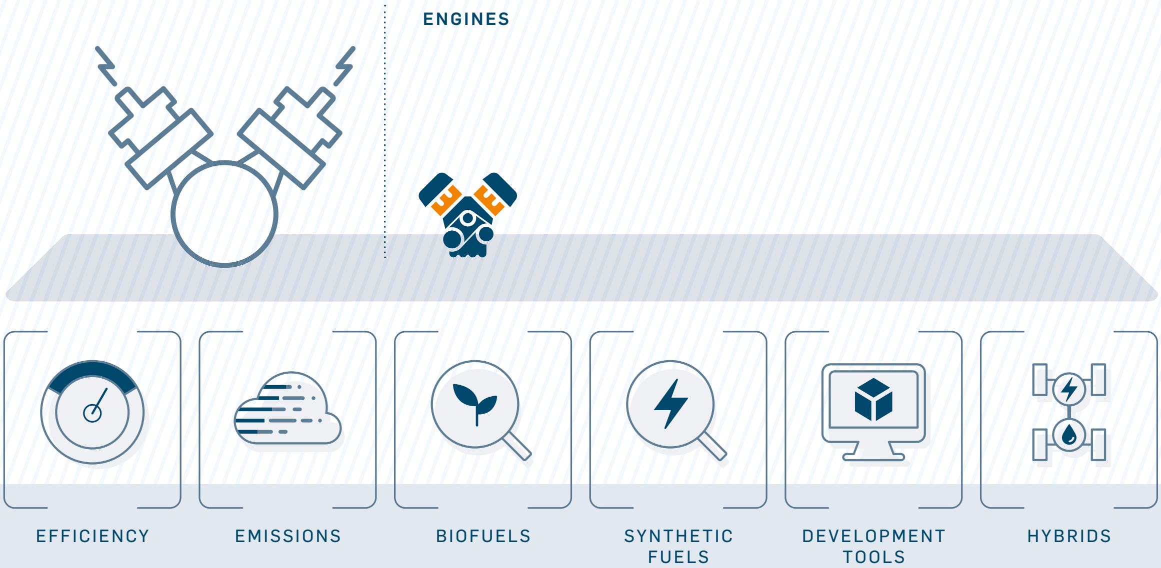
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1429	CO_2-neutral Long-haul Heavy-duty Powertrains 2050 II // FVV-EM // 01-04-2021 to 31-03-2023	**Herbert Schneider,** ISUZU MOTORS Germany
1433	HyFlex ICE // FVV-EM // 01-03-2021 to 28-02-2023	**Marc Sens,** IAV
1450	Ejector-Bypass TC // BMWK/AiF // 01-10-2021 to 30-09-2023	**Dr. Tom Steglich,** IAV
1460	On-board Emission Conformity Monitoring (OBECOM) // FVV-EM, CORNET // 01-01-2022 to 31-12-2023	**Dr. Heike Többen,** Purem
1463	Future Mobility Dialogue // FVV-EM // 01-07-2022 to 31-01-2023	**Prof. Dr. Thomas Garbe,** Volkswagen
1472	Hybrid Powertrains for Alternative Fuels // BMWK/AiF // 01-04-2022 to 30-09-2024	**Dr. Udo Schlemmer-Kelling,** FEV
1473	Maneuvering with Hybrid Ships // BMWK/AiF // 01-04-2022 to 30-09-2024	**Dr. Udo Schlemmer-Kelling,** FEV
1474	Axial Turbine T/C for Lean Burn Concepts // FVV-EM, BMWK/AiF // 01-04-2022 to 31-03-2024	**Marc Sens,** IAV

Completed projects

1355	Powertrain 2040 // FVV-EM // 01-04-2019 to 31-12-2021	**Dr. Thorsten Schnorbus,** FEV Europe
1384	H_2 in the Gas Network // FVV-EM // 01-01-2020 to 31-12-2021	**Dr. Dietrich Gerstein,** DVGW **Dr. Ulrich Kramer,** Ford-Werke
1385	T/C for Lean Burn Concepts // FVV-EM // 01-04-2020 to 31-12-2021	**Marc Sens,** IAV
1407	Zero-impact Vehicle Emissions (Conceptual Study) // FVV-EM // 01-09-2020 to 31-03-2022	**Prof. Dr. Kurt Kirsten,** APL
1410	SocioMotion // FVV-EM // 01-11-2020 to 31-05-2022	**Prof. Dr. Thomas Garbe,** Volkswagen

Combustion SI

PLANNING GROUP 2



COORDINATOR

Dr. André Casal Kulzer, Porsche (until 31.12.2021)

Carsten Weber (from 01.01.2022)

PROJECT MANAGEMENT

Ralf Thee, FVV

RESEARCH PRIORITIES

Planning group 2, ›Combustion SI‹, was dedicated to the following topics:

- → Efficiency of the engine
- → Hybridisation
- → Alternative fuels
- → Artificial intelligence in development, big data and digitalisation

And tackled 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

PG 2 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
1456	EmiRed Innovative RDE Engine-out Emission Reduction // FVV-EM // 01-02-2022 to 31-03-2023	**Christine Burkhardt,** EnginOS
M0622	Hydrogen Combustion Engine with Water Injection	**Dr. Helmut Ruhland,** Ford Werke
M0822	Investigation of Wall Heat Transfer in H_2 Engines	**Dr. David Lejsek,** Robert Bosch
M0922	AI-based, Fast Knock Control	**Dr. Michael Fischer,** Tenneco
M1322	KI HC/CO Model for Future SI Engines	**Dr. Christian Schnapp,** TOYOTA GAZOO Racing Europe
M1622	Potential of SI Pre-Chamber Insulation	**Dr. Patrick Gastaldi,** Aramco
M1721	IPI2 Initial pre-ignition II // CORNET, FVV-EM	**Albert Breuer,** Ford-Werke
M2621	Sustainable LPG/DME Blends as Autogas Replacement	**Dr. Werner Willems,** FORD Research and Innovation Center
M2821	FlameWallXfer Wall Heat Transfer in Gasoline Engines // FVV-EM, CORNET	**Gabriel Dilmac,** Porsche
M3720	Mixture Preparation / Homogenization with H_2-DI // BMWK/AiF	**Michael Rieß,** IAV
M4220	Multicomponent Fuels / Wall Film Interaction // BMWK/AiF	**Jérôme Munier,** Porsche
	Ongoing projects	
1343	Spray Modelling for DI Gasoline Engines // FVV-EM // 01-01-2019 to 31-03-2022	**Dr. Christian Jörg,** Hitachi
1348	Fuel Composition for CO_2 Reduction // FVV-EM // 01-03-2019 to 28-02-2022	**Koji Kitano,** Toyota
1357	Homogenisation Model SI Engines II // BMWK/AiF // 01-07-2019 to 31-03-2022	**Marc Sens,** IAV
1367	Water Injection in Spark-Ignition Engines II // FVV-EM // 01-10-2019 to 31-03-2022	**Prof. Dr. André Casal Kulzer,** vormals Porsche
1370	Fast Knocking Prediction for Gasoline Engines // FVV-EM // 01-10-2019 to 28-02-2022	**Dr. Michael Fischer,** Tenneco
1374	Fuel Influence on Particulate Characteristics // BMWK/AiF // 01-09-2019 to 30-09-2022	**Dr. Wolfgang Samenfink,** Robert Bosch
1387	Benchmark Platform for Scale Resolving Simulations // BMWK/AiF // 01-01-2020 to 30-06-2022	**Dr. Frank Krämer,** Ford-Werke **Kathrin Giefer,** Ford-Werke
1426	Heuristic Search and Deep Learning // BMWK/AiF // 01-11-2020 to 30-04-2023	**Dr. Christian Schnapp,** TOYOTA GAZOO Racing Europe

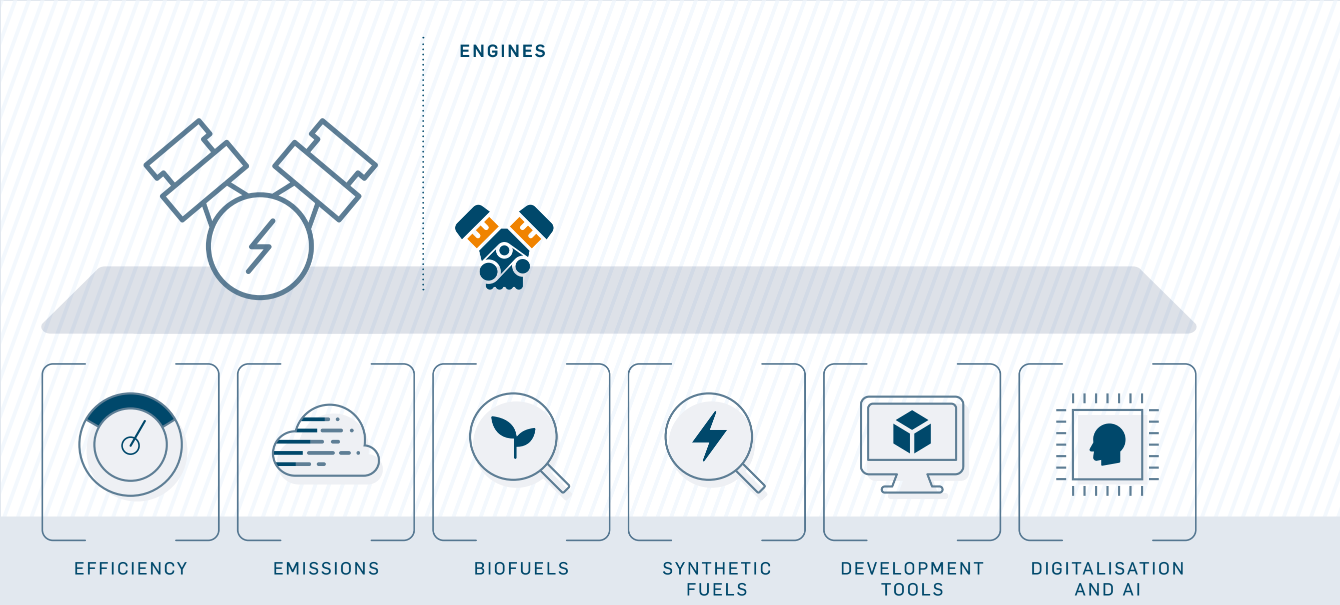
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1431	SACI Combustion System with Active Pre-Chamber // FVV-EM // 01-01-2021 to 30-06-2023	**Jonas Villforth,** Porsche AG
1434	ICE2030 // FVV-EM // 01-02-2021 to 31-01-2023	**Arndt Döhler,** Stellantis Opel Automobile
1435	Modelling Turbulence // CORNET, FVV-EM // 01-01-2021 to 31-03-2023	**Dr. David Lejsek,** Robert Bosch
1446	DIH_2jet (DI Hydrogen Combustion Process) // FVV-EM, CORNET // 01-07-2021 to 30-06-2023	**Dr. Stephan Liebsch,** IAV
1448	Fuel Composition – RDE and Soot Formation // FVV-EM // 01-09-2021 to 31-08-2023	**Dr. Christian Töpel,** Freyberger engineering **Dr. Lars Menger,** BMW
1449	Near-zero Emission Concept for H_2 DI Otto Engines // FVV-EM // 01-10-2021 to 30-09-2024	**Dr. David Lejsek,** Robert Bosch
1454	Prediction of Inhomogeneous H_2-SI Combustion // FVV-EM // 01-06-2022 to 30-11-2023	**Dr. Maximilian Brauer,** IAV
1476	Preferential Evaporation of Alternative Fuel Mixtures // BMWK/AiF // 01-05-2022 to 31-10-2024	**Jérôme Munier,** Porsche
1478	EKIM Engine Knock Model for Future Fuels // CORNET // 01-05-2022 to 30-04-2024	NN

Completed projects

1349	Influencing Wall Heat Losses in SI Engines // FVV-EM, BMWK/AiF // 01-01-2019 to 31-12-2021	**Dr. Thorsten Unger,** Porsche

Combustion CI

PLANNING GROUP 3



COORDINATOR
Dr. Christian Weiskirch,
MAN Truck & Bus

PROJECT MANAGEMENT
Ralf Thee, FVV

RESEARCH PRIORITIES

Planning group 3, ›Combustion CI‹, was dedicated to the following topics:

- Efficiency of the engine
- Alternative fuels, hydrogen combustion
- Artificial intelligence in development, big data and digitalisation

And tackled the following lines of research / focuses:

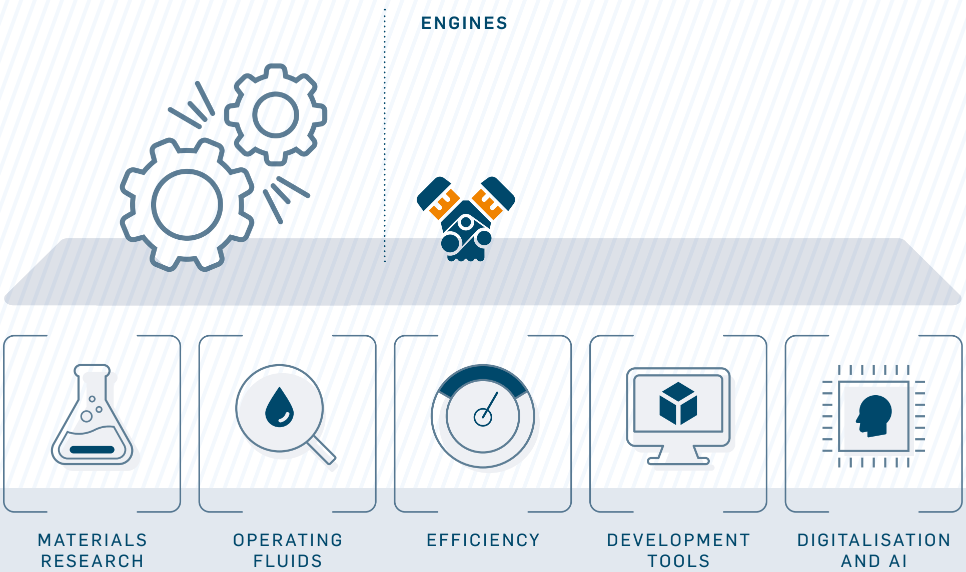
- Combustion modelling/simulation
- New/dual combustion processes, gas/dual-fuel engines
- Fuel distribution and preparation, high-pressure injection / spray diagnostics
- Variable valve control, air path
- Coatings, additive manufacturing

PG 3 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0621	Power Density Increase of Hydrogen CI Engines // BMWK/AiF	**Dr. Markus Wenig,** Winterthur Gas & Diesel
M1919	Diesel Engine Process Chain // BMWK/AiF	**Dr. Wolfgang Bauer,** MAN Truck & Bus
M3121	Methanol as Fuel for Existing Ships	**Dr. Philipp Henschen,** MAN Energy Solutions
	Ongoing projects	
1318	Air Insulation Diesel Engine // FVV-EM // 01-07-2018 to 31-12-2022	**Dr. Patrick Gastaldi,** Aramco
1346	Potentials of Airpath Variabilities for HD Gas Engines // FVV-EM // 01-01-2019 to 31-03-2022	**Dirk Weberskirch,** MAN Truck & Bus
1352	PremixedDiesel // CORNET, FVV-EM, BMWK/AiF // 01-01-2019 to 30-06-2022	**Dr. Simon Schneider,** MAHLE International
1368	Innovative HD Combustion System Design // FVV-EM // 01-07-2019 to 30-06-2022	**Dr. Reza Rezaei,** IAV
1403	eSpray // FVV-EM, CORNET // 01-06-2020 to 30-11-2022	**Dr. Uwe Leuteritz,** Liebherr-Components
1408	Cold Start Emission Reduction // FVV-EM // 01-09-2020 to 28-02-2023	**Dr. Maximilian Brauer,** IAV
1442	Hydrogen Combustion and Comparison PFI/DI concepts // FVV-EM // 01-04-2021 to 31-03-2023	**Dr. Reza Rezaei,** IAV
1459	GIHPCO Gas Injection High-pressure Combustion // FVV-EM, CORNET, FVV-EM // 01-01-2022 to 31-12-2023	**Dr. Enrico Bärow,** Woodward L'Orange
	Completed projects	
1405	Closed-cycle Hydrogen CI Engine // FVV-EM // 01-09-2020 to 15-12-2021	**Dr. Markus Wenig,** Winterthur Gas & Diesel

Strength & Tribology

PLANNING GROUP 4



COORDINATOR
Dr. Dieter Eppinger,
SEG Automotive Germany

PROJECT MANAGEMENT
Max Decker, FVV

RESEARCH PRIORITIES

Planning group 4, ›Strength & Tribology‹, was dedicated to the following topics:

- → Materials research
- → Artificial intelligence in calculation models
- → Digitalisation in data acquisition and processing
- → Hydrogen contact and its effects

And tackled the following lines of research / focuses:

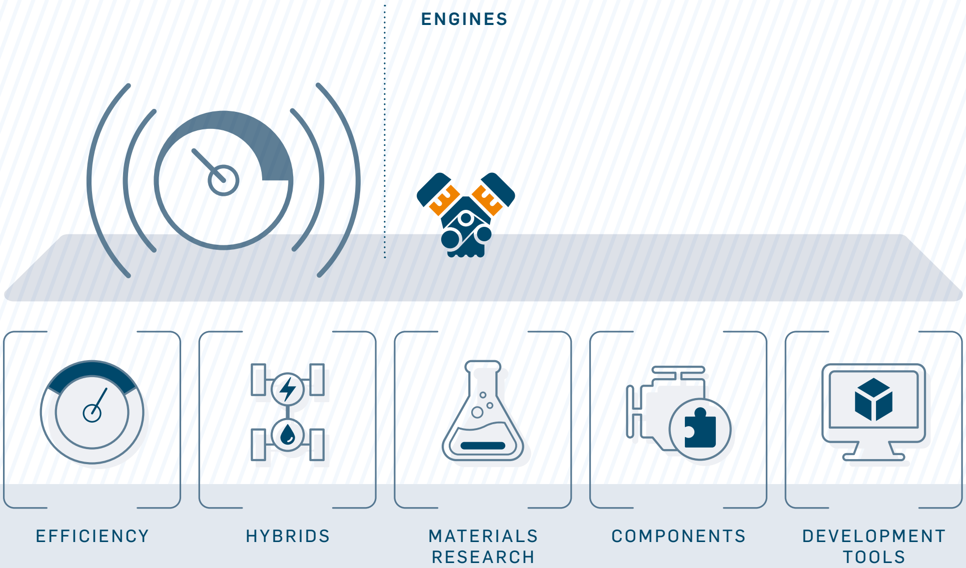
- → New operating fluids and coolants
- → Tribology and coatings
- → Damage characteristics under different loads
- → Lifespan calculations
- → Strength calculations

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
M0122	Component Dimensioning in Hydrogen Environment // BMWK/AiF	**Dr. Stefan Averbeck**, MAN Energy Solutions
M0419	Corrosion Loads due to new Drive Concepts	**Regina Franke-Hörth**, SEG
M0420	Base Engine Components for H_2 ICEs	**Dr. Daniel Hrdina**, MAHLE International
M0520	Machine Learning – MLµσ // BMWK/AiF	**Dr. Michael Berg**, IAV
M0819	Design Concepts of Copper Welds	**Micha Haußmann**, SEG **Dr. Stephan Issler**, Steinbeis-Transferzentrum
M1722	Functional Properties of Recycled Metals	**Dr. Dieter Eppinger**, SEG
	Ongoing projects	
1350	Fatigue Influence Braze Quality // BMWK/AiF // 01-01-2019 to 30-06-2022	**Prof. Dr. Matthias Türpe**, MAHLE International
1377	Shaft Bores // BMWK/AiF // 01-11-2019 to 28-02-2023	**Stefan Roth**, MAN Energy Solutions
1379	Tribomaps Friction Enhancing Laser Structures // BMWK/AiF // 01-12-2019 to 30-10-2022	**Dr. Anton Stich**, AUDI
1393	Fretting Fatigue Strength Assessment // BMWK/AiF, FVV-EM // 01-01-2020 to 31-07-2022	**Dr. Reiner Böschen**, Rolls-Royce Solutions
1396	Fuel Oil Flow Measurement // CORNET // 01-01-2020 to 31-12-2021	**Dr. Motoichi Murakami**, TOYOTA **Dr. Marcus Gohl**, APL
1402	Exhaust Gas Effected Tribosystems // BMWK/AiF // 01-06-2020 to 30-11-2022	**Dr. Heiko Haase**, Rolls-Royce Solutions
1404	Simulation Damage Characteristics – Validation Tests and Lifetime Calculations // FVV-EM, FVV-EM // 01-09-2020 to 30-04-2022	**Jan Becker**, Porsche
1441	Lifetime Model Winding Insulation // BMWK/AiF // 01-03-2021 to 31-08-2023	**Dr. Zeljana Beslic**, SEG
1445	Flow Erosion II // BMWK/AiF // 01-06-2021 to 30-11-2023	**Jens Strassmann**, Volkswagen
1465	Cooling Flow Measurements Using MRI // FVV-EM // 01-09-2022 to 31-08-2024	**Dr. Mirko Plettenberg**, AVL List
	Completed projects	
1409	Machine Learning – MLµσ (Preliminary study) // FVV-EM // 01-08-2020 to 31-01-2021	**Dr. Michael Berg**, IAV

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‹, was dedicated to the following topics:

- → Efficiency of the engine
- → Dynamic and acoustic behaviour of new powertrain variants / operating strategies
- → Hybridisation

And tackled the following lines of research / focuses:

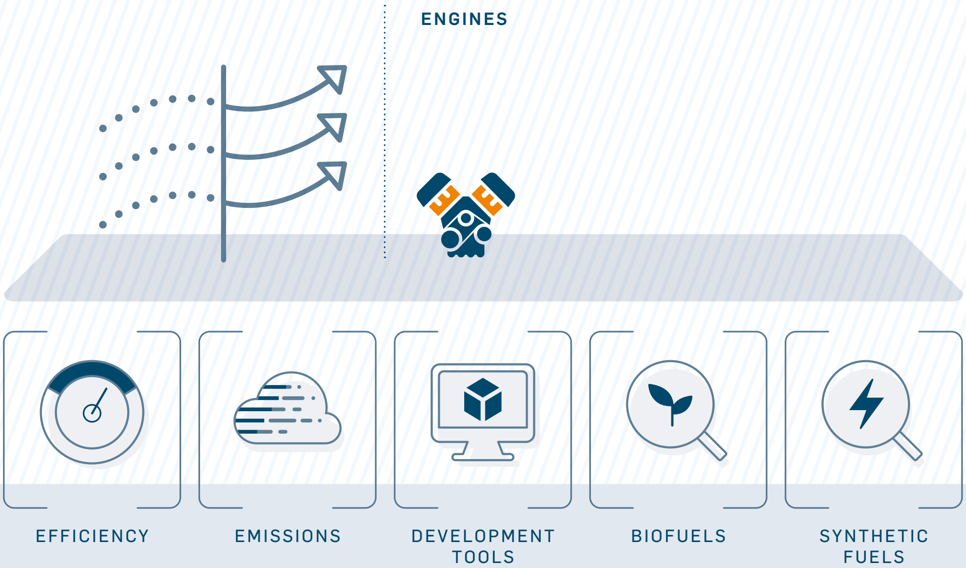
- → Acoustic behaviour of powertrain components
- → Interferences
- → Vibration damping
- → Detecting acoustic phenomena in conventional and new powertrain variants

PG 5 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0620	Dissonance (Part-) Electric Powertrains // BMBF	**Dr. Julian Becker,** HEAD acoustics
M2421	Pass-by Noise Simulation	**Dr. Stefan Heuer,** MAN Truck & Bus
M2921	NVH optimized E-motor Types for HEV Power Unit	**Hans Johannesson,** Volvo
M3421	Interior Sound Prediction of Electric Vehicles // BMWK/AiF	**Dr. Jan Herrmann,** Robert Bosch
M3819	Exterior Noise of Electric Vehicles	**Dr. Stefan Heuer,** MAN Truck & Bus
M4119	MExTol // BMWK/AiF	**Hans Johannesson,** Volvo
	Ongoing projects	
1369	Interference Noise in the Vehicle Compartment with Electrified Drives // FVV-EM, FVV-EM // 01-09-2019 to 31-08-2022	**Dr. Stefan Heuer,** MAN Truck & Bus
1457	Acoustic of Hydrogen Piston Engines // FVV-EM // 01-06-2022 to 31-05-2023	**Dr. Stefan Heuer,** MAN Truck & Bus
1470	NVH-optimised Elastomeric Drive Bearings // BMWK/AiF // 01-07-2022 to 30-06-2024	**Hans Johannesson,** Volvo

Emissions & Immissions

PLANNING GROUP 6



COORDINATOR
Dr. Volker Schmeißer,
Daimler Truck

PROJECT MANAGEMENT
Max Decker, FVV

RESEARCH PRIORITIES

Planning group 6, ›Emissions & Immissions‹, was 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 tackled the following lines of research / focuses:

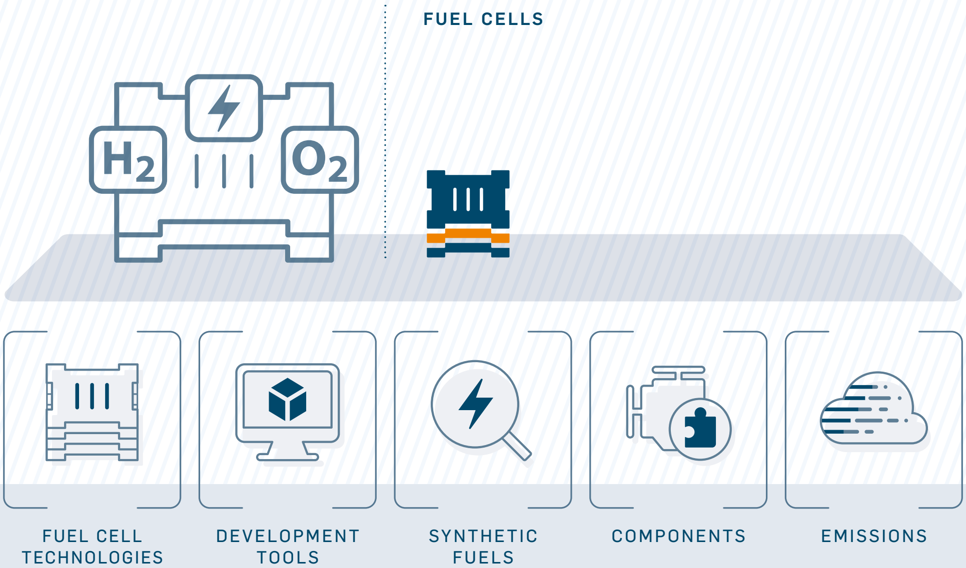
- → Purification and reduction of exhaust gas, alternative means of reduction
- → Modelling approaches for reaction kinetics on the catalyst
- → Local condition monitoring of emissions
- → High-resolution online measuring techniques
- → Lifespan of exhaust gas purification components
- → Non-regulated exhaust gas components

PG 6 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0222	Ash Structure under Influence of Condensation Water	**Dr. Bernhard Lüers,** FEV
M0322	NH_3 Influence on Particle Oxidation	**Dr. Marcus Gohl,** APL
M1017	Regeneration Strategies for Methane Catalysts // FVV-EM, BMWK/AiF	**Klaus Rusch,** Rolls-Royce Power Systems
M1222	Optimisation of Exhaust Gas Mass Flow Measurement	**Prof. Dr. Georg Wachtmeister,** DERC
M2019	Exhaust Gas Condensates of Future Fuels // BMWK/AiF	**Dr. Andreas Jäger,** IAVF
M2020	CCSonShips Decarbonisation of Marine Propulsion Systems // FVV-EM, CORNET // 01-06-2022 to 31-05-2024	**Klaus Meyer,** Robert Bosch
M2221	NO_2 and N_2O with Carbon Free Fuels // BMWK/AiF	**Dr. Bernhard Lüers,** FEV
M2620	Exhaust Gas Radial Distribution Measurement // BMWK/AiF	**Nikos Symeonidis,** Toyota
M2720	Oxygen Storage II // BMWK/AiF	**Jeremias Bickel,** Robert Bosch
	Ongoing projects	
1324	CFD Analysis of Particle Formation // BMWK/AiF // 01-07-2018 to 31-03-2022	**Dr. Paul Jochmann,** Robert Bosch
1341	Impact of New Silica-containing Fuels on Exhaust Gas Aftertreatment Components // FVV-EM // 01-03-2019 to 28-02-2022	**Peter Lauer,** MAN Energy Solutions
1372	Cold Start CNG Catalyst // BMWK/AiF // 01-08-2019 to 28-02-2022	**Dr. Michael Fischer,** Tenneco
1391	Cleaning Mechanisms in the Exhaust Path // BMWK/AiF // 01-01-2020 to 31-08-2022	**Raimund Vedder,** Atlanting
1398	TWC Impact on Particulate Properties // BMWK/AiF // 01-03-2020 to 31-08-2022	**Dr. Julie Le Louvetel-Poilly,** Toyota
1400	Deposits from AdBlue II // FVV-EM, CORNET // 01-04-2020 to 30-09-2022	**Raimund Vedder,** Atlanting
1412	Zero Impact Tailpipe Emission Powertrains // FVV-EM // 01-09-2020 to 31-08-2022	**Dr. Frank Bunar,** IAV
1461	N_2O Exhaust Gas Treatment in Ammonia Engines // FVV-EM // 01-07-2022 to 30-06-2024	**Dr. Daniel Peitz,** HUG Engineering
1464	Formation of Particles with UWS Injection // FVV-EM // 01-08-2022 to 31-07-2024	**Dr. Jochen Hammer,** Purem
1466	HT-H_2-DeNOx // BMWK/AiF // 01-07-2022 to 30-06-2024	**Dr. Frank Bunar,** IAV
M0121	H_2-DeNOx II // BMWK/AiF // 01-02-2022 to 31-07-2024	**Dr. Frank Bunar,** IAV
M1019	TWC Reaction under High-frequency Lambda Switching // CORNET, BMWK/AiF // 01-01-2022 to 31-12-2023	**Toshihiro Mori,** Toyota
M2320	FaconSCR Model // BMWK/AiF // 01-02-2022 to 31-07-2024	**Dr. Harald Beck,** MAN Truck & Bus

Fuel Cells

PLANNING GROUP 7



COORDINATOR

Dr. Volker Formanski,
BMW Group

PROJECT MANAGEMENT

Martin Nitsche, FVV

RESEARCH PRIORITIES

Planning group 7, ›Fuel Cells‹, was dedicated to the following topics:

- → System integration of fuel cells in mobile/stationary applications
- → Reduction of costs through innovative solutions
- → Hydrogen compatibility

And tackled the following lines of research / focuses:

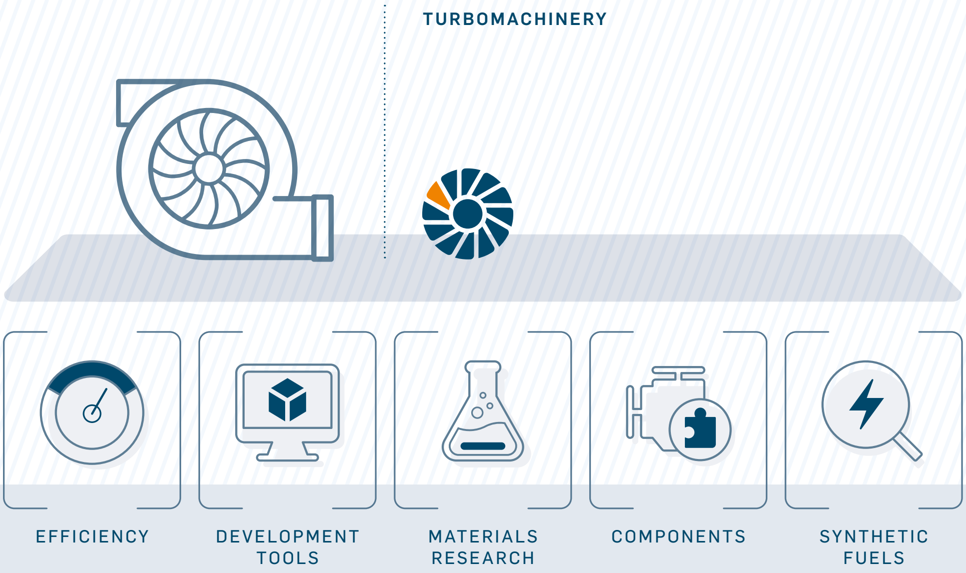
- → Operating types and conditions of fuel cells
- → Hydrogen compatibility, handling, material properties of hydrogen-carrying components
- → Air path and filtering
- → Thermal management
- → Interfaces to the fuel cell and related components/units, e.g. compressors, expanders

PG 7 | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
M0217	Innovative FC Air Supply // BMWK/AiF	**Dr. Oliver Berger,** Volkswagen
M0517	Simulation/Balance of Plant // FVV-EM	**Stefan Rothgang,** Pierburg
M0721	Liquid-water Morphology in Fuel Cell Systems	**Alexander Heinle,** AUDI
M0817	Integrated Fuel Cell Simulation // FVV-EM	**Stefan Bohatsch,** Volvo
M0921	Model Development of Fuel Cell PEM Membranes	**Dr. Marius Zubel,** FEV
M1917	Methodology for SoH Detection // BMWK/AiF	**Richard Schauperl,** AVL List
M2317	Fuel Cells Air Contaminations (Study) // FVV-EM	**Markus Kersting,** IAV
M2521	Carbon Bipolar Plates for Heavy-duty Application	**Uwe Griesmeier,** ZF Friedrichshafen
	Ongoing projects	
1406	Energy Recovery in Fuel Cell Applications // FVV-EM // 01-09-2020 to 31-03-2023	**Dr. Dirk Jenssen,** Volkswagen
1411	FC Cold Start // FVV-EM // 01-09-2020 to 31-08-2022	**Dr. Stefan Kaimer,** Ford-Werke
1455	CFD Simulation of Droplet Separators // FVV-EM // 01-06-2022 to 30-11-2024	**Dr. Michael Harenbrock,** MANN+HUMMEL
1471	Cooling Fuel Cells II // BMWK/AiF // 01-04-2022 to 30-09-2024	**Dr. Markus Kaiser,** nexiss
M4120	Lifetime Simulation of Ion Exchange Filters // BMWK/AiF // 01-06-2022 to 30-11-2024	**Dr. Michael Harenbrock,** MANN+HUMMEL

Turbomachinery

PLANNING GROUP T



COORDINATOR
Dr. Dirk Hilberg,
Rolls-Royce Deutschland

PROJECT MANAGEMENT
Dirk Bösel, FVV

RESEARCH PRIORITIES

Planning group T, ›Turbomachinery‹, was dedicated to the following topics:

- → Efficiency of turbines and compressors
- → Alternative fuels, hydrogen combustion
- → Innovative operating fluids and coatings

And tackled the following lines of research / focuses:

- → Aerodynamics of turbomachines
- → Hydrogen compatibility, handling, material properties of hydrogen-carrying components
- → 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

PG T | RESEARCH PROJECTS

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
	Planned projects	
T0121	Stability of IN718 at High Service Times // BMWK/AiF	**Dr. Dirk Kulawinski,** Siemens Energy **Dr. Torsten Neddemeyer,** Siemens Energy
T0122	Digital Twin centrifugal compressor	**Dr. Matthias Schleer,** Howden Turbo
T0220	Sensitivity and Probabilistic (ComDynA_SP) // BMWK/AiF	**Dr. Andreas Hartung,** MTU Aero Engines
T0222	Casing Treatment Centrifugal Compressor	**Dr. Matthias Schleer,** Howden Turbo
T0321	Acoustoelastically Coupled Compressors // BMWK/AiF	**Klaus Steff,** Siemens Energy
T0322	Improved Axial Plain Bearing Modelling	**Michael Bottenschein,** Voith
T0421	Time Dependent Crack Closure // FVV-EM, DFG	**Henning Almstedt,** Siemens Energy
T0422	Multiaxial Fatigue, Component & Operation-related	**Dr. Hartmut Schlums,** Rolls-Royce Deutschland
T0522	Intentional Mistuning II	**Thomas Winter,** PBS Turbo
T0622	Air Bearings in Charging Systems	**Dr. Oliver Alber,** MAN Energy Solutions
T0721	Nonlinear Dynamic Contact Identification // DFG, FVV-EM	**Dr. Andreas Hartung,** MTU Aero Engines
T0722	Blade Forces and System Damping II	**Dr. Thomas Hildebrandt,** NUMECA
T0820	Inverse Dynamic Analysis // DFG, FVV-EM	**Dr. Andreas Hartung,** MTU Aero Engines
T0821	OpenTestCase Hot Gas and Cooling Air Rig	**Dr. Georg Scheuerer,** ISimQ
T0822	Combined Dynamical Analyses (ComDynA): Validation	**Dr. Andreas Hartung,** MTU Aero Engines
T0921	Experimental Validation of Higher Blade Modes	**Dr. Thomas Klauke,** Rolls-Royce Deutschland
T1019	Aerodynamics of Tandem Stators III // BMWK/AiF	**Dr. Henner Schrapp,** Rolls-Royce Deutschland
T1021	NextGenSARA	**Dr. Martin Reigl,** GE Power
T1121	Prediction of Gas Turbine Emissions II	**Dr. Ruud L.G.M. Eggels,** Rolls-Royce Deutschland
T1221	Modelling of Primary Atomisation of Liquid Jets	**Dr. Ruud L.G.M. Eggels,** Rolls-Royce Deutschland
T1321	Unsteady Tandem Flow II	**Dr. Henner Schrapp,** Rolls-Royce Deutschland
T1419	Jet in cross flow mixing processes in combustors // BMWK/AiF	**Dr. Marco Konle,** MTU Aero Engines

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NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
T1421	Dynamic of Jet Flames under Elevated Pressure	**Dr. Lukasz Panek,** Siemens Energy
T1521	Acoustics in Suction Pipes	**Vera Kress,** MAN Energy Solutions
T1603	Qualifizierung bleifreier Mehrschicht-Gleitlager	**Marc Witte,** Rickmeier
T1618	Intelligente Hybridgleitlager	**Sebastian Wolking,** SAINT-GOBAIN
T1619	Correlation-Framework for NDE Data with Defects // BMWK/AiF	**Dr. Christian Amann,** Siemens Energy
T1621	Damping Evaluation in Presence of Nonlinearities	**Dr. Andreas Hartung,** MTU Aero Engines
T1629	Prozessmediengeschmierte Gleitlager // BMWK/AiF	**Dr. Christoph Weißbacher,** GTW
T1721	Multiphase-flow in Compressor Casing Channels	**Prof. Dr. Marius Swoboda,** Rolls-Royce Deutschland
T1821	Influence of Water Vapour on TBC	**Susanne Schrüfer,** Rolls-Royce Deutschland
677 III	Radialkippsegmentlager Ölzuführungseinfluss III // BMWK/AiF	**Nico Havlik,** RENK

Ongoing projects

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1270	Self-excited Combustion Dynamics in Multiburner Systems (ROLEX) // FVV-EM // 01-05-2017 to 31-10-2021	**Dr. Michael Huth,** Siemens Energy
1273	Radial Turbine Temperature Field II // BMWK/AiF // 01-04-2017 to 31-03-2022	**Dr. Tom Heuer,** BorgWarner
1325	Crack Behaviour Multiaxial (ARIMA) // BMWK/AiF // 01-10-2018 to 31-03-2022	**Dr. Andreas Fischersworring-Bunk,** MTU Aero Engines
1326	Stress Relaxation Behaviour II // BMWK/AiF // 01-04-2018 to 31-03-2022	**Dr. Martin Reigl,** GE Power
1329	HT-Threshold Calculation Methods // BMWK/AiF // 01-10-2018 to 31-03-2022	**Frank Vöse,** MTU Aero Engines
1337	Circumferentially Inhomogeneous Centrifugal Compressor Flow // BMWK/AiF // 01-12-2018 to 31-05-2022	**Dr. Thomas Hildebrandt,** NUMECA
1351	TMF Crack Path Calculation for Turbocharger Hot Parts // BMWK/AiF // 01-02-2019 to 30-09-2022	**Dr. Andreas Koch,** Rolls-Royce Deutschland
1353	Wheel-space Sealing II // BMWK/AiF // 01-04-2019 to 31-03-2022	**Dr. Karsten Kusterer,** B&B-AGEMA
1354	Industrial Radial Compressor with Wide Operating Range // BMWK/AiF // 01-02-2019 to 31-07-2022	**Dr. Matthias Schleer,** Howden Turbo
1358	Dynamic of Swirl and Jet Flames // FVV-EM, FVV-EM // 01-04-2019 to 31-08-2022	**Dr. Lukasz Panek,** Siemens Energy

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1360	Unsteady Tandem Flow // DFG, FVV-EM // 01-10-2019 to 31-03-2022	**Dr. Henner Schrapp,** Rolls-Royce Deutschland
1371	Robust Fracture Deformation Parameters // AVIF, FVV-EM // 01-07-2019 to 30-06-2022	**Dr. Torsten-Ulf Kern,** Siemens Energy
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 // BMWK/AiF // 01-11-2019 to 31-10-2022	**Dr. Joachim Schmied,** Delta JS
1380	Probabilistic Lifetime Model Comparison – Creep-Fatigue // AVIF // 01-01-2020 to 31-12-2022	**Henning Almstedt,** Siemens Energy
1383	Acoustic Emission into Discharge Pipes II // FVV-EM, DFG // 01-02-2020 to 30-09-2022	**Dr. Irhad Buljina,** MAN Energy Solutions
1386	Turbo High Temperature Steel // BMWK/AiF // 01-02-2020 to 31-01-2023	**Dr. Markus Dinkel,** Schaeffler
1388	Blade Forces and System Damping // BMWK/AiF // 01-01-2020 to 31-12-2022	**Dr. Thomas Hildebrandt,** NUMECA
1389	Intentional Mistuning // BMWK/AiF // 01-01-2020 to 31-12-2022	**Thomas Winter,** PBS Turbo
1390	Aluminum High Temperature Fatigue // BMWK/AiF // 01-01-2020 to 31-03-2023	**Dr. Reiner Böschen,** Rolls-Royce Solutions
1392	Material Applications FeAl (WAFEAL) // BMWK/AiF // 01-01-2020 to 30-09-2022	**Dr. Dan Roth-Fagaraseanu,** Rolls-Royce Deutschland
1397	Prediction of Gas Turbine Emissions // FVV-EM, DFG // 01-04-2020 to 31-12-2022	**Dr. Ruud L.G.M. Eggels,** Rolls-Royce Deutschland
1401	LPBF High-Temperature Lifetime // BMWK/AiF // 01-05-2020 to 30-04-2023	**Dr. Roland Herzog,** MAN Energy Solutions
1421	Dynamic of Swirl and Jet Flames II // FVV-EM, DFG // 01-12-2020 to 30-11-2023	**Dr. Lukasz Panek,** Siemens Energy
1422	Extended Operation Range of YSZ // DFG, FVV-EM // 01-11-2020 to 31-10-2023	**Dr. Arturo Flores Renteria,** Siemens Energy
1423	Combined Dynamical Analyses (ComDynA): Analytics // BMWK/AiF // 01-10-2020 to 30-09-2022	**Dr. Andreas Hartung,** MTU Aero Engines
1424	Fill Factor Influence // BMWK/AiF // 01-10-2020 to 31-03-2023	**Dr. Christoph Weißbacher,** GTW
1425	Bidirectional Aeromechanical Coupling II // FVV-EM, DFG // 01-11-2020 to 31-10-2022	**Dr. Andreas Hartung,** MTU Aero Engines
1427	COMBROS-R/A Software Documentation in English // FVV-EM // 01-01-2021 to 30-04-2021	**Klaus Steff,** Siemens Energy

↓ Continue on the next page

NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1432	Particle Transport in Compressor Casing Channels // FVV-EM // 01-03-2021 to 28-02-2022	**Prof. Dr. Marius Swoboda,** Rolls-Royce Deutschland
1436	W14 Concepts / FKM Guideline // BMWK/AiF // 01-01-2021 to 30-06-2022	**Dr. Shilun Sheng,** Siemens Energy
1437	Squeeze Film Dampers II // BMWK/AiF // 01-01-2021 to 30-06-2023	**Dr. Oliver Alber,** MAN Energy Solutions
1439	Fuel Cell Compressor Design // BMWK/AiF // 01-03-2021 to 31-08-2023	**Dr. Thomas Hildebrandt,** NUMECA
1440	Constraint Effect in Component Design // BMWK/AiF // 01-03-2021 to 31-08-2023	**Dr. Christian Amann,** Siemens Energy
1443	Centrifugal Compressor in Flexible Operation // FVV-EM, BMWK/AiF // 01-03-2021 to 29-02-2024	**Dr. Matthias Schleer,** Howden Turbo
1444	Modelling of Metal-graphite Composites // BMWK/AiF // 01-06-2021 to 29-02-2024	**Dr. Dan Roth-Fagaraseanu,** Rolls-Royce Deutschland
1447	Flexible HP-Turbines // DFG, FVV-EM // 15-06-2021 to 14-06-2024	**Christoph Lyko,** Rolls-Royce Deutschland
1451	Aeroelastic Cascade DELTA II // CORNET // 01-09-2021 to 31-08-2023	**Dr. Sabine Schneider,** Rolls-Royce Deutschland
1453	Modelling of Primary Atomisation Using SPH // FVV-EM // 01-01-2022 to 31-03-2023	**Dr. Ruud L.G.M. Eggels,** Rolls-Royce Deutschland
1458	Creep-fatigue Crack Behavior of Welded Joints II // AVIF // 01-01-2022 to 31-12-2024	**Dr. Shilun Sheng,** Siemens Energy
1462	Optimization with Frequency Domain Based Methods // FVV-EM, BMBF // 01-04-2022 to 30-09-2024	**Dr. Stephan Behre,** MTU Aero Engines
1465	Dedicated Piston Bore Interface Layout for H_2-ICEs // BMWK/AiF // 01-07-2022 to 31-12-2024	**Dr. Robert Krewinkel,** MAN Energy Solutions
1467	Hot Gas Ingestion into Wheel Cavities // BMWK/AiF // 01-01-2022 to 30-06-2024	**Dr. Marco Konle,** MTU Aero Engines
1469	Tilting Pad Bearing Elastokinetics // BMWK/AiF // 01-07-2022 to 31-12-2024	**Dr. Tobias Wiedemann,** MAN Energy Solutions
314 V	Damage Tolerance on Plain Bearings // BMWK/AiF // 01-10-2016 to 30-06-2019	**Michael Lutz,** MAN Energy Solutions
677 II	Radial Tilting Pad Bearing Oil Supply Influence II // BMWK/AiF // 01-01-2018 to 31-03-2021	**Nico Havlik,** RENK
803 II	Gleitlagersystemtoleranzen GL // BMWK/AiF // 01-03-2019 to 28-02-2022	**Sebastian Wolking,** SAINT-GOBAIN
836 II	Alternative Lagermetalle II // BMWK/AiF // 01-03-2022 to 31-08-2024	**Dr. Christoph Weißbacher,** GTW
847 I	Mikrostrukturierung von Gleitlagerflächen // BMWK/AiF // 01-11-2018 to 31-10-2021	**Dr. Oliver Alber,** MAN Energy Solutions

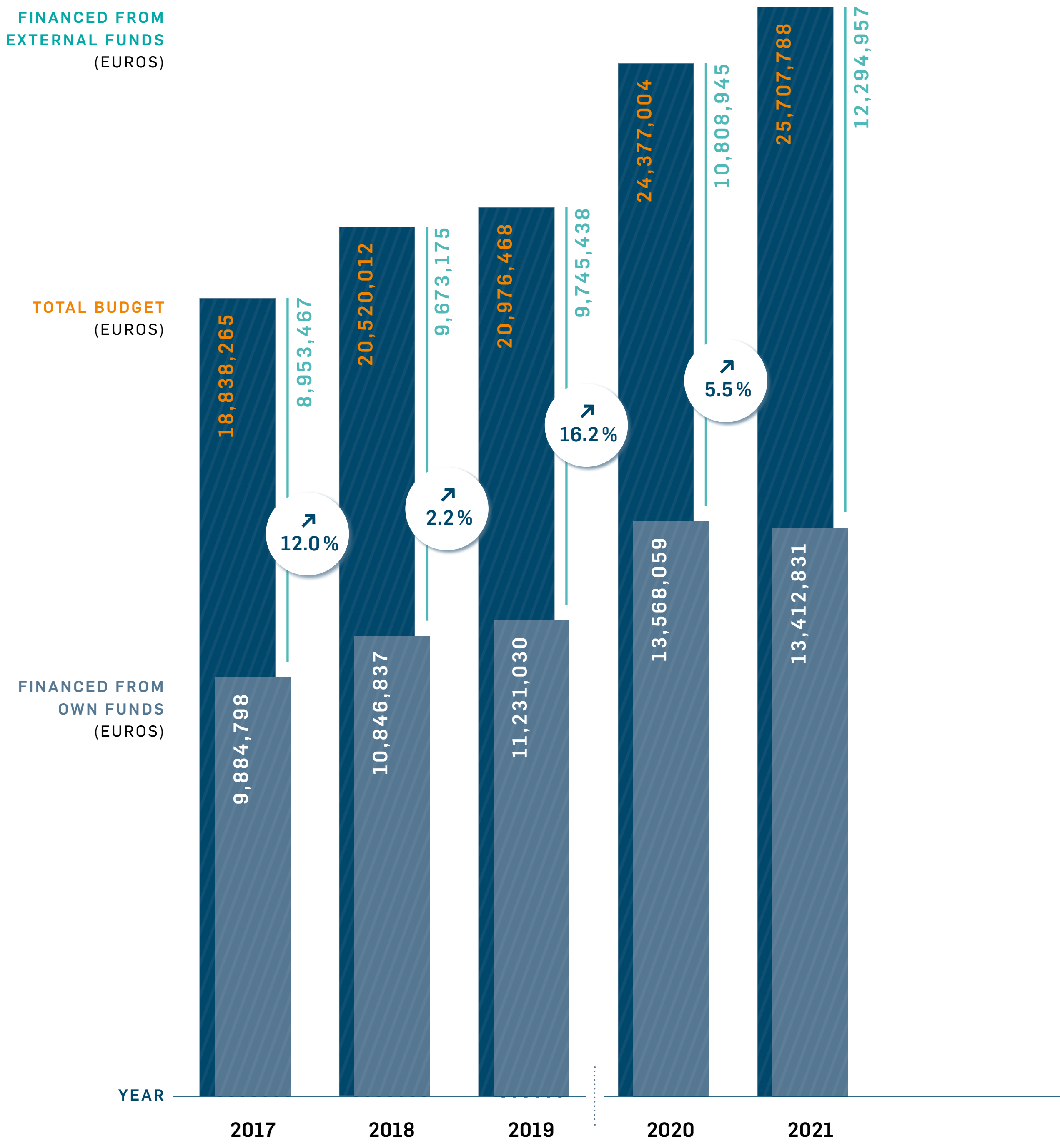
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
880 I	Werkstoffqualifizierung // BMWK/AiF // 01-11-2019 to 31-10-2022	**Sebastian Wolking,** SAINT-GOBAIN
915 I	Gleitlager-Schmierstoff-Qualifizierung // BMWK/AiF // 01-11-2020 to 31-01-2023	**Cornelia Recker,** Klüber Lubrication München

Completed projects

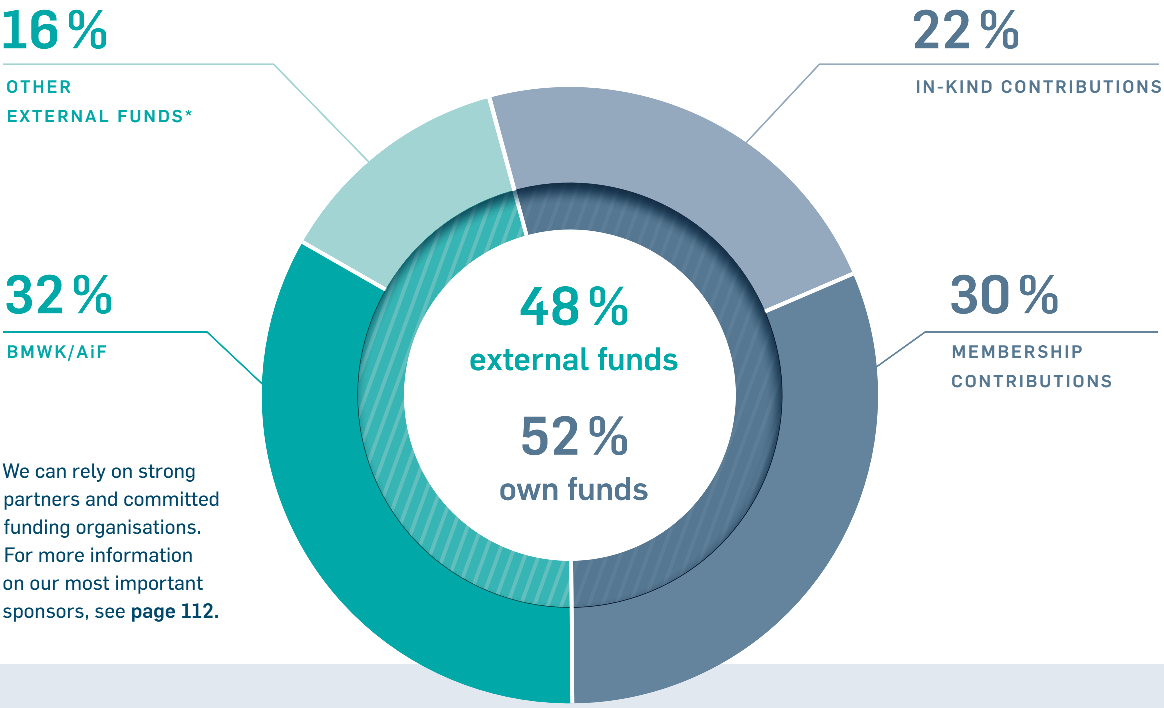
NO	TITLE // FUNDING ORGANISATION // DURATION	PROJECT COORDINATOR
1232	Secondary Flow Influence // FVV-EM // 01-10-2016 to 31-12-2021	**Dr. Stephan Behre,** MTU Aero Engines
1345	Hot Gas Ingestion into Wheel Cavities in Gas Turbines – Test Turbine // FVV-EM // 01-02-2019 to 31-10-2021	**Dr. Marco Konle,** MTU Aero Engines
1356	Tilting Pad Bearing Dynamics // FVV-EM, BMWK/AiF // 01-03-2019 to 30-11-2021	**Klaus Steff,** Siemens Energy
1373	Dynamics of TC Rotors with Coupled Bearings // BMWK/AiF // 01-10-2019 to 31-03-2022	**Thomas Klimpel,** Turbo Systems Switzerland
1438	Heat Transfer Reduction at Turbine Casing Parts // FVV-EM // 01-07-2021 to 28-02-2022	**Norbert Pieper,** Siemens Energy
836 I	Alternative bearing materials // BMWK/AiF // 01-06-2018 to 31-07-2021	**Martin Limmer,** RENK

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 112.**

YEAR-OVER-YEAR ANALYSIS

	Membership contributions	In-kind contributions	Total own funds
Change	↘ −3.2 %	↗ 1.8 %	↘ −1.1 %
2020	7,983,185	5,584,874	**13,568,059**
2021	7,727,864	5,684,966	**13,412,831**

	BMWK/AiF	Other sponsors	Total external funds
Change	↗ 17.6 %	↗ 6.9 %	↗ 13.7 %
2020	6,929,079	3,879,866	**10,808,945**
2021	8,148,353	4,146,604	**12,294,957**

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

BMWK/AiF –

Federal Ministry for Economic Affairs and Climate Action/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 (BMWK). Within the scope of Industrial Collective Research, the BMWK 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

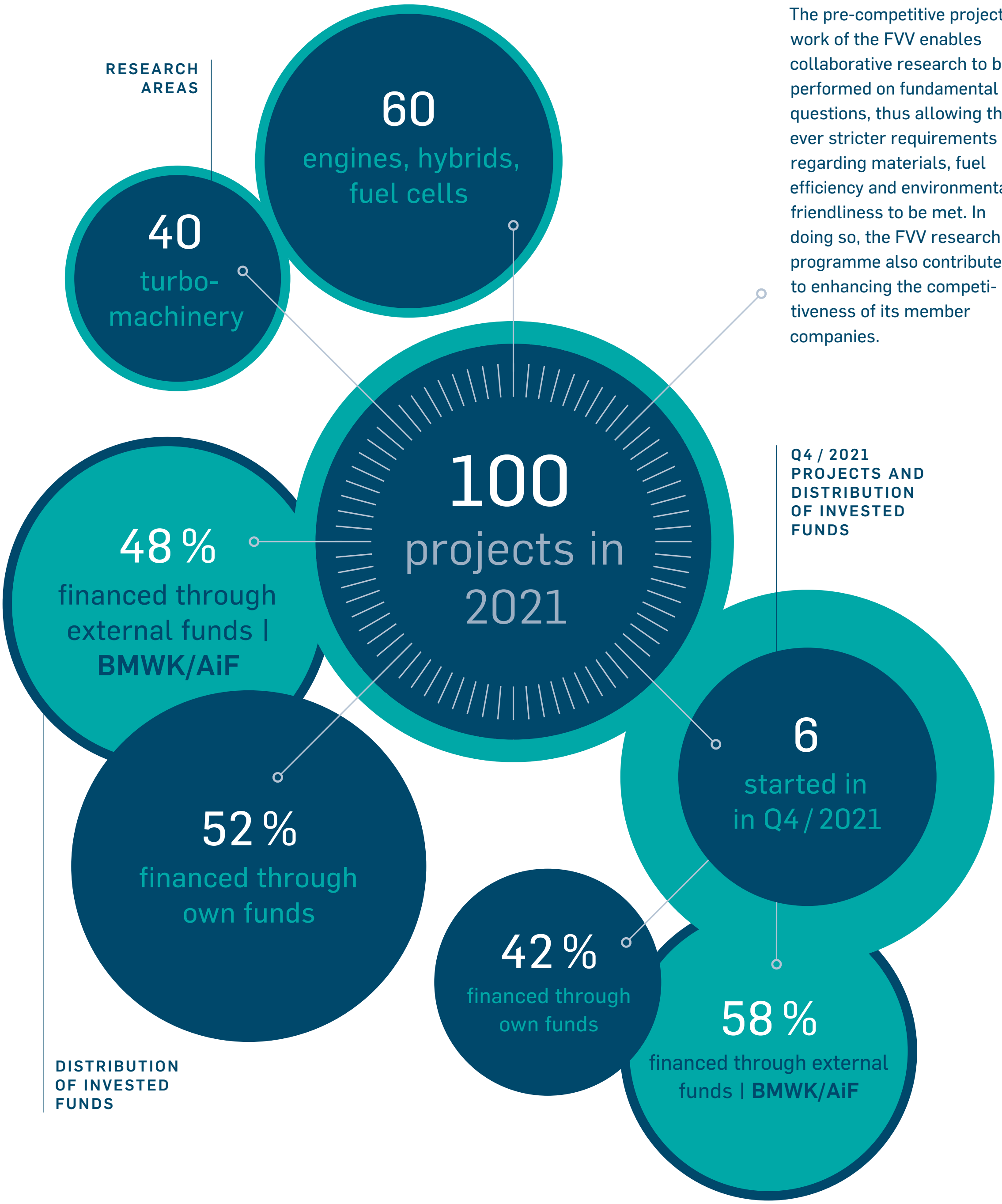
The objective of the AVIF is to fund research in the area of steel processing and application in Germany. Since its foundation, the AVIF has funded around 240 research projects with a funding volume of €55 million. It plays a significant role in raising knowledge of the possible applications of steel 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 + Fuel Cells

DISTRIBUTION OF FUNDS | BMWK/AIF AND OWN FUNDS

LOCATION	EUROS	%
Aachen	1,411,365	16.5 %
Stuttgart	1,353,269	15.9 %
Karlsruhe	852,464	10.0 %
Darmstadt	570,203	6.7 %
Hanover	570,203	6.7 %
Magdeburg	547,490	6.4 %
Braunschweig	401,596	4.7 %
Zurich / Windisch (CH)	322,423	3.8 %
Hamburg	269,507	3.2 %
Berlin	222,739	2.6 %
Duisburg	212,432	2.5 %
Freiberg	171,407	2.0 %
Erlangen-Nürnberg	165,274	1.9 %
Chemnitz	159,740	1.9 %
Vienna / Graz (AT)	152,825	1.8 %
Valencia (ES)	122,112	1.4 %
Munich	115,344	1.4 %
Cottbus	112,029	1.3 %
Dortmund	98,150	1.2 %
Freiburg	93,053	1.1 %
Coburg	78,740	0.9 %
Flensburg	75,699	0.9 %
Rostock	73,493	0.9 %
Dresden	73,421	0.9 %
Lemgo	70,000	0.8 %
Others < 60,000 €	238,377	2.8 %
	8,533,355	

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

RTD PERFORMERS

Research partners Turbomachinery

DISTRIBUTION OF FUNDS | BMWK/AIF AND OWN FUNDS

LOCATION	EUROS	%
Aachen	1,026,156	28.6 %
Stuttgart	349,164	9.7 %
Berlin	348,242	9.7 %
Freiburg	335,596	9.4 %
Darmstadt	334,583	9.3 %
Freiberg	178,641	5.0 %
Clausthal	154,566	4.3 %
Munich	138,487	3.7 %
Bremen	127,750	3.6 %
Karlsruhe	104,340	2.9 %
Bochum	77,271	2.2 %
Magdeburg	70,778	2.0 %
Wuppertal	69,800	2.0 %
Cottbus	69,298	1.9 %
Duisburg / Essen	68,190	1.9 %
Dresden	54,244	1.5 %
Hanover	51,500	1.4 %
Cologne	19,649	0.6 %
Frankfurt	10,428	0.3 %
	3,588,683	

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

RTD PERFORMERS

Annual statement of accounts

BALANCE SHEET

	31 DECEMBER 2020		31 DECEMBER 2021	
ASSETS SIDE	EUROS	EUROS	EUROS	EUROS
A. Current assets				
I. Receivables and other assets				
01. Advance payments	3,694,060.08		1,361,846.70	
02. Other assets	483,337.33		7,766.66	
		4,177,397.41		1,369,613.36
II. Cash on hand and bank balances		4,587,778.68		4,937,297.13
B. Non-current assets				
I. Securities		1,082,113.61		1,087,195.70
		9,847,289.70		**7,394,106.19**
LIABILITIES SIDE	EUROS	EUROS	EUROS	EUROS
A. Amount carried forward for research activities				
01.a Own funds	5,576,074.39		3,912,538.65	
01.b Reserves of own funds	224,000.00		224,000.00	
02. External funds	1,413,975.79		38,331.19	
		7,214,050.18		4,174,869.84
B. Provisions				
01. Provisions for pensions and similar obligations	376,720.00		423,603.00	
02. Other provisions	147,503.03		162,816.09	
		524,223.03		586,419.09
C. Liabilities				
01. Liabilities to research institutes	2,083,569.04		2,596,324.18	
02. Other liabilities	25,447.45		36,493.08	
		2,109,016.49		2,632,817.26
		9,847,289.70		**7,394,106.19**

REPORT OF THE INTERNAL AUDITORS

Science for a
moving society

Bericht über die Rechnungsprüfung am 8.08.2022

Die auf der Mitgliederversammlung 2021 der FVV e.V. gewählten Rechnungsprüfer:

Arndt Döhler, Opel Automobile GmbH, Rüsselsheim

Dirk Ragus, Nemak GmbH, Frankfurt

haben am 8. August 2022 in den Räumen FVV e.V., Frankfurt, die Rechnungsprüfung für das Jahr 2021 auftragsgemäß vorgenommen.

Als Unterlagen standen zur Verfügung:

Der Jahresabschluss zum 31. Dezember 2021 mit den darin aufgeführten Übersichten für:

- Einnahmen- Ausgaben- Rechnung 2021
- Kosten der Geschäftsstelle 2021
- Eigenmittelausgaben 2021 für Forschungsvorhaben
- Fremdmittelausgaben 2021 für Forschungsvorhaben
- Gesamtmittelausgaben 2021 für Forschungsvorhaben (Fremd- und Eigenmittel)
- Vermögensaufstellung zum 31.12.2021
- der vom Wirtschaftsprüfer GGV GmbH, Frankfurt am Main, erstattete Bericht über die Prüfung der Jahresrechnung zum 31. Dezember 2021 vom 25. Mai 2022 über die ordnungsgemäße Rechnungslegung der FVV e.V.

Die gewählten Rechnungsprüfer haben Einsicht in die Kosten und stichprobenweise in die Einzelbelege über die Verwendung der Eigenmittel der FVV e.V. genommen (Projekte 4342, 4060, 4330), wobei Herr Goericke (GF FVV) und Frau Stupar (Projektmanagement Finanzen FVV) die gewünschten Erläuterungen gegeben haben.

Die vorgenommenen Prüfungen haben zu keinerlei Beanstandungen geführt und die Rechnungsprüfer schließen sich hinsichtlich der Verwendung der Mittel dem Bestätigungsvermerk des Wirtschaftsprüfers an.

Frankfurt, den 8.08.2022

Arndt Döhler

Dirk Ragus

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BANK Commerzbank Frankfurt | IBAN DE72 5008 0000 0091 5324 00 | SWIFT-BIC DRESDEFFXXX

AiF Mitglied

Arndt Döhler (Opel Automobile) and Dirk Ragus (Nemak) conducted the voluntary internal audit for the 2021 financial year on 8 August 2022. The audit did not lead to any objections: the auditors appointed by the Annual Meeting of Members agree with the auditor's report with regard to the use of own funds.

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

→ www.fvv-net.de/en | Transfer | Download | Publications

Science for a moving society

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Prime**Movers.** is an annual research magazine on Industrial Collective Research (IGF) on emerging technologies for sustainable and efficient energy conversion systems powering mobile and stationary applications, published by the research association 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.

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