FVV ANNUAL MAGAZINE

# Prime**Movers.**

2021 | »Networked action for zero emissions«

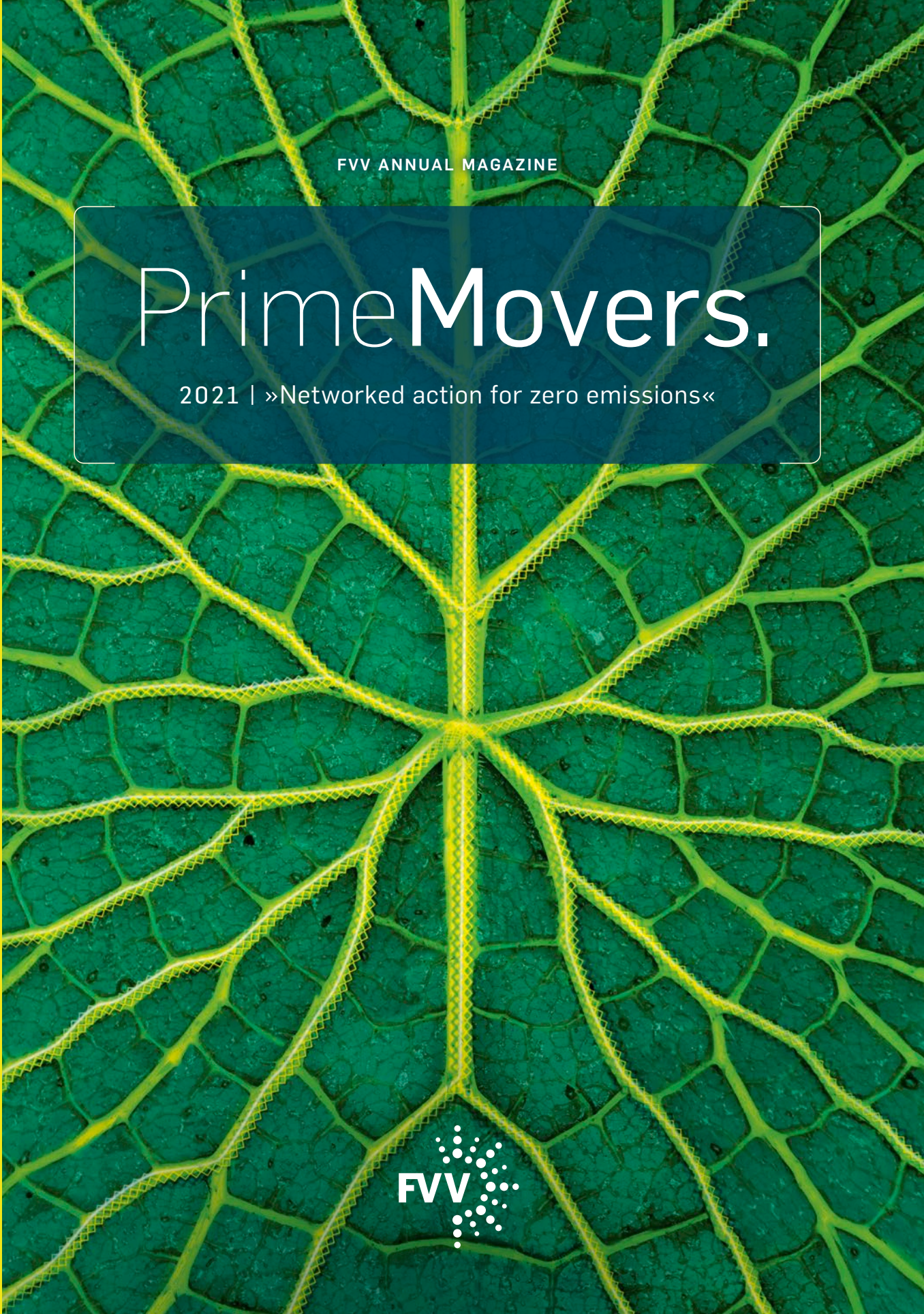


Photo: creativix_ Adobe Stock

# »Networked action for **zero emissions**«

*Prof. Dr. Peter Gutzmer, President of FVV,*
*on the value of networks in an era of transformation*

Dear FVV members,
dear readers,

Five years ago, almost exactly to the day, FVV celebrated its 60th anniversary. If you were to pick up the book that was published to mark this occasion, you'd notice two things: unlike in preceding technology-focussed anniversary publications, people were at the heart of our book that year. People who work with us, particularly engineers in industry and researchers at universities. People who work with passion and commitment to develop the technology we need to move society forward. By putting people front and centre, we turned the spotlight on the core value of FVV: the networking of bright minds. We also looked at the shift that was already well under way by 2016. One of the subheadings in an interview I gave for the book was: »There are enormous changes on the horizon.« Now, in 2021, this shift is still not complete. In fact, the pace of change has picked up. It has become so all-encompassing that the word ›transformation‹ – which is usually used to refer to societal systems – has established itself in the free economy. Like many other concepts, transformation is open to interpretation. So I want to explain how we experience transformation in FVV – both in terms of the work we do and how we organise it.

»Systematic research that involves many different energy sources and energy converters demands a large, collective network.«

For many years, the pre-competitive, collective research coordinated by FVV was focussed on highly detailed research questions: how does the geometry of a piston head affect the efficiency of a direct-injection combustion engine? Or how can we accurately predict the exact lifespan of an innovative, highly temperature-resistant material for an aircraft turbine? What is the perfect reduction agent for nitrogen oxide exhaust gas aftertreatment? Within the frameworks of such projects, people at FVV have been able to drive technological progress, develop more efficient machines and reduce emissions – and they continue to do so today. Without this research, there would be higher levels of hazardous substances in the air we breathe and higher concentrations of environmentally harmful emissions in our atmosphere. And our industrial sector would not have access to such highly qualified, skilled engineers.

However, we are also acutely aware that we cannot pave the way for a climate-neutral world by fine-tuning details. It is no longer enough to hone in on the machines we use for energy conversion when we actually need to restructure our entire world to use only renewable sources of energy. We need to optimise our entire system, beyond the traditional sector boundaries of energy and transport. With this in mind, the Board and the Scientific Advisory Committee of FVV have spent the last few years pushing for research into alternative energy sources. The fuel studies have been, and continue to be, an important source of new knowledge and information. The recently published fourth study shows that it will be virtually impossible to keep to the greenhouse gas budget set out in the Paris Agreement if we focus exclusively on ensuring that all new vehicles produce no emissions, without coming up with sustainable alternatives for the vehicles already in circulation around the world [→ page 16]. It is also important for me to say that these kinds of meta-studies are designed not only as a kind of roadmap for our cross-sector value creation network, but also to highlight new directions for our research.

This signposting function is all the more evident in the research programmes that the FVV Board initiates and drives forward, in some cases dedicating significant internal resources to do so. In these programmes, our goal is to identify the most important innovation issues for digitalisation and climate neutrality and to develop projects to provide the answers we need. The enthusiastic response to our latest research initiatives on hybrid powertrains and energy converters in hydrogen systems [→ page 28] is very encouraging. Fuel cell research now accounts for a large part of our work. Alongside combustion engines and turbomachinery, we are turning our attention to this third energy converter – one that could be hugely important in a world that runs on renewable energy sources.

Our fuel cell projects – both the ones we have already put into action and those in the pipeline for the future – also demonstrate that efficient energy conversion will be a key area of research in the future. However, the manufacture of chemical energy carriers from renewable sources will remain more costly than recovering and processing fossil energy feedstock for the foreseeable future, and at the very least until regulations are introduced to make the

Photo: Uwe Nölke

latter option significantly more expensive. But, in a practice-oriented network like FVV, efficiency in energy conversion processes can be taken to new levels, which in turn will significantly boost the market acceptance of new technologies. And so, we see that the long-established benefits of collective research are just as important today as they have always been. In fact, they might even be more important: systematic research that involves many different energy sources and energy converters demands a large, collective network.

We have strong links with international partners such as the Japanese research association AICE [→ page 50] and the major maritime technology organisation CIMAC [→ page 52]. We also collaborate closely with the Research Association for Drive Technology (FVA) on our electrified powertrain projects. Although FVV is an independent research organisation, it has its headquarters at the VDMA, the largest industrial association in Europe. This means that we can consistently coordinate the political work of the association with the scientific expertise of FVV [→ page 38].

Will all this be enough given the scale of the transformation taking place? We have undoubtedly achieved a great deal already, and we've set the ball rolling for even more progress in the future. However, the future of FVV will be decided not only by its members or even by its Board – but by society's acceptance of certain technologies. There are two aspects to consider here: firstly, the generation and use of renewable energy sources requires further research, followed by the relatively rapid construction of the relevant infrastructure. Without public funds and international cooperation facilitated at government level, this will be difficult to achieve. Secondly, Germany will only be able to defend its leading position in many of the key technological fields – from electrolysis to aircraft turbines – if there is a steady supply of qualified new talent with an academic background. We need to present a convincing package not only to the government and wider society, but also to young people.

Over the past few years, we have consistently renewed our image and the profile we present to the world to communicate the fact that FVV is researching for the future; this magazine is part of that strategy. In the future, we want our image to reflect the transformation of our research programme towards digitalisation and climate neutrality. At the time of writing, no final decisions have been made. But I am sure that the outcome of this process will be a huge step forward for us. And that won't be the end of the changes, either. That's not what this is all about: our task is to keep the future open!

Let's continue to work together and build on our global network to pave the way for a zero-emissions future in energy conversion. //

**PROF. DR. PETER GUTZMER**
President

Sustainability 14

People
*Dr. Zeljana Beslic*
22

People
*Dr. Dirk Hilberg*
54

Hybrid power-trains | Hydrogen 28

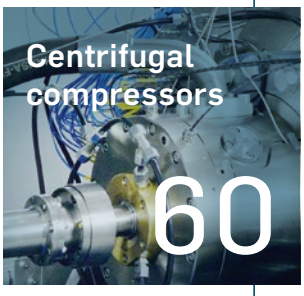
Energy sources
16

Additive manufacturing
64


**Opinion**
*Karl Haeusgen*
44


**Transformation**
*Dietmar Goericke*
08


**People**
*Dr. Ekkehard Pott*
32


**Centrifugal compressors**
60


**Multiplied benefits**
38
48

**Opinion**
*Stefanie Engelhard*
46

Networking 70

**FVV Annual Report 2020 / 2021**
75

People behind modern research 76

Research programme 86
- Priorities 88
- Planning groups 94

Facts & Figures – 2020 business year 118

Download | Imprint 128

## Who is driving our future?

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


SEG AUTOMOTIVE
IAVF
SCANIA
SCHAEFFLER
Wir leben Autos.
ETAS Engineering Tools
BWF Steinbeis-Transferzentrum Bauteilfestigkeit und -sicherheit, Werkstoff- und Fügetechnik (BWF)
Heraeus
ISUZU
iSimQ
LIEBHERR
KENOU
MODINE APPLIED THERMAL INNOVATION
Nemak Innovative Lightweighting
TENNECO
NESTE
WIN GD Winterthur Gas & Diesel
HJS Emission Technology
KS
AVL
FKFS
SIEMENS
APL Group APL IAVF APS IVP
ERC
Albonair
Ansys
EVONIK POWER TO CREATE
ENGINOS Engine Optimization Systems
FEV
GT
BASF We create chemistry
BMW
Eberspächer
ZF
LAVISION FOCUS ON IMAGING
DUNGS Combustion Controls
M. JÜRGENSEN A Promise Kept
+GF+
KST.
ifp Energies nouvelles
DAIDO METAL
SUBARU
WTZ INNOVATIVE SCIENCE & RESEARCH
MAGNA
Elgan
FUCHS
Rolls-Royce
MANN+HUMMEL
Garrett ADVANCING MOTION
FREYBERGER engineering
iST
CURTISS-WRIGHT
OMEGA RENK
Ghofer powertrain
BENTELER Automotive
Prins ALTERNATIVE FUEL SYSTEMS
LUBRISENSE Oil Emission Measurement Technology
INTES
VOLVO
TESONA Sensors & Engineering
mtu A Rolls-Royce solution
GUIDO PRESSURE · PRECISION · PERFORMANCE
HEINZMANN
INTERKAT
JENBACHER INNIO
HEAD acoustics
FEDERAL MOGUL
INPROSIM Innovative Produkt Simulation GmbH
CORYTON FOR A CLEANER FUTURE
THESYS Experts for Thermal Solutions

# »In the middle of a **twin transformation**«

Photo: Sarah Kastner

For **FVV Managing Director Dietmar Goericke,** the vision of climate neutrality is at the core of collective research. This vision can only be achieved through the use of $CO_2$-neutral energy sources and efficient energy converters. FVV is expanding its network and deploying modern digital methods such as artificial intelligence to make this happen.

**Mr. Goericke, many people are talking about the end of the combustion engine. Does this mean that all research on combustion engines is obsolete?**
You have to take a closer look before you can make this kind of sweeping statement. The smaller the vehicle, the more likely it is that it can be fully electrified. But for many forms of mobility, such as the engines widely used in nonroad machinery and in our energy systems, chemical energy carriers will still be essential in the long term. To utilise these technologies, we need the efficient energy converters – engines, turbomachinery and fuel cells – that are the topic of the practical research we organise.

**So the debate isn't affecting FVV's work?**
Looking solely at the figures, no. In 2020, we recorded the highest research expenditure we've ever seen in our over 60-year history. And in recent years we've gained many new members, including numerous small and medium-sized companies, who want to benefit from the results of collective research in this era of transition.

**And what about the actual content of the work that you do?**
Of course, our work is currently dominated by research into climate-neutral energy converters. We are committed to the targets set out in the Paris Agreement. But we will only be able to achieve these targets if we can make technological decisions based on science. With this in mind, we have complemented our conventional research projects into specific technologies with what are known as orientation studies. In these studies, we pool knowledge on individual technology paths – such as hydrogen technologies or synthetic fuels – from many of our member companies and identify the need for action and research based on fact.

**The main argument against the use of synthetic fuels is their low efficiency. Why should public funds be used to pay for research into energy converters that rely on these fuels?**
There are two reasons: firstly, any energy system that is based solely on renewable energy needs large energy storage systems to function. Chemical energy carriers offer precisely this storage potential without requiring

**DIPL.-ING. DIETMAR GOERICKE**
was appointed as the Managing Director of FVV in 2000. As Managing Director RTD Industrial Collective Research at VDMA, he is responsible for the association's pre-competitive collective research jointly conducted by industry and science and for its European research policy. Goericke has many years of experience in the energy and transport transition and in innovative mobility concepts at both a national and European level. He is a member of a number of advisory bodies, including the Kopernikus projects for the energy transition (Federal Ministry of Education and Research) and the committee on research supporting the energy transition in transport (BEniVer, Federal Ministry for Economic Affairs and Energy). He completed his studies in aerospace engineering at the Technical University of Berlin in 1987.

huge volumes of raw materials. Secondly, it's important to always consider the efficiency of the entire chain, from energy generation right down to the wheel or propeller. This is where chemical energy carriers do quite well. The energy can be generated in areas of the world where the productivity of solar or wind energy systems is much higher than it is here. However, it is definitely true to say that we need efficient energy converters along the entire chain. Efficiency has always been a central topic of our research.

**And the interplay between the energy source and the energy converter is the decisive factor.**
This is why we are constantly expanding the pool of companies who collaborate with us on research, and we welcome new members from the mineral oil sector who are also looking for ways to move away from fossil fuels. Synthetic energy sources also have the potential to significantly boost the efficiency of combustion engines and fuel cells – as demonstrated by the current ›ICE 2030‹ project, which focuses on vehicle powertrains with an engine efficiency of 50 per cent.

**But this is a hybrid configuration.**
That's right. And why not? Hybrid powertrains harbour huge potential not only for cars, but also for countless other applications, including ferries and construction machinery, because they allow mechanical energy to be recuperated. Last year, we even launched our own dedicated hybrid research programme. It is time we stopped pitting electric powertrains and combustion engines against one another. Different types of energy source and converter can complement one another perfectly within an energy system.

Photo: Uwe Nölke

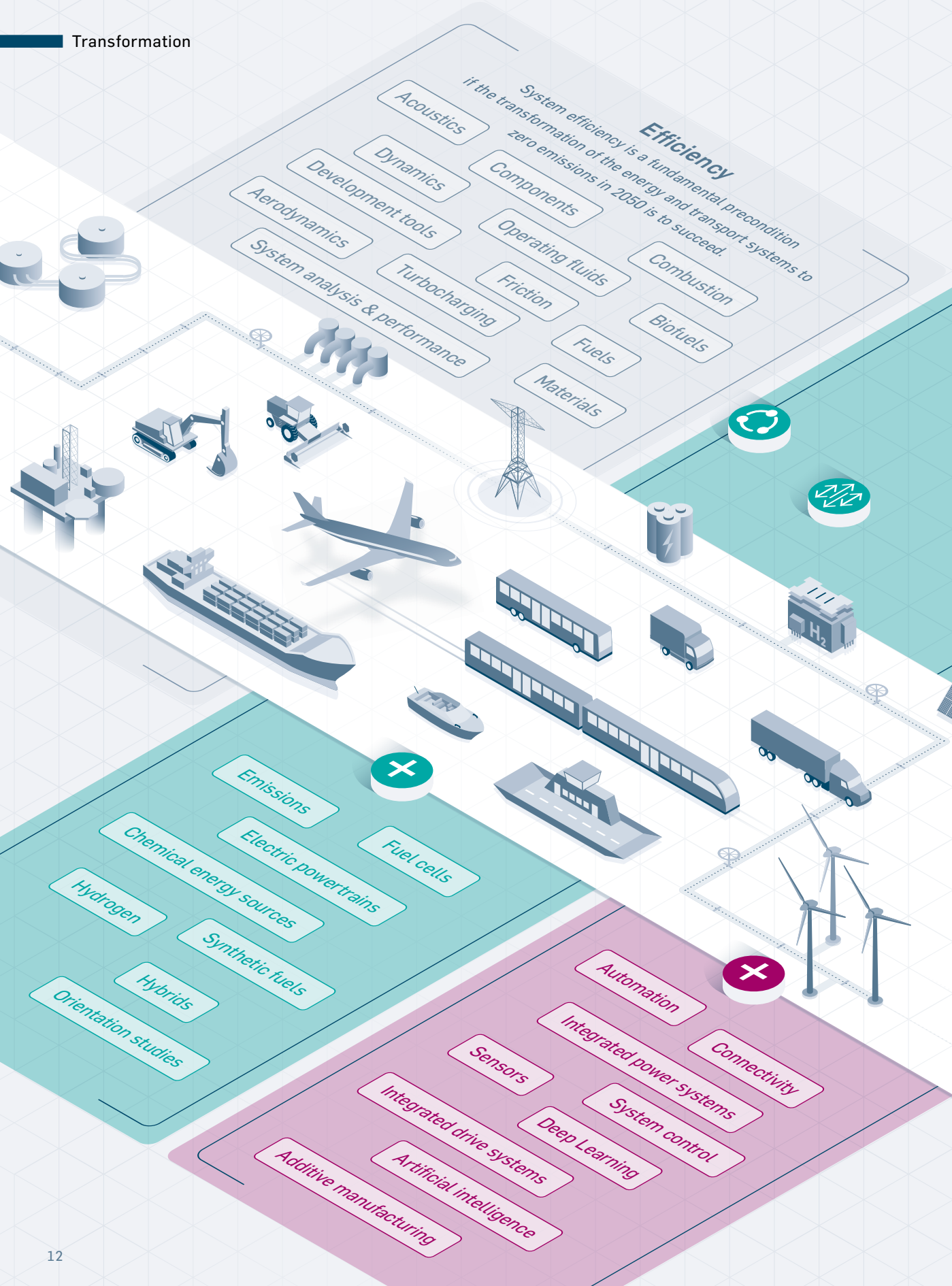
# »For our members, digitalisation and climate neutrality are both major challenges.«

**FVV has a diverse base of members comprised of companies of all sizes, from car manufacturers and suppliers of fuel cells to providers of large turbomachines for the aviation or shipping industry. Do your members benefit from this variety?**
I've observed that, in this era of rapid technological change, there is a growing interest in scientific exchange beyond the boundaries of specific applications. Of course, the service life requirements for a fuel cell will differ depending on whether it is going to be used in a car or on a cruise ship. But many of the basic technologies – whether they're for the materials or the development of simulation tools – are transferable or, at the very least, it is worth considering whether they could be transferable. After all, collective research is also about finding out what definitely doesn't work.

**FVV has also recently launched a project focussing on artificial intelligence. Is this just a fad?**
Not at all! We're in the middle of a twin transformation: for our members, digitalisation and climate neutrality are both major challenges. In the pre-competitive collective research we carry out at FVV, the development of powerful simulation tools has consistently been a focal point of our work. This work has helped to build a strong SME sector in Germany, which would not always be able to afford access to this methodical expertise otherwise. Developing new computing tools based on artificial intelligence processes is simply a logical continuation of our work to date. This is particularly true because we have the right framework conditions in place: our projects have always generated large volumes of data – on material properties, for example – and this data is pre-competitive and therefore available to all members.

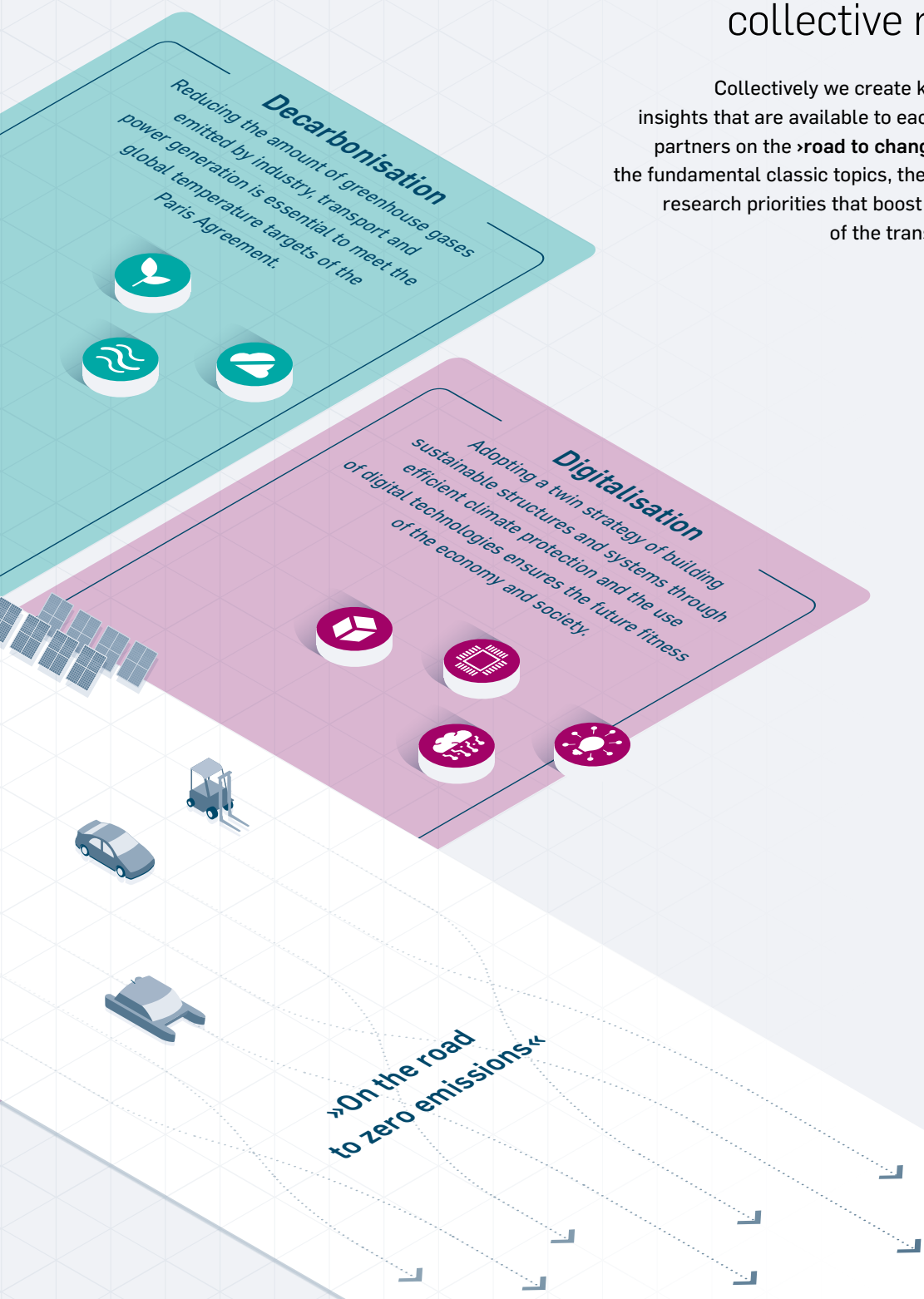
**How has the coronavirus pandemic affected the work of FVV?**
I've been impressed by how well the planning groups have progressed in spite of the pandemic. The digital working group meetings for some projects attracted more participants than ever before – partly because there was no need to travel. In spite of this, I'm very much looking forward to the first in-person conference in November. A network like FVV cannot thrive solely on organised online meetings; it relies on the spontaneous and trusting exchange of knowledge and information between people.

**Thank you for the interview, Mr. Goericke. //**


Efficiency
System efficiency is a fundamental precondition if the transformation of the energy and transport systems to zero emissions in 2050 is to succeed.
Acoustics
Dynamics
Development tools
Aerodynamics
System analysis & performance
Components
Operating fluids
Friction
Turbocharging
Combustion
Biofuels
Fuels
Materials
Emissions
Electric powertrains
Fuel cells
Chemical energy sources
Hydrogen
Synthetic fuels
Hybrids
Orientation studies
Automation
Integrated power systems
Connectivity
Sensors
System control
Deep Learning
Integrated drive systems
Artificial intelligence
Additive manufacturing

# The ›Twin Transformation‹ as part of pre-competitive collective research

Collectively we create knowledge-based insights that are available to each of our network partners on the **›road to change‹**. In addition to the fundamental classic topics, the FVV is installing research priorities that boost the achievement of the transformation goals.



# Sustainability as a compass

To move forward in uncharted territory, you need experience, knowledge and orientation. To navigate the era of transformation that we currently find ourselves in, we therefore need political direction and a clear technological compass. In its orientation studies, FVV develops proposals for future technologies to aid our sustainable economic, environmental and social transformation.

With scientifically sound studies based on neutral facts, FVV helps decision-makers from the worlds of politics, business, science and society to get to grips with complex technical questions. Climate-neutral, regenerative energy sources – such as electricity from renewables, hydrogen or the synthetic fuels that we urgently need to achieve a sustainable transformation and use resources in a greener way – play a key role in the research programme: regardless of the energy converter, vehicles, mobile machinery, planes, boats, ships and power generators will only be able to conserve resources and achieve greenhouse gas neutrality and zero net emissions with climate-neutral energy sources.

As the studies on the energy sources of the future take all applications and all options for energy generation and provision into account, researchers are able to use them to comprehensively assess innovative technologies. FVV orientation studies are always open to the best solution from a technical, economic and environmental point of view.

FVV orientation studies employ systematic thinking, take the economic aspects of innovation and competition into account, and place the principle of life cycle emissions at the centre of all analysis, in a global energy and carbon system with a $CO_2$ budget expressed as a residual amount of greenhouse gas emissions that may still be emitted up to the year 2050.

»Decisions almost always come down to sustainability.« In 2015, the United Nations published its Agenda 2030, setting out 17 global Sustainable Development Goals. These goals are intended not just for governments around the world, but also for civilians, the private sector and science. With this in mind, FVV bases its orientation studies around six UN Sustainable Development Goals, each of which is given equal weighting. //

SUSTAINABLE DEVELOPMENT GOALS

→ https://sdgs.un.org/goals


**FVV pursues the following Sustainable Development Goals on the path to climate neutrality:**

**[7]** Ensure access to affordable, reliable, sustainable and modern energy for all.

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

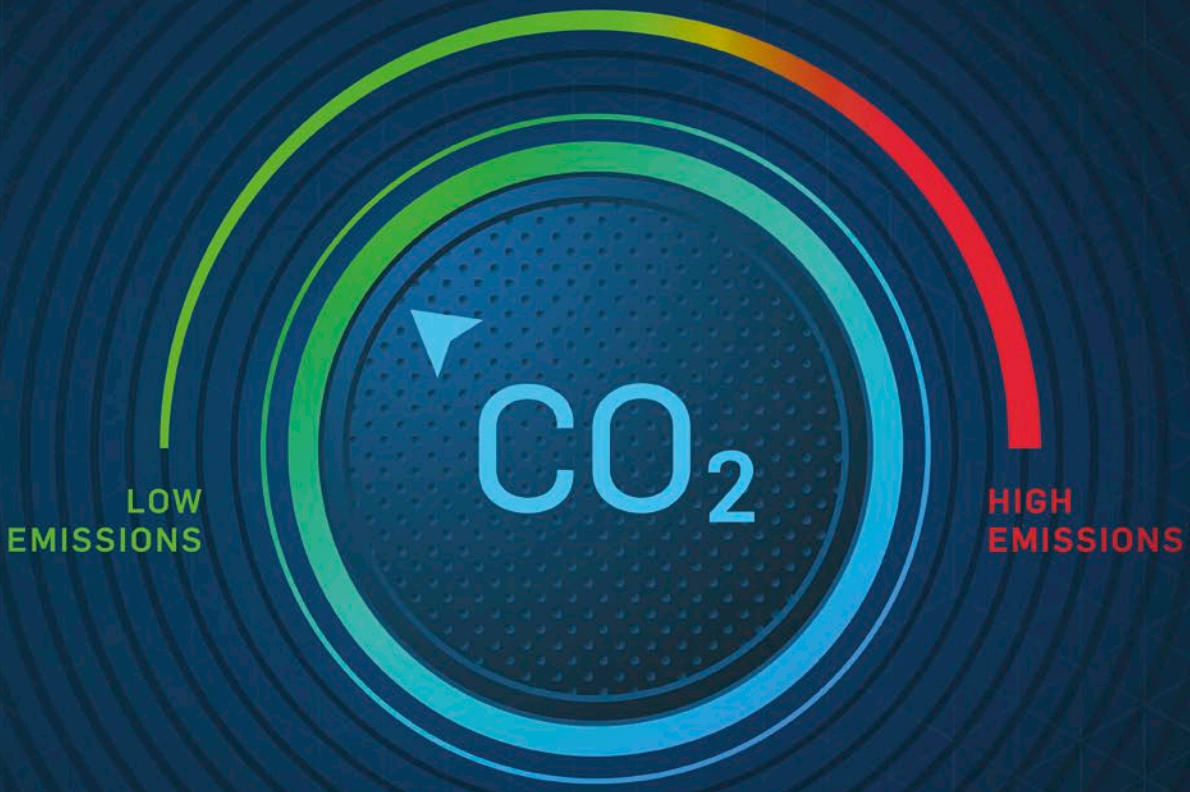
**[9]** Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.

**[12]** Ensure sustainable consumption and production patterns.

**[13]** Take urgent action to combat climate change and its impacts.

**[17]** Strengthen the means of implementation and revitalise the global partnership for sustainable development.

# Energy accounting for the climate




The new, fourth fuel study published by FVV expands the framework of the previous studies in a number of ways: alongside societal costs and various environmental factors, it also compares the cumulative $CO_2$ emissions for various energy sources and powertrains and demonstrates how these emissions stack up against the $CO_2$ budget set for Europe. This analysis shows that it will not be possible to meet the 1.5-degree target without taking existing vehicles into account.

**The overall result is all that matters //** Whether or not $CO_2$ neutrality is achieved in the year 2050 has no bearing on whether the goals set out in the Paris Agreement are met; what matters is the absolute volume of greenhouse gases emitted up to that point. The aim of the new study is to develop technological paths that will enable the European transport sector to meet the Paris climate objective.

Unlike in many other studies on this topic, project manager Ulrich Kramer's team decided to adopt a holistic cradle-to-grave approach that factored in all relevant emissions, from vehicle production and the creation of a sustainable energy supply through to use and recycling. The study also included emissions generated by the creation of the infrastructure, such as the construction of wind turbines, electrolysers and charging columns. Using this approach, the study calculated the cumulative emissions of six energy sources and seven powertrain technologies up to the year 2050. The study – for which around 60 FVV member companies supplied data and contributed their expertise – was conducted by Frontier Economics, a consultancy firm specialising in energy issues, in partnership with the Heidelberg-based Institute for Energy and Environmental Research (ifeu), which provided information on the environmental impact of each technology path and calculated the available $CO_2$ budget.

The most important result was that regardless of which of the 42 studied technology paths Europe selects, the continent will exceed its greenhouse gas budget by 2032 through transport emissions alone. This is because vehicles that are already in circulation – and that will no longer exist by 2050 – account for the majority of emissions. Regardless of the scenario, if the rate of introduction remains the same, these vehicles will account for around 70 per cent of the overall emissions. Kramer concludes: »The faster a technology or a mix of technologies can replace the use of fossil fuels in the transport sector, the better it will be for our climate. The rate at which sustainable energy is rolled out in the transport sector is key to achieving the $CO_2$ targets.«

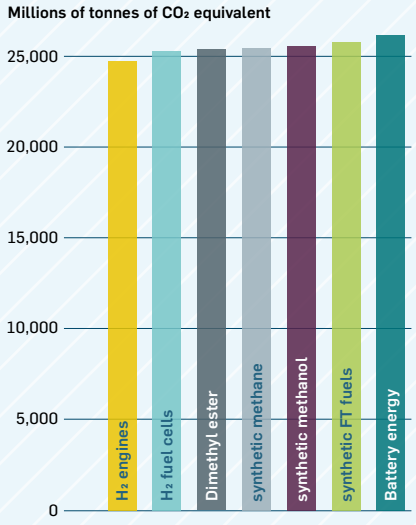
At identical rates of introduction, the various technology paths will all generate roughly the same level of cumulative $CO_2$ emissions between 2021 and 2050: there is just a 14 per cent difference between the most climate-friendly scenario – switching to green hydrogen and using it in combustion engines – and the least beneficial scenario, which is the use of Fischer-Tropsch fuels produced in Germany. Delaying or accelerating the introduction of any of these technology paths will drastically alter the rankings. »This is why it is essential to take the potential rates of introduction into account if we want to define efficient climate strategies,« explains Kramer.

Photo: Fajar, Adobe Stock

The study also highlights significant differences between the technologies in numerous other areas. The amount of energy required for the transport sector, for example, varies between 2,000 and 10,000 terawatt hours, with battery-powered electric vehicles – predictably – performing best. However, the study also shows that if synthetic fuels are produced in sunny or windy regions outside Europe, fuel cells only require around twice as much energy as purely battery-powered mobility, while combustion engines need three to four times as much. Furthermore, to run vehicles on electricity alone in a completely sustainable energy system, a huge amount of electrolysis capacity is required to safeguard the energy supply for transport during ›dark periods‹ where there is no sun or wind. By 2050, relying solely on electric mobility from domestic sources would require us to establish electrolysis capacity of around 1,000 gigawatt hours – almost as much as we would need if we were to exclusively use fuel cells. Other paths require up to 2,200 gigawatts of installed capacity. To put these figures in context, the EU is currently planning to build 40 gigawatts of electrolysis capacity by 2030, to cover all sectors.

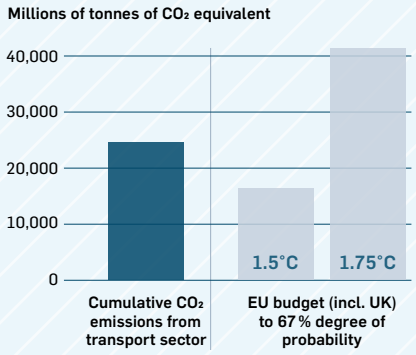
If we add up all the costs of building the required infrastructure incurred by 2050 along with the additional costs of alternative powertrains, the economic picture looks completely different: the most cost-effective way to achieve climate-neutral transport is to use methanol generated with green electricity as an energy source. The option of using sustainably produced Fischer-Tropsch diesel and petrol in existing vehicles comes in at number three in the rankings. The most expensive option

### Cumulative greenhouse gas emissions for the European transport sector, 2021 to 2050




→ If we consider all of the greenhouse gas emissions from the entire energy chain and the creation of energy infrastructure, there are only minor differences between the various energy sources.

### Comparison of cumulative greenhouse gas emissions up to 2050 with the EU budget (incl. UK)




→ Regardless of which alternative energy sources and converters are chosen, existing vehicles account for the majority of total emissions generated by the transport sector.

is battery-powered mobility, followed by a combination of hydrogen and fuel cells. »This is because of the high additional costs of the vehicle, which dominate the overall costs,« explains Kramer. »However, it is good to know that the complete defossilisation of the European transport sector can be achieved at a cost of no more than one per cent of the European gross national product per year over a period of 30 years.«

The authors of the study were also tasked with identifying potential bottlenecks that could arise in the process of getting the various paths up and running. Land use is not an issue for any of the technology paths, partly because none of the scenarios investigated involved using biomass as a primary energy source for road transport. The situation is somewhat different when it comes to the raw materials required for a full electrification of the transport sector. At the very least, if this solution were to be scaled up rapidly – as would be preferred given the meagre remaining $CO_2$ budget – there is a potential for bottlenecks to arise in the lithium and cobalt supply chain for batteries. For fuel cell powertrains, the high volumes of platinum required could become a bottleneck.

According to project manager Kramer, the fact that the new, fourth fuel study published by FVV bases its projections on 100-per cent scenarios in which we rely solely on one solution gives it a decisive advantage over other studies: »This is the only way we can properly compare the carbon footprint and costs along the entire energy chains, including the required infrastructure.« The data obtained from this analysis could be used to calculate the impact of mixed scenarios at a later stage. »I think it would be sensible to conduct a follow-up study to look in detail at the timing bottlenecks we could encounter during the introduction of the various energy and powertrain paths,« says the expert. »This study should also consider the feasible rate at which the use of synthetic fuels in existing vehicles can be ramped up.« One thing is already very clear from the FVV study: »Modelling the entire energy system is the only way to obtain valid results.«

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BRIEFING PAPER

»Modelling the entire energy system is the only way to obtain valid results.«

# »A **complete** picture«

**Dr. Ulrich Kramer,** the project manager for the FVV fuel studies, discusses the surprising findings of the latest study.

**Dr. Kramer, you were the project manager for the latest FVV fuel study. Which results were a surprise even to you?**
As engineers, we are always looking ahead and striving to develop useful new technologies. The fact that the petrol and diesel vehicles already in the market would dominate the overall result to such a great extent was a surprising finding for me. This is still the case even if we factor in the greenhouse gas emissions required to build new infrastructures. Based on this information, I've concluded that we must really keep an eye on our existing vehicle stock when bringing new, climate-friendly technologies to market.

**DR. ULRICH KRAMER**
is an expert in advanced and alternative fuels at Ford-Werke GmbH

Photo: Dirk Lässig

**The study takes into account not only the climate footprint of vehicles from production through to recycling, but also the creation of the entire energy infrastructure required to run them. Isn't that overcomplicating things a little?**

To the best of my knowledge, there are no other studies that have pursued such a comprehensive approach, particularly as we factored in not just greenhouse gases, but also other environmental factors and the economic costs. But all this work was worth it, because this is the only way we can get a complete picture of how different technological options will eat into our remaining $CO_2$ budget and what the work involved will cost in each case.

**Was that also the reason why you opted not to write off the emissions generated by the construction of infrastructure over the course of its life?**

That's right. According to the ISO rules, $CO_2$ emissions from manufacture should be written off over the service life of the system. Using this method of calculation, wind energy production, for example, never reaches a point at which it is completely free of $CO_2$ emissions. However, if you look at the available $CO_2$ budget, the emissions are generated in the year the infrastructure is set up and the $CO_2$ actually gets into the atmosphere. This conventional perspective artificially writes off real emissions, which gets in the way of efficient optimisation of the entire system. So we decided to take a more honest route.

**Does that mean that we're actually engaging in the wrong debate if we focus solely on zero-emission vehicle powertrains?**

This is a debate that fails to address the reality of climate change. For example, in the climate-neutral world of 2050, we will largely be able to erect wind turbines in a way that produces no greenhouse gases. But today we can't do that, and we take that into account in the study. Adopting a more holistic perspective also tells us that the sector objectives we have today could be counterproductive. For example, it is much cheaper in an economic sense to build one more wind turbine than it is to upgrade the technology of all vehicles. We have the space for wind turbines. And lightweight vehicle construction – driven by ambitious tank-to-wheel targets – might even be counterproductive in terms of the cumulative greenhouse gas emissions.

**You could take a very pessimistic view of the study and think it's all pointless anyway because no matter which technologies we use in the future, the vehicle fleet we use today is what matters.**

I don't see it that way. First of all, the pace at which we can ramp up new technologies is what determines how much $CO_2$ from the transport sector makes its way into the atmosphere. We want to look at this in more detail in a follow-up study. Secondly, we can combine technologies. It is important that we also consider technology options that will also reduce emissions in vehicles that are already on the roads. There are many arguments in favour of a technological mix of electromobility – supplied with energy generated in Europe – and combustion engines powered by synthetic fuels that have been efficiently produced in the sunny and windy regions of the world. We will explore this idea in more depth in our planned follow-up study. //

# The **reliability engineer**

From gear wheel edges to coil insulation: engineer **Dr. Zeljana Beslic** researches damage to develop more sustainable products.

Photos: Dirk Lässig

**A single dent on the edge of one tooth; one flaw in the coil of an electrical motor //** Although barely visible to the naked eye, these kinds of defects could cause a vehicle to break down – rendering it completely out of action. To prevent this situation, engineers investigate problems, study damage mechanisms, perform complex calculations and measurement series over long time periods, and develop ways to solve the issues. This work is Zeljana Beslic's world. When the 33-year-old mechanical engineer talks about her job, she does so with a smile: »Me, a reliability engineer …«

Beslic has proven herself reliable throughout her school and employment history. Her childhood curiosity about what a gear lever in a car does and how the vehicle moves was encouraged by her father, a mechanic who took Beslic – an only child – along with him to his garage. Beslic followed the path of many an engineer before her, enjoying maths, physics and chemistry in school. Before taking her final leaving exams, she knew she wanted to study mechanical engineering. Art was another passion, but was destined to remain a hobby.

Even though Beslic grew up in the automotive metropolis of Stuttgart, she kept her options open when choosing the direction of her studies. Because she had a strong interest in powertrains, she attended Professor Michael Bargende's lectures on combustion engines. However, machine elements were what really captured her imagination, and she thus decided to focus on design engineering. After completing her preliminary diploma, Beslic started an internship with Bosch to gain practical experience of machine elements in an industrial setting. It


was here that she wrote her degree dissertation, in which she conducted an experimental investigation into a planetary gear train for an exhaust gas recovery system. Back then, in 2013, Beslic shared the view held by many other engineers with significantly more experience – she believed that alternative powertrains would become important at some point in the future, but the priority now was to engineer combustion engines for greater efficiency.

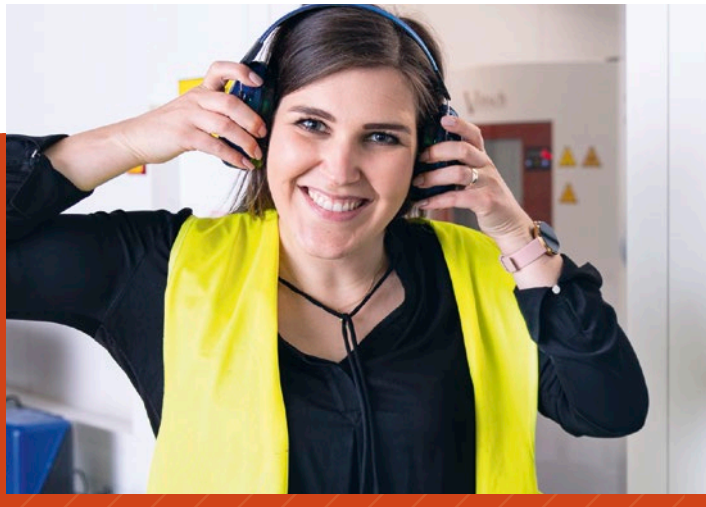
Once she had completed her studies, Beslic was looking to get stuck into her next scientific challenge. She remained at the Institute of Machine Components (IMA), taught younger students, managed the CAD lab and kept her eyes peeled for a topic for her doctorate. »Initially I spent a lot of time reading, because I wanted to identify an innovative and scientifically relevant issue,« recalls Beslic. She finally decided to focus on tribological damage to gear wheels. The fact that the damage first had to be caused before it could be analysed – in extensive series of tests – was a major challenge. It was also important to recognise the damage quickly without having to constantly interrupt the tests and remove the gear wheels. To get around these

»…I wanted to identify an innovative and scientifically relevant issue.«

issues, Beslic employed an acoustic testing process. »The human ear can't discern anything about the condition of individual teeth, but a frequency analysis does tell you what you need to know.« Based on her findings, and with the support of her institute, she developed a process that enables a gear to be switched in a way that minimises the stress on any teeth that are already damaged – a process that has since been registered for a patent.

By 2018, Beslic had almost tied up her project and was looking to make her next career move. She opted to join SEG Automotive, a Bosch spin-off and supplier of starter motors that had shifted its focus to electric traction motors. »In the meantime, I had realised that alternative powertrains would ultimately account for a large section of the market,« she explains. »I want to be part of this change process and, like SEG Automotive, which also has its origins in conventional powertrains, I want to help shift attention towards electrification.« In this role, Beslic uses her expertise to boost the reliability of electric powertrains. Because the damage mechanisms in electric powertrains are changing, Beslic spends a great deal of her time developing appropriate validation methods and test strategies. This is the only way of ensuring that, at the end of the development process, the product meets all the requirements of a long life on the road.

Beslic had only been at SEG Automotive for just over two months when her department manager, Dr. Dieter Eppinger – who also heads the Strength & Tribology planning group at FVV – sent out an email requesting ideas for new FVV projects. The young engineer responded with the suggestion of investigating the lifespan of coil insulation in electric motors. This was a topic of great importance; after all, even a minimal amount of damage to the insulation could cause a short circuit, resulting in the complete failure of the electric motor. Beslic attended the FVV planning group meeting in which a decision was made on the proposal. The majority voted in favour of her suggestion, but



**DR.-ING. ZELJANA BESLIC,**
born in 1988, graduated from the University of Stuttgart with a degree in mechanical engineering. Her doctoral thesis focussed on modelling tribological damage degradation on gear wheels in vehicle gearboxes. The reliability and testing engineer joined SEG Automotive in Stuttgart in 2018. She is the coordinator of FVV's ›Lifetime Model Winding Insulation‹ project launched in March 2021.

»We should always look at the **entire product life cycle.**«

some members rejected it because it veered away from the usual combustion engine-related topics. The project has now been running since March 2021, and Beslic herself has taken on the role of project coordinator.

On the one hand, she is enthusiastic about FVV's work: in her view, the fact that the knowledge gained from collective research is available to all is of enormous benefit, particularly to smaller companies. On the other hand, she would like to see the organisation develop a younger ›spirit‹ and be more receptive to the concept of electric powertrains. However, there is another point that she is keen to emphasise: »I don't believe in making a radical, rapid switch to electromobility. There is no point in charging electric cars with power generated from coal.« Accordingly, Beslic supports efforts to further optimise the conventional powertrain to reduce both consumption and exhaust emissions.

Regardless of the type of powertrain, something can only be sustainable if it functions reliably in the long term. »We should always look at the entire product life cycle,« says Beslic with conviction. So it's little wonder that the engineer is fascinated by Brooklyn Bridge, a feat of engineering completed in 1883. During a trip to New York a few years ago, she asked the man who is now her husband if he could get up at the crack of dawn the next day to paint the bridge in the early morning light. //

# Programmed for success

Hybrid powertrains and hydrogen as energy sources are crucial elements of the journey to climate neutrality. But that's not all – they are also central to two new FVV research programmes, encompassing numerous projects that are designed to provide scientifically sound answers to some of the most pressing questions of our era.

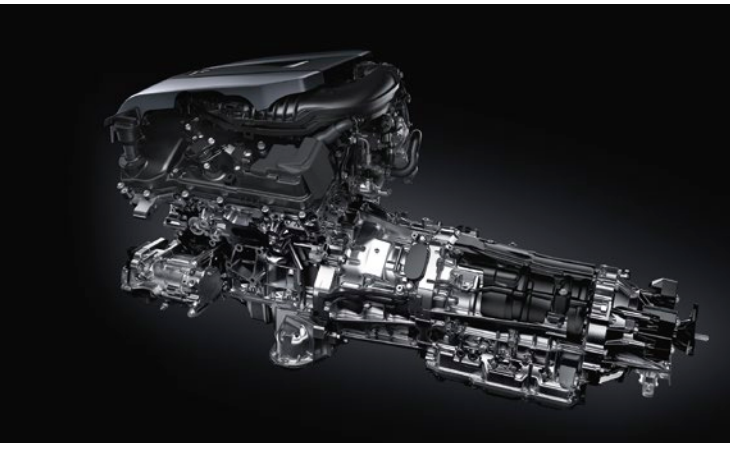
**It's more about the journey than the destination //** Given that most greenhouse gases are slow to break down in the atmosphere, it is important to identify the technologies that will allow us to rapidly reduce emissions. One of the options is to hybridise combustion engine powertrains; the other is to use hydrogen directly in the transport sector. Over the past twelve months, the FVV Board has launched hybrid and hydrogen research programmes to look at these options more closely. Both programmes comprise numerous individual projects in which companies and RTD performers are looking for specific, feasible technical solutions.

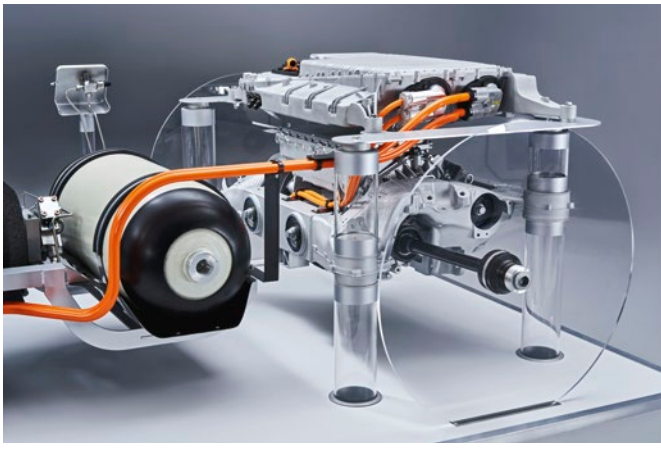
Hybrid powertrains are already commonplace in mass-produced vehicles – yet some key research questions remain unanswered. For example, there are many ways to combine electric and mechanical technology in hybrid powertrains. But what is the best way to combine these components such that the environmental benefit is maximised while also keeping production costs to a minimum? On behalf of FVV, the Technical University of Darmstadt is conducting research to answer this question. As part of this work, the university is aiming to develop a software program for suppliers, including medium-sized companies, by the end of 2022. The scientists have adopted an object-oriented approach from the world of IT, combining the high modularity of the system architecture with shortened computing times in the simulation. At RWTH Aachen University, meanwhile, researchers are studying how the operating strategy of a hybrid vehicle can be optimised to maximise the amount of time spent driving on electric power without producing local emissions. Traditional driving cycles are not ideal for this purpose, because they fail to account for factors such as special emissions zones or traffic congestion – but the predictive journey management system that the team in Aachen is developing would solve this issue.

Another relevant research topic is the combination of synthetic fuels and hybrid powertrains for all forms of transport that cannot be fully electrified. Efficiency is high on the agenda for these powertrains: high engine efficiency makes the entire energy chain more efficient, which in turn reduces the amount of solar and wind energy required for fuel production. FVV's ›ICE 2025+‹ project, which was completed last year, proved that synthetic fuels do have

→ Hybrid powertrains (below) are already a mature technology. The main area where research is required is the operating strategy.
For hydrogen engines (right), improving power density is just one area of research.

Photos: Toyota (below), BMW (right)





the potential to boost thermal efficiency. In the current follow-up project ›ICE 2030‹, scientists from Aachen, Braunschweig, Darmstadt and Stuttgart have set out to demonstrate that a thermal efficiency of at least 50 per cent is achievable.

At a molecular level, hydrogen is the simplest of all synthetic fuels. If it is generated via electrolysis from solar and wind energy, it can be used to power combustion engines in a way that is completely climate-neutral. This means that hydrogen engines are an attractive and readily available alternative for sectors such as heavy goods transport, where it will not be possible to achieve complete electrification in the foreseeable future. However, to run on hydrogen, a number of key engine technologies – including the carburation and ignition systems – will need to be adapted to the new energy source. There are still some fundamental phenomena that need to be explored here, for example in order to significantly increase power density while also preventing uncontrolled auto-ignition. The Karlsruhe Institute of Technology and a number of other organisations are currently investigating these questions on behalf of FVV. In another project initiated by IAV, a team is creating a simulation model for direct hydrogen injection.

An understanding of the phenomena that occur in an engine – along with the realistic simulation of these processes – have always been key to the collective research conducted by FVV. »Switching to hydrogen as an energy source means that we need to revisit many research questions,« explains Martin Nitsche, Deputy Managing Director of FVV. This is true of research into both operating safety and materials. As the results will be available to all member companies, they will accelerate the introduction of new technologies while also strengthening the competitive position of medium-sized suppliers.

FVV's hydrogen research programme includes the use of fuel cells as energy converters. The focal points of this fuel cell research – which is organised by a specific planning group – are operating behaviour and system design. After

all, the stack alone does not determine the costs, and therefore the market penetration, of the technology; what matters most is its behaviour in real-life conditions. The current projects are investigating topics such as cold-start characteristics and air supply.

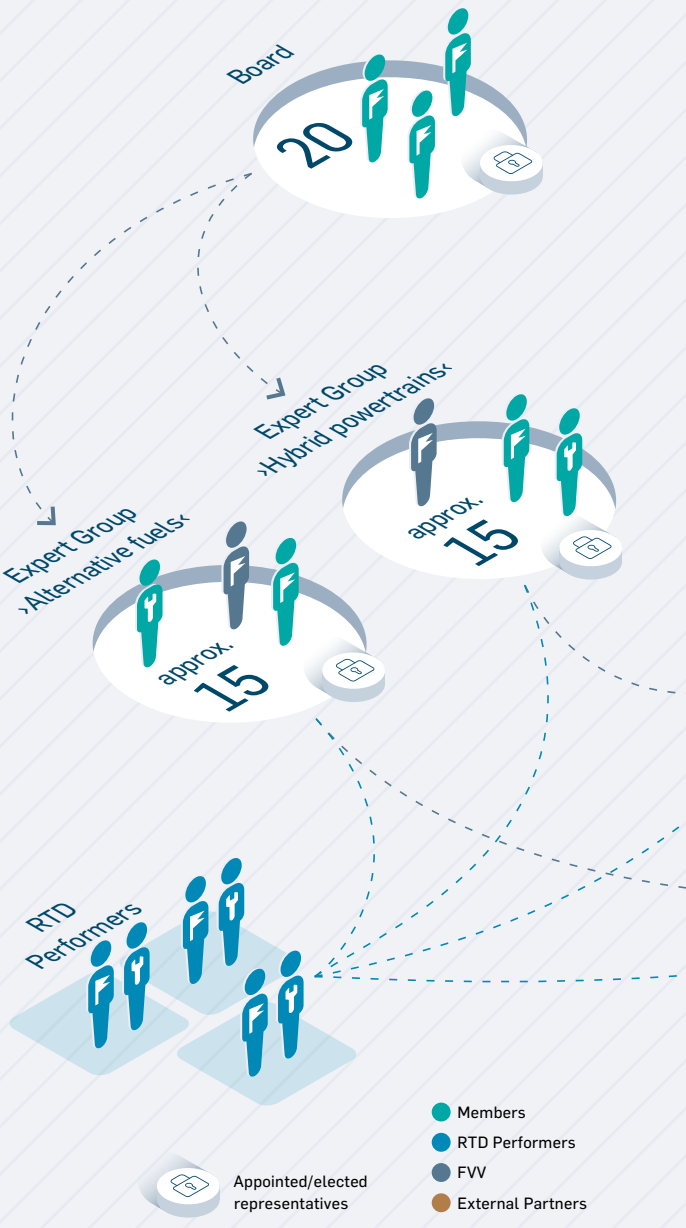
The hybrid and hydrogen research programmes are the direct results of a transformation process in which the FVV Board is responding to the rapid shift towards climate-neutral energy and transport systems. The strategic research questions for the programmes were initially formulated by the Board and the Scientific Advisory Committee. The RTD performers working with FVV were then able to submit specific project proposals. »By doing this, we are complementing the initial bottom-up approach with a top-down process,« explains Nitsche. »This enables us to align Industrial Collective Research even more closely with the questions that urgently require a scientific answer.« //

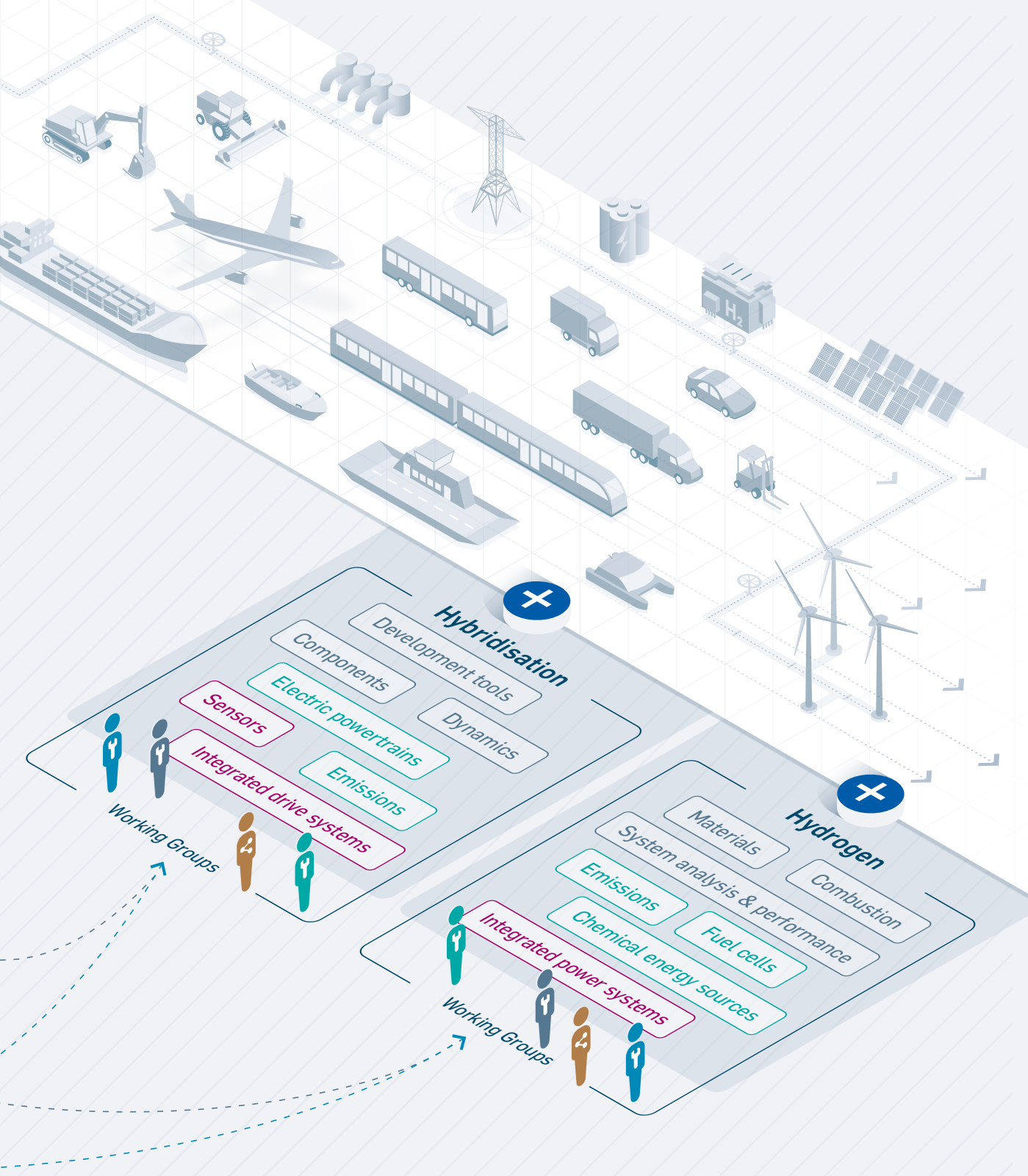
PROGRAMME HYBRID

PROGRAMME HYDROGEN

## How can new future topics be rapidly accelerated towards the ›road to change‹?

In key areas of the transformation, the FVV management can accelerate the bottom-up innovation process [→ page 90] that is standard in Industrial Collective Research and manage this process centrally via expert groups.






→ The **Board** can use **expert groups** to generate ideas for key technologies in order to meet the zero emissions target.

→ Together with the **RTD performers**, concrete project ideas are developed and used as the basis for a research programme.

→ **Working groups** are formed for each individual project; the results generated by each group are available to all members.

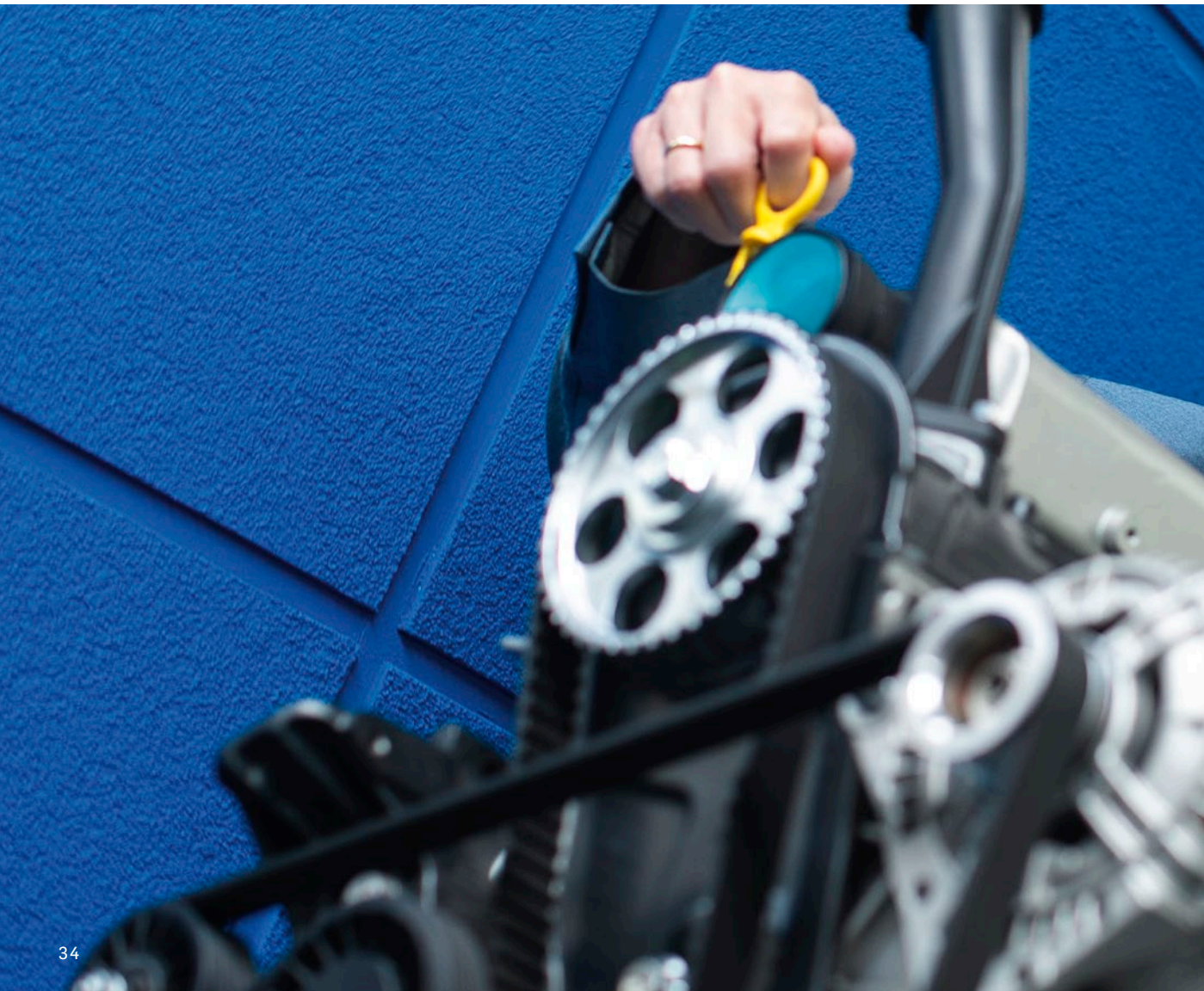
# The **virtues** of an engineer

For three decades, **Dr. Ekkehard Pott** has been working to develop combustion engines with ever lower levels of emissions – following fact-based and linear processes.

Photos: Dirk Lässig

**Facts over feelings //** For a logical and clear-headed engineer like Ekkehard Pott, this statement is a way of life. So getting all of Volkswagen's petrol and diesel powertrains ready for the forthcoming introduction of the Euro 7 standard is the perfect job for him. He adopts a level-headed approach to limit values and technologies; one must match the other, without question. In conversation, Pott is focussed at all times, not once veering off topic. He says little about himself, but speaks readily about production series, technology and physical interconnections.

Pott's career history has also followed a clearly mapped-out path. Before he had even left school, he had decided to pursue a career in engineering. His decision to focus on mechanical engineering was inspired by the state of the army truck that he was constantly asked to repair during his national service. Keen not to specialise too early in his training, Pott opted to study automotive engineering. »The course gave me a full 360-degree view of automotive technology,« says Pott today. The young engineer first came into contact with Volkswagen during a university project in which he optimised a front-end structure to improve safety in the event of an accident.



»We already knew that we would have to get to grips with the problem of $NO_x$ emissions.«

»They took me seriously right from the beginning,« he recalls. Pott immediately knew that this company was where he wanted to work. In 1991, after completing his degree, Pott commenced a technical traineeship at the Volkswagen plant in Wolfsburg.

Over the next 30 years, he remained loyal to Volkswagen and soon began to specialise in combustion engines. Even at the beginning, exhaust gas purification played an important role; his first engine research task was to develop emission reduction concepts for lean-burn engines. »We already knew that we would have to get to grips with the problem of $NO_x$ emissions.« While working, Pott also embarked on a doctorate at the Technical University of Berlin, which he completed within four years. As part of his work, he developed a vehicle-specific simulation program that could be used to predict not only emissions, but also fuel consumption, allowing direct connections to be made between these two parameters for the first time. From 1997, Pott worked on the development of an $NO_x$ adsorber for lean-burn spark-ignition engines with direct injection, with which he eventually moved to the department for spark-ignition engine pre-development. In 2000, the technology was rolled out in series production in the Lupo. Pott responds matter-of-factly when asked if he is proud of this achievement: »It had to work that way, there was no technological plan B at that point.«

In 2002, Pott was asked to head up the spark-ignition engine pre-development team. »I felt like I had won the lottery,« recalls Pott. But his new role was still a major challenge. Pott was suddenly in charge of 60 employees rather than five; at the same time, he had to stay fully up to speed with all

technical progress because Volkswagen was busy developing the first generation of direct-injection petrol engines with turbocharging, which were later marketed as the TSI engine. »This technology enabled us not only to meet the consumption targets we had set ourselves, but also to boost torque to deliver a significantly better experience behind the wheel.« FVV also played a role in the company's success: »Many projects delivered fundamentally important findings on direct injection in spark-ignition engines.« Pott also recruited a number of employees who had completed their studies or doctorate as part of an FVV project team, which meant that they joined the company with a wealth of relevant knowledge.

Once Pott's work had helped petrol engines get significantly closer to catching up with diesel, the engineer switched sides in 2007 to manage the series development of large diesel engines – namely five-cylinder models and the V10 engine. Five-cylinder engines are primarily found in light-duty commercial vehicles, particularly the Transporter series of vans. The shift towards four-valve and common rail technology was under way, and the company wanted to reduce the number of engine variants it produced. Pott's task was therefore to adapt the four-cylinder diesel engine to the Transporter, necessitating a design specifically for commercial vehicles that took load requirements and available space into account. By 2009, this goal had been achieved – but many van drivers were sad to say goodbye to the five-cylinder engine. Pott resists this temptation: »You can't let your heart rule your head when making these decisions. The four-cylinder model has proven to be more cost-effective, more economical and more reliable.«

By 2017, the engine development team at Volkswagen were cleaning up in the wake of the diesel scandal. Pott – maintaining a clear head as ever – decided against a more comprehensive management role, instead opting to return to a position with a more technical focus. His ambition was a good match for the company's needs; when preparing its engines for the Euro 7 emissions standard, Volkswagen

**DR.-ING. EKKEHARD POTT,**
born in 1964, studied mechanical engineering at RWTH Aachen University. Having specialised in automotive engineering, he embarked on his career in 1991, working in a number of positions in Volkswagen's engine research and development departments. He is currently responsible for modular design development, calculation, methods and exhaust gas aftertreatment. Pott is also Chairman of FVV's Scientific Advisory Committee.


needed to demonstrate that its engines were fully compliant with the regulations. This was a task that Pott liked the sound of. Around this time, he also became more involved with FVV, which he had first encountered in 1995 as a young engineer. In 2020, he was appointed Chairman of the research organisation's Scientific Advisory Committee, during a phase of major transformation towards climate-neutral powertrains. »The impetus that pre-competitive collective research can provide in this phase is more important than ever before,« says Pott with conviction.

Although Pott never fails to present a balanced and carefully thought-out argument in his role as an engineer, when he opens up his own red and white T2 for the photographer, his expression is one of pure passion and joy. Pott bought the 1979 van from a dealer in Arizona and had it fully restored, taking care of every detail himself. The switches, for example, are originals sourced from other vehicles. The T2 only goes out in good weather; Pott has a garage full of other vintage vehicles to choose from on grey days. His hobby isn't a point of contention in his marriage, either: Pott's wife shares his passion for historic cars and the couple enjoy going to rallies together. //

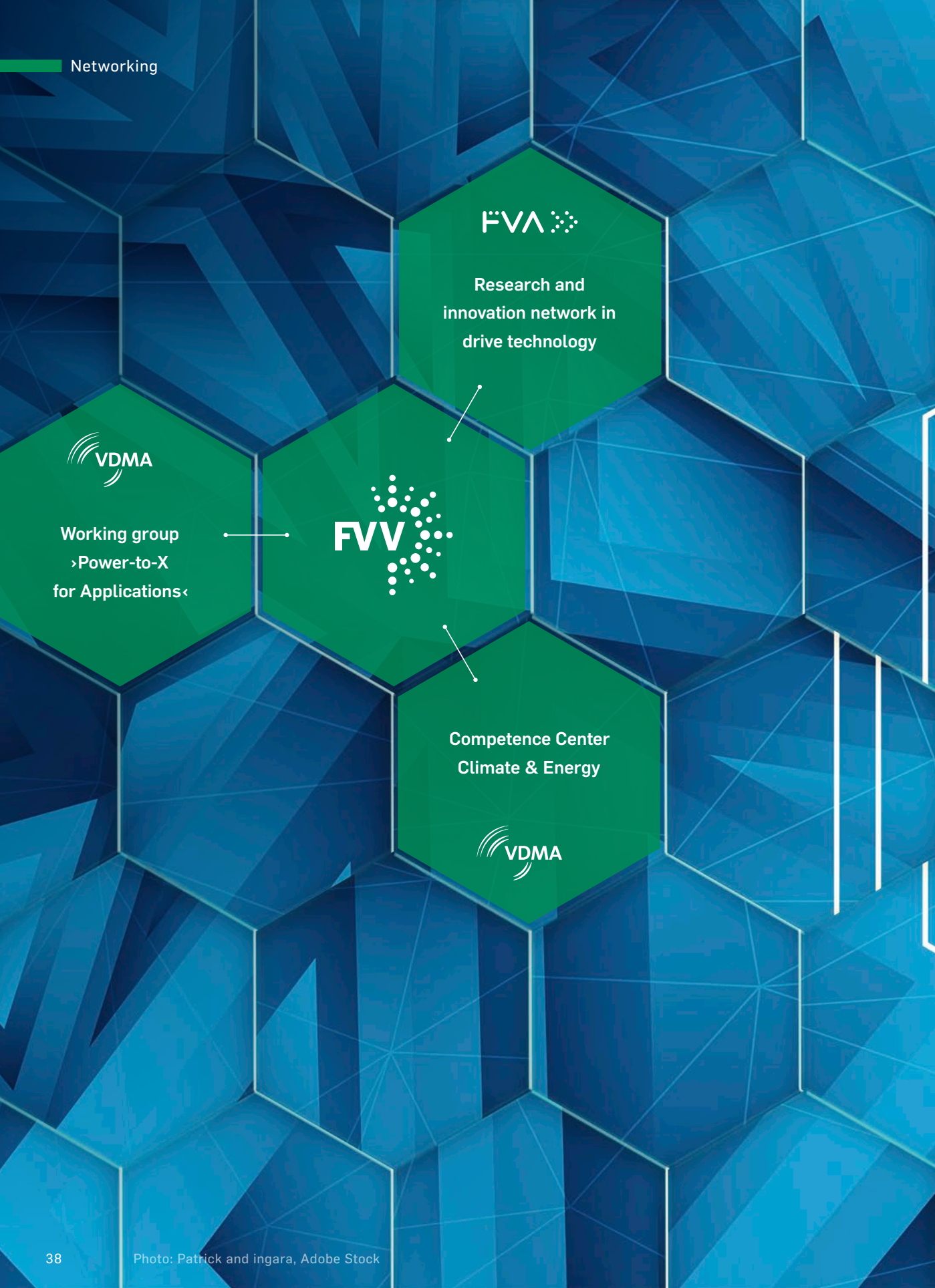





Photo: Patrick and ingara, Adobe Stock

# Multiplied benefits

VDMA is the voice of the mechanical and plant engineering industry in Germany, and has organised the FVV office ever since its foundation. The result is a network that extends far beyond the boundaries of the research association. FVV member companies such as MAN Energy Solutions, Rolls-Royce Power Systems or ZF are involved at several levels and thereby multiply their benefit from the collaboration.

# Calling the system into question

**The perfection of a tooth flank //** It is a vivid symbol of the values behind the German mechanical engineering industry's export prowess. However, merely having the necessary mechanical properties is no longer enough to guarantee success in the global market, and hasn't been for some time. This has an impact on the work of the **Research Association for Drive Technology (FVA)**, the office of which, like FVV's, is organised in Forschungskuratorium Maschinenbau (FKM) – the research federation for the mechanical engineering industry within VDMA. »As electrification increases, electronic hardware and software is gaining in importance,« explains Dr. Otmar Scharrer, Senior Vice President R&D E-Mobility at the supplier ZF and Board member of FVA. He believes that this systems expertise will play a key role in giving future powertrains properties that make them stand out from the competition: for example, he views hybrid powertrains as a technical marvel, the acoustic behaviour of which is dependent on the interplay of all subsystems, whether the control system, the engine and gear mechanisms or the electrical components. Scharrer feels that collective research plays a dual role here: »Firstly, it gives even small and medium-sized suppliers knowledge of the basic interrelationships. And secondly, the young engineers involved in the research projects learn to think systematically right from the beginning.«

FVA's research focuses are changing along with the needs of its member companies: »We added the work on electrified powertrains to the portfolio early on,« comments Hartmut Rauen, the long-standing Managing Director of FVA. »Through the E-MOTIVE expert forum for electric vehicle powertrains, we and FVV generate knowledge that the members of both research associations benefit from.« Rauen, who is also Deputy Executive Director of VDMA, sees collective research from a different angle: »Together, FVA and FVV not only cover the entire range of energy converters, but also all applications.« After all, if collective research succeeds in creating climate-neutral and competitive powertrains for all mobile applications from forklift trucks to heavy-duty mine trucks, the whole of the mechanical engineering industry will benefit.

**DR. OTMAR SCHARRER**
Senior Vice President
R&D E-Mobility
(ZF Friedrichshafen)

 Photo: ZF

# The timing

**Getting the timing just right //**
Dr. Uwe Lauber, Chief Executive Officer of MAN Energy Solutions, is convinced that a climate-neutral world can only be achieved with green hydrogen and synthetic energy carriers that are based on it. Indeed, around 300 million tonnes of fuel are currently used in shipping alone, with only a small portion of this able to be replaced by the direct use of electricity. Synthetically produced ammonia or methanol could be used on board instead: »Research and development are already at an advanced stage,« explains Lauber. »From a technical point of view, we could completely replace fossil-based energy carriers in most applications by 2030 at the latest.« Lauber believes that the real challenge is in ramping up the production of synthetic fuels. »We are talking about major plant investments in regions outside Europe.« This will require many specialised companies to collaborate on a technical level, as well as the political will to shape the change, for instance when working together with states in which solar and wind energy allow electricity – and thus also hydrogen – to be generated cheaply. VDMA's **Power-to-X for Applications (P2X4A)** working group, chaired by Lauber, will help with both aspects. »We bring together the worlds of politics and business, for instance in order to draw up realistic road maps.« Such a road map has already been devised for aviation, and a similar concept is currently in development for the marine sector.

Peter Müller-Baum, Managing Director of VDMA's Engines and Systems trade association, has headed the working group since its foundation in 2018. »We have drawn a lot of attention to the topic of power-to-X in a short period of time,« he reports, while highlighting the fact that many political decision-makers in Berlin and Brussels are now very aware of the key role played by synthetic energy carriers. Moreover, lively technical exchange is taking place between the member companies, which, alongside large plant manufacturers, include many small and medium-sized suppliers of parts such as compressors or pumps. The European mechanical engineering industry is in the starting blocks.

**DR. UWE LAUBER**
Chief Executive Officer
(MAN Energy Solutions)

# The rules

**Hydrogen – the driver of the energy transition //** Renewable power production needs to become much more cost-efficient – that is the demand of Dr. Daniel Chatterjee, who is responsible for the technology strategy of Rolls-Royce Power Systems. However, technical progress alone will not be enough to make hydrogen and the synthetic fuels based on it cheaper than fossil-based energy carriers. »Regulation plays a decisive role here,« explains Chatterjee, who chairs the VDMA Climate and Energy Forum. »All sectors that require very high energy densities are prepared to make the switch to climate-neutral energy carriers. However, no company will risk its economic competitiveness for this.« Providing the political actors in Berlin and Brussels with constructive criticism is one of the association's most important tasks: »Many member companies are highly specialised small and medium-sized enterprises which would not be heard on their own,« continues Chatterjee. Global corporations from all sectors are also involved in the association – something the physicist sees as a significant advantage: »The climate protection policies of the future must not stop at the borders of individual countries or be restricted to certain industry sectors. We believe in global solutions.« Chatterjee praises FVV's orientation studies, which in his view have provided an important basis for the association's political work.

Because climate policy is of key importance for the entire mechanical engineering industry, VDMA has founded a **competence centre** dedicated to the topic of **climate and energy**. It is headed by Matthias Zelinger, who is responsible for turbomachinery research at FVV in his role as Deputy Managing Director. In his view, allowing the sector to innovate is his most important task: »I can certainly understand the state also making decisions regarding technology before making large-scale investments in infrastructures,« says Zelinger. However, it should always be kept in mind that climate protection is a global task and that business is keen to develop functional global solutions together with the legislators. //

**DR. DANIEL CHATTERJEE**
Director Technology Management
(Rolls-Royce Power Systems)



Photo: RRPS

# The interplay

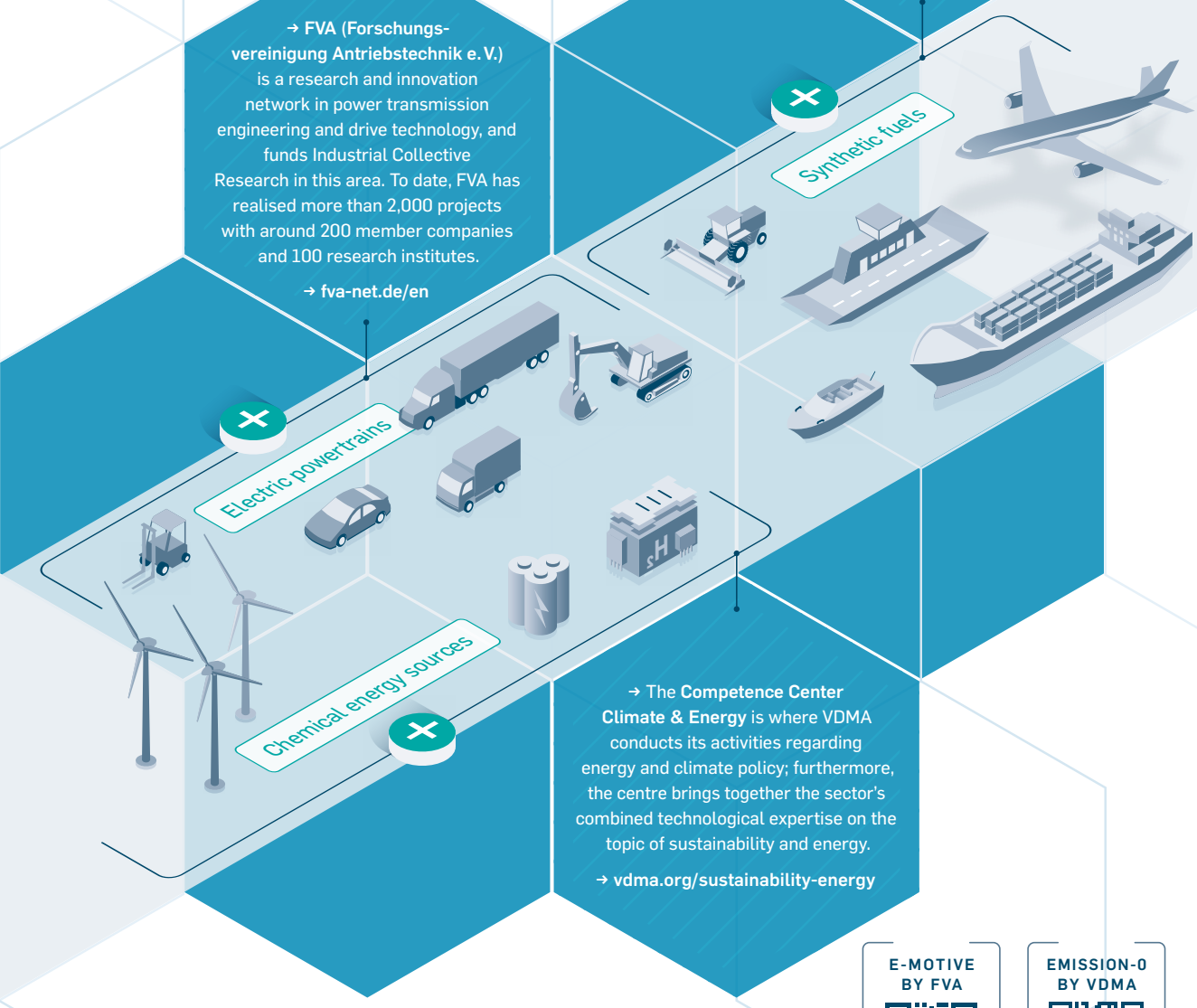
By bringing together the various disciplines, members multiply their expertise and their ability to play an active role on the ›road to change‹.

→ The ›**Power-to-X for Applications**‹ working group organises political and technical exchange along the entire P2X value creation chain. It lobbies for alternatives to direct electrification and a technology-neutral view of the energy transition in the political and public arenas.

→ **p2x4a.vdma.org/en**

→ **FVA (Forschungsvereinigung Antriebstechnik e. V.)** is a research and innovation network in power transmission engineering and drive technology, and funds Industrial Collective Research in this area. To date, FVA has realised more than 2,000 projects with around 200 member companies and 100 research institutes.

→ **fva-net.de/en**




→ The **Competence Center Climate & Energy** is where VDMA conducts its activities regarding energy and climate policy; furthermore, the centre brings together the sector's combined technological expertise on the topic of sustainability and energy.

→ **vdma.org/sustainability-energy**

E-MOTIVE BY FVA

EMISSION-0 BY VDMA

# »Trust **collective intelligence!**«

**Karl Haeusgen, VDMA President,** on the advantages of a technology-neutral transformation

It is a widely held view that we need to respond to the global challenge of climate change by transforming our largely fossil fuel-based economy. However, the exact form that this transformation will take is the subject of intense discussion. So let's take a closer look at this topic now. The voices that have been most prominent in this debate so far are those that interpret ›transformation‹ to mean a radical move away from all previous business models and technologies. Usually, these kinds of beliefs come coupled with demands for a higher level of state control. But I always wonder: why are we so confident that the state will make the decisions that are right for us – particularly when it comes to deciding which technologies to pursue and which to abandon?

When I look at the German mechanical and plant engineering landscape, I see a different picture: I see the collective intelligence of a powerful SME sector in almost all regions. This economic model, based on a free market with clear and consistently implemented rules, is what has made us a leading supplier to factories and critical infrastructures all over the world. Time and time again, it has been proven that answers to pressing environmental questions can be found quickly in this kind of market. In 1964, for example, the first edition of the Technical Instructions on Air Quality Control (›TA Luft‹) not only brought blue skies back to the Ruhr region, but also acted as a springboard for German companies to become technological leaders in industrial exhaust air purification – without prescribing the use of any specific technologies. I see no reason why an open technological competition would not be capable of producing climate protection technologies that would be successful around the world – as long as enormous state infrastructure investments are not allowed to stifle technological diversity.

Aside from collective intelligence, there is a second success factor for the German SME sector: the European unification process. In the global competition with the other two major economic blocs, China and the USA, a strong European home market is a secure foundation from which to do business. Although it can prove challenging to achieve consensus as

Photo: HAWE Hydraulik SE

part of an association of democratic states, we should do everything within our power to not only define common objectives, but also to agree a set of rules and regulations shared by all member states. The diversity in the technical solutions we come up with – for energy systems, for example – should be viewed not as a threat, but as an opportunity. By the year 2020 at the very latest, it was clear that the entire world is moving towards climate neutrality. However, it is extremely unlikely that all countries will follow the same route to their ultimate destination, regardless of the societal and geographical conditions that will affect their journeys.

The more open-minded we remain in the face of this transition, and the more great minds we have looking for answers, the more likely it is that ›Made in Germany‹ and the European CE mark will become synonymous with the best climate protection technologies in the world. This is why we are pleased to have FVV's Industrial Collective Research into sustainable powertrains and energy conversion systems as part of our network. //

**KARL HAEUSGEN**, born in 1966, is the main shareholder of a family-owned business and is a long-serving member of VDMA. In October 2020, he was appointed President of the association. On completing his studies, the business economist initially worked in numerous mechanical engineering companies before moving to HAWE Hydraulik, where he was appointed Managing Director in 1996 and spokesperson for the Board of Management in 2008. He is now the Chairman of the company's Supervisory Board.

# »Engineers wanted!«

**Stefanie Engelhard, company founder,**
on how engineers can contribute to climate protection

Since the mid-1970s, research findings have repeatedly proven that air pollution resulting from human activity is causing global warming. Now, scientists even believe that the process of climate change began back in 1830 with the start of the industrial revolution. For many years, warnings were ignored; knowledge did not lead to action. But luckily, this has all changed in the past few years, and politicians around the world are now largely ready to intervene.

The only question is: how? When people think about reducing emissions, they often think that it's all about doing without: travel less, use your central heating less, consume less meat and food from faraway countries, drive slower, buy fewer clothes. But the idea of ›less‹ could also be replaced with ›differently‹. And this is where we engineers come in. We are the only ones who can develop new technologies that will allow us all to live more sustainable lives. I'm optimistic that new technologies and new processes will enable us to adapt to the changing climate while also preventing the crisis from worsening. In 2018, Jeffrey Sachs, the economist and pioneer behind the Sustainable Development Goals, wrote: »The time for engineers to take centre stage has arrived.« And we want to step up! But in some cases, the conditions we need to hit the ground running are still lacking.

In my view, the greatest challenge is financing. Of course, there are investors who already focus on sustainability, but these criteria are still rarely applied to venture capital. And we cannot tackle the climate crisis with software solutions alone; innovative hardware solutions are what we really need. But these investments involve significantly larger sums and longer investment periods. Hardware innovations can, of course, become tangible patents. This is new territory for many venture capitalists, and prevents us engineers from reaching our full potential. As a result, innovations often fall by the wayside before they can come to fruition, or an engineer abroad gets to the finish line first.

I have first-hand experience of these challenges. My husband Lars and I founded the high-tech start-up Unleash Future Boats to develop environmentally friendly, autonomous boats for clean and sustainable water travel. Our boats are equipped with

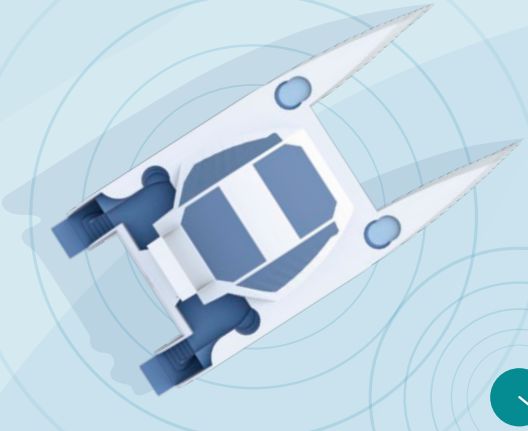


Photo: Kabuja

an electric powertrain with fuel cells and green hydrogen, making them completely free of emissions. We recently launched our prototype ZeroOne. From early 2023, the first zero-emissions small ferries will take to the waters of the Schlei, an estuary in Schleswig-Holstein, Germany.

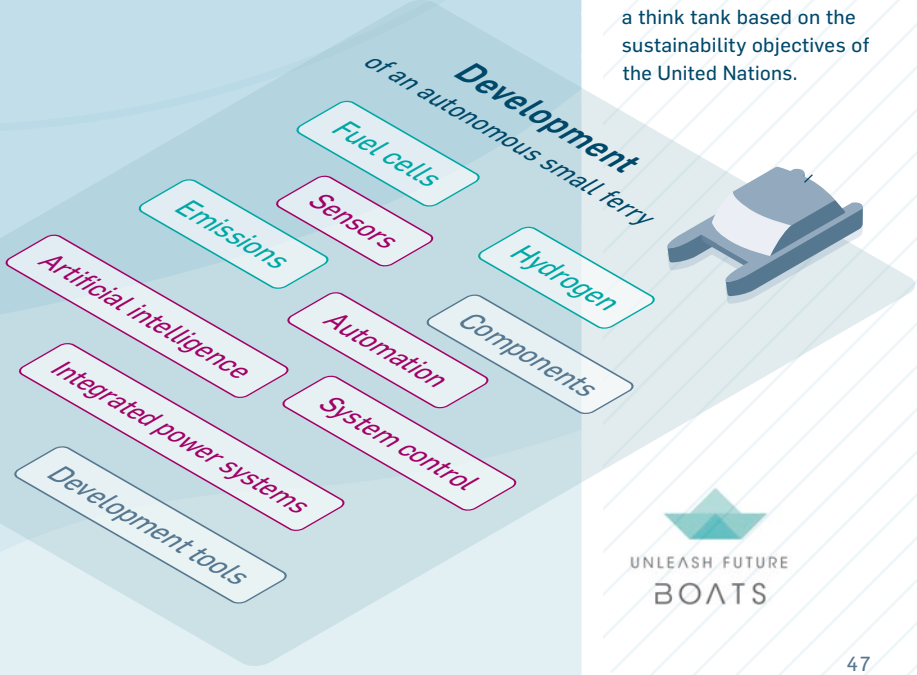
Politicians were impressed with our idea, and we've had interest from large cities both in Germany and abroad. But it has still been a challenge for us to secure German investment for our project. We have already had a number of enquiries from abroad – but we would rather make our knowledge and innovation available to Germany. //

**STEFANIE ENGELHARD** is a co-founder of Unleash Future Boats, a start-up that develops highly automated small ferries with zero emissions. On completing her studies, the electrical engineer initially worked for various well-known companies – most recently as a project manager at Audi – before deciding to set up her own engineering consultancy. She has also been a partner in a number of start-ups. Engelhard works for various organisations on a voluntary basis, including the Viable World Design Network, a think tank based on the sustainability objectives of the United Nations.

**→ With their zero-emissions small ferries, Engelhard and her husband want to conquer the waves of the energy transition – and help achieve seven UN Sustainable Development Goals in the process.**

#4 #8 #9 #11 #13 #14 #17

*Turn to page 15 for a full list of the Sustainable Development Goals.*




UNLEASH FUTURE BOATS

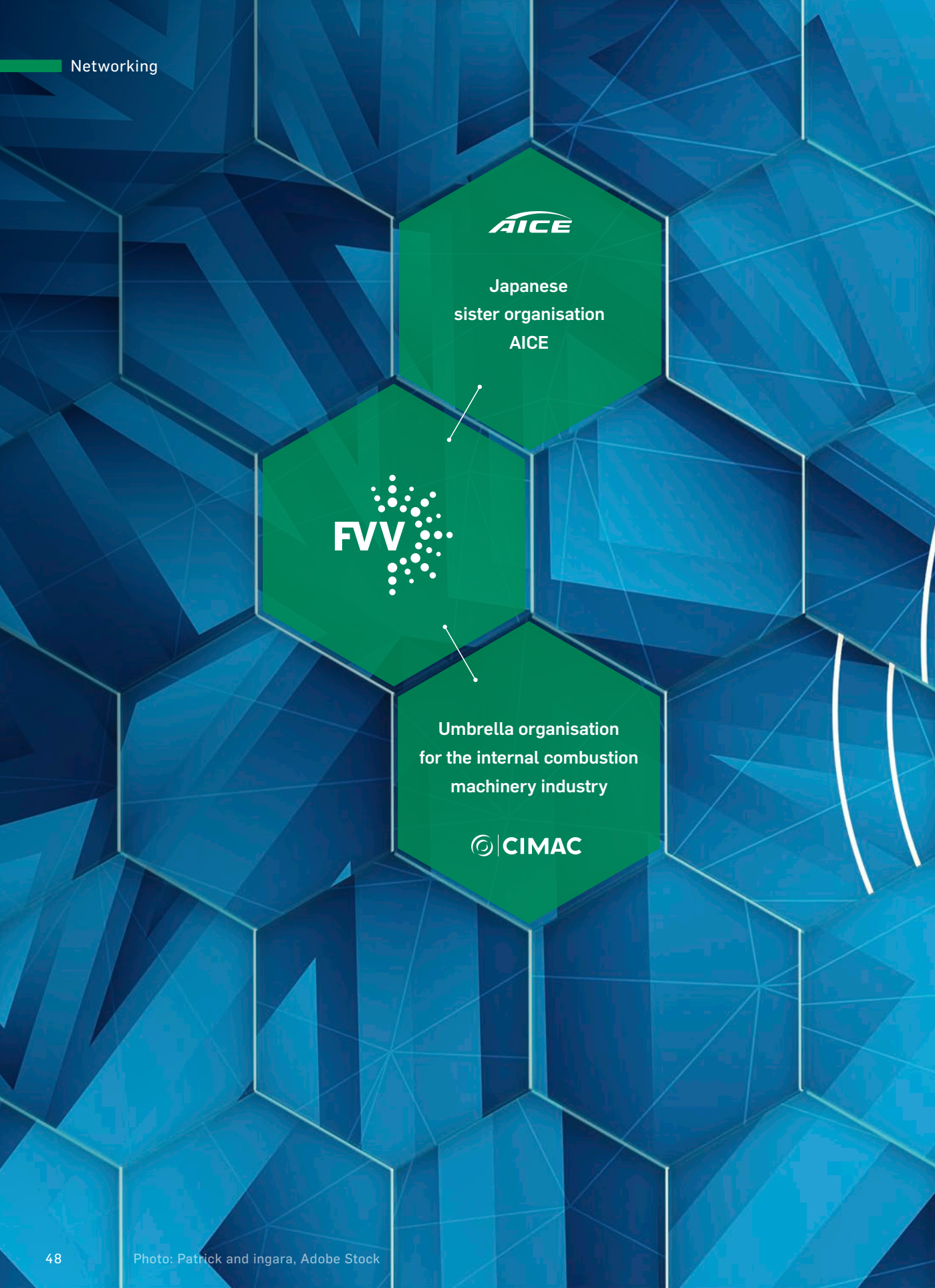





Photo: Patrick and ingara, Adobe Stock

# **Global** cooperation is more vital than ever

Climate protection is a global task – as is the development of competitive products for the world market. Whether for passenger cars or container ships, collaborating with international partners is both a sensible and inspiring way to bring new technologies to market more quickly. For this reason, FVV shares a long-standing partnership with the Japanese research association AICE and CIMAC, the umbrella organisation for the internal combustion machinery industry.

# On an equal footing

**Log on, switch on your microphone and upload your presentation //** Video conferences were among the tools used by Christine Burkhardt and Yoshihiro Imaoka even before the COVID-19 pandemic. They coordinated the first joint project by FVV and the **Japanese research association AICE** predominantly via digital means. The project focussed on performing fundamental research with the objective of lowering exhaust emissions during real driving operation: which chemical mechanisms are executed in the exhaust manifold during post-oxidation? And is it possible to replicate these with a simple model? »In the past, we concentrated our research activities on the processes in the cylinder and did not know enough about post-oxidation,« comments Imaoka. He reports that his employer, Nissan, is now using the one-dimensional simulation model created as part of the research project which was completed in 2020.

Imaoka is convinced that further research on combustion engines is worth it. As such, the roadmap of AICE aims for efficiency to be increased to more than 50 % by 2030 thanks to the use of innovative technologies – an objective comparable to that of the FVV project ›ICE 2030‹. The expert even believes that a figure of 60 % is achievable in the future. In combination with electrification, synthetic fuels and carbon capture from the air, this should enable fully climate-neutral mobility by the middle of the 21st century. Even on-board carbon capture in vehicles should at least be explored as an option. »The cooperation with FVV is helping us solve complex problems more quickly,« comments Imaoka.

**YOSHIHIRO IMAOKA**
Research Manager
(Nissan Motor Corp)

**CHRISTINE BURKHARDT**
Managing Director
(EnginOS)

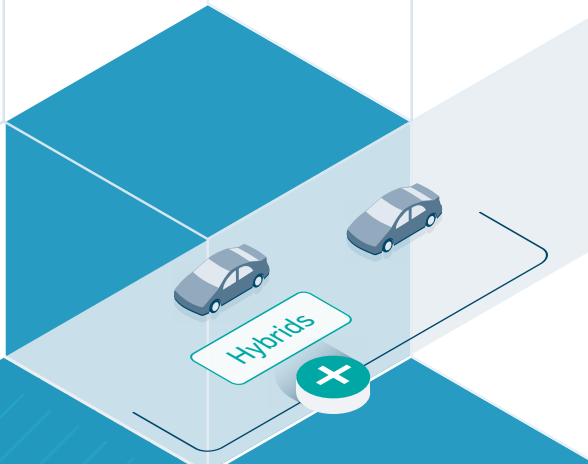


Photo: NISSAN

Photo: Rui Camilo

According to Burkhardt, the same also applies for suppliers and engineering service providers in Germany, many of which are SMEs. »Japan and Germany are on an equal technical footing in terms of engine research and development. If we work together, we will achieve our goal more quickly.« The post-oxidation project clearly illustrates how the areas of expertise of the associations involved complement one another: the German side contributed its experience in one-dimensional simulation calculation, while the Japanese association possessed special measuring technology that could be used to verify the simulation results.

Alongside the scientific findings, AICE and FVV benefited from the joint project in another way: through the practical training of young engineers. »This allows young people to learn how to work together in global teams at an early stage of their training,« reports Imaoka, adding that many of those involved at the universities were from different cultural backgrounds: a young engineer born in India and based in Tokyo and an Italian research assistant located in Stuttgart regularly spoke in the video conferences for the post-oxidation project.




→ Inspired by FVV, the **›Research Association of Automotive Internal Combustion Engines‹ (AICE)** was founded by eight Japanese automotive manufacturers in 2014 in order to perform collective research.

→ **aice.or.jp**

→ The **›PostOxidation‹** project (FVV project number 1336) mentioned above was initiated in 2017 and was supported by funds from **CO**llective **R**esearch **NET**working (CORNET) (funding number 234 EN), which the German Federal Ministry for Economic Affairs and Energy uses to partially fund transnational Industrial Collective Research projects.

# Research and regulation

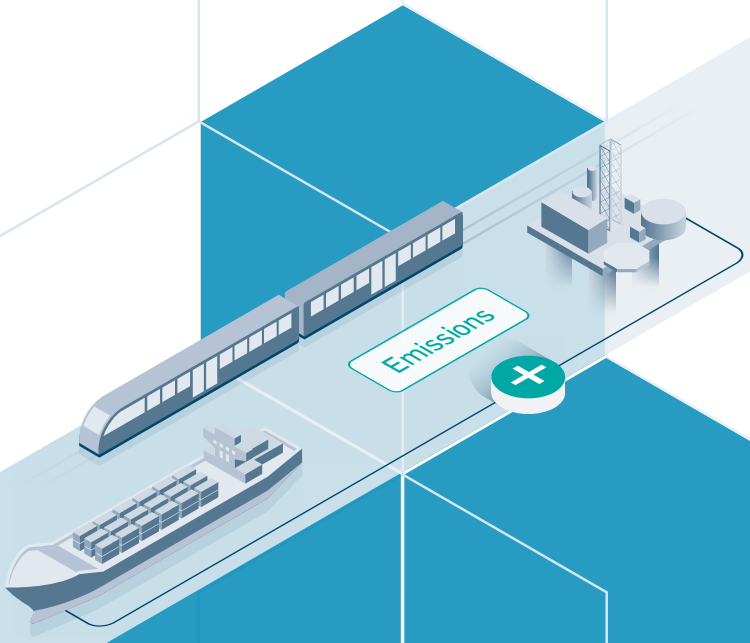
**Rotterdam – Shanghai //** Around 11,000 nautical miles separate the two seaports of Rotterdam and Shanghai, one of the most heavily frequented routes in international merchant shipping. Dr. Dirk Bergmann, CTO Turbocharging at ABB, often uses this example to illustrate the challenges faced by the shipping sector. After all, a climate-neutral energy carrier must have a sufficient energy density to enable the more than 300-metre-long container ships to travel non-stop between the major hubs of world trade – and a global agreement must also be reached on this energy carrier. »The ship propulsion and tank system need to be designed differently depending on whether ammonia or methanol is used, for example,« explains Bergmann. »And the same applies for the entire infrastructure at the port.« For this reason, he is Chair of the Greenhouse Gas Strategy Group at **CIMAC**, a global association that represents the interests of manufacturers and operators of large engines. Shipping is just one of many applications, but is a particularly important one for climate protection: around three percent of global $CO_2$ emissions are caused by ships, and this share is growing.

The International Maritime Organization (IMO), a United Nations agency, is actually responsible for agreeing global standards in the maritime sector. However, its regulations only encompass the years up to 2026; by then, the $CO_2$ emissions adjusted for the transport capacity of the ships are to fall by eleven percent. »We really need a far more long-term objective,« says Bergmann. »Most of the merchant vessels that will be launched in the coming years will still be traversing the oceans in 2050.« Therefore, considerably more climate-friendly propulsion systems that are to be fitted in 2030 must be the subject of intensive research today. However, the IMO's objectives are not to be revised again until 2025. In order to advance technological development despite this, the CIMAC Strategy Group is working on an outlook that illustrates and evaluates the technical options. An initial policy paper was published at the beginning of last year.

**DR. DIRK BERGMANN**
CTO Turbocharging
(ABB Switzerland)

Photo: ABB

»The scientific research of FVV is essential for this process,« comments Bergmann. For example, ammonia is deemed a highly promising energy carrier as it does not release carbon dioxide during combustion. However, the ignitability of ammonia is low. »It is like trying to make fire with wet wood,« adds Bergmann by way of comparison. Despite this, he believes that the problem can be solved through further research that focuses intensively on the combustion process of ammonia. »With its research, FVV is laying the groundwork that will allow us at CIMAC to develop proposals for new regulations.« After all, climate-neutral energy carriers will have difficulty establishing themselves without binding rules for all market participants – and not just in shipping. //




→ **CIMAC** represents the global interests of the large engine sector vis-à-vis regulatory authorities and standardisation bodies. Its members include both the producers and operators of large engines – either directly as corporate members, or via national member associations.

→ **cimac.com**

→ The Central Secretariat of the association has been located at the **Engines and Systems trade association of VDMA** for 25 years.

# Setting the **course**

Aerospace scientist **Dr. Dirk Hilberg** almost pursued a career at a freight forwarding company. Now he organises research projects in future technologies, both for his employer, Rolls-Royce, as well as at FVV. He is convinced that there is more than one way forward in life. But at some point, decisions have to be made.

Photos: Dirk Lässig

→ Hilberg spends his free time building model railways. In his professional life, he opted to focus on another means of transport – but he's still on track to contribute towards sustainable mobility.

**Individuals reach their limits relatively quickly //** While this applies to many walks of life, it is particularly true for model train enthusiasts whose homes are too small for the planned setup. Therefore, fans – primarily men – of model trains from ten European countries have been meeting up and developing modules that fit together since the 1980s. They connect their individual models to create a single set, which can reach up to 12,000 m² in size, before re-enacting realistic train operations following timetables agreed in advance. One of these men is Dirk Hilberg, who works for Rolls-Royce as a technology manager. His love for the railway harks back to his early childhood, when he regularly asked his mother to push his pram to a railway crossing so he could observe the trains. »I'm still a huge model train enthusiast today,« Hilberg admits. Despite this, he chose his career in aircraft engine construction.

At the age of sixteen, with maths and physics his favourite subjects, Hilberg realised: »I want to become an engineer.« Throughout his entire career, he has been fascinated by the fact that he is the link between the scientific and practical worlds. Once faced with choosing a specific degree, Hilberg selected aerospace engineering, a discipline that was synonymous with technological progress in the years following the moon landing. »I intuitively knew that this area held the most exciting tasks for engineers,« he comments. »And this generally still applies today.«

Back in 1980, only a few German universities offered this degree. Hilberg decided to go to TU Berlin, a choice with the very welcome benefit that residents of West Berlin were not conscripted for military service. A student apartment in the back of a courtyard, coal heating, a

shared bathroom on the corridor and a large, seemingly impersonal university – for Hilberg, who had a sheltered upbringing in Marburg, finding his way in the capital city was an almost shocking experience. He struggled to get started in university life and took a part-time job as a driver in a small forwarding company. Hilberg was subsequently promoted to the head of the Berlin subsidiary and worked 40 to 50 hours per week, earning a decent salary but barely progressing in his studies.

It took several years until Hilberg realised that now was the time to set the course for the future. He quit his job and completed his entire degree, including diploma thesis, at the engine institute within four semesters.

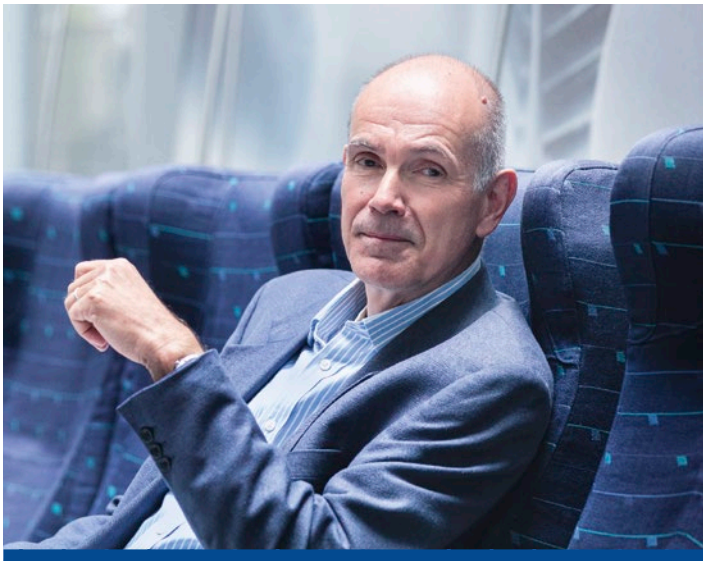
»I intuitively knew that this area held the **most exciting tasks** for engineers.«

Hilberg turned down an offer to work at Lufthansa Technik, instead deciding to complete a doctorate at TU Berlin, where he focussed on turbulent flows, analysed structures and developed calculation methods. This fundamental scientific research helped Hilberg receive a post-doctorate scholarship from the Alexander von Humboldt Foundation in 1994, first taking him to the Stony Brook University before he returned to TU Berlin.

In the meantime, Rolls-Royce had opened a site for developing engines for business aircraft just outside Berlin, initially in collaboration with BMW. By 1997, almost 1,000 people worked at the site in Dahlewitz. Hilberg, who was now married and the father of two children, began to doubt the potential of a career in academia, and took a job as a development engineer for air systems. »I was immediately plunged into the middle of the development for the BR715 series,« remembers the engineer.

Moving from academia to practical work came easy to him. »Taking responsibility for a safety-critical product, and therefore for human lives, drives me on every day and gives me at least as much joy as academic awards,« says Hilberg. And his approach to economic aspects, developed during his time at the forwarding company, is once again invaluable. What could be regarded as a diversion actually proved to be great training for his subsequent positions, both as a program manager for core engines and for his current role in research and technology management, for which Hilberg has been responsible since 2018.

As a member of a working group, Hilberg first came into contact with the research association shortly after joining Rolls-Royce. The high academic level at the association came as a positive surprise to him from the very first meeting, and he has since been closely involved in its work. As Deputy Head of the Scientific Advisory Committee of FVV, Hilberg is responsible for the general direction of collective research on turbomachines. The fact that a single planning group covers completely different turbomachines, ranging from small exhaust gas turbochargers, to aircraft turbines, all the way up to large, stationary gas



**DR. DIRK HILBERG,**
born in 1960, is responsible for cross-company research programs as a Senior Manager Research & Technology at Rolls-Royce Germany. The engineer, who completed his doctorate at TU Berlin, has held several different positions at the engine manufacturer since joining the company in 1997. At FVV, he is Deputy Chairman of the Scientific Advisory Committee and leads the PGT ›Turbomachinery‹ planning group on a voluntary basis.

turbines, is beneficial, according to Hilberg. »We inspire one another. After all, fluid mechanics or the fundamentals of materials engineering do not depend on the size of a machine.«

Hilberg believes that the use of hydrogen as a source of combustion or fuel also offers great potential for synergies – not just for turbines, but also in engine research at FVV.

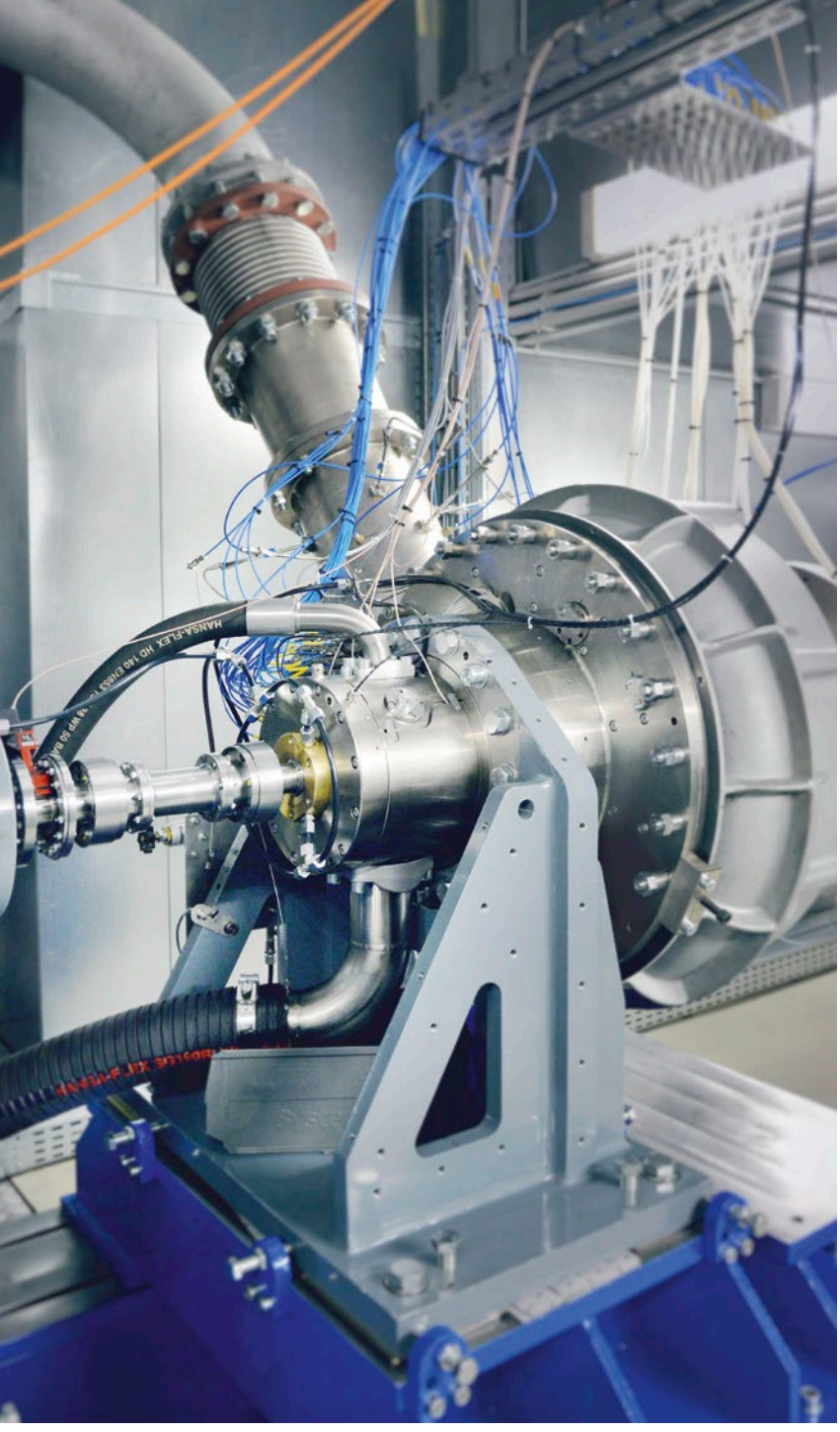
»It is everyone's task to reduce $CO_2$ emissions. To do so, we absolutely need chemical energy stores, such as hydrogen and electricity-based fuels, for certain applications.« However, this requires cross-discipline collaboration, as a system which is based purely on fossil fuels must be converted. In this regard, individuals can quickly reach their limits, particularly in research. //

# Maximum **efficiency** in research

The radial compressor is a piece of technology that is often ignored – yet it plays a critical role in a modern industrial society. For 50 years, FVV's Centrifugal Compressor Research working group has been ensuring that these components run ever more efficiently and with lower levels of noise. In this research programme, industry engineers and scientists strive to maximise the efficiency of this key component.

**The things we can't see often matter the most //** In the copper smelting plants that produce the materials for electric motors, centrifugal compressors are just as crucial to the process as they are in the production of renewable fuels. They provide fuel cells with the required gases, and the turbochargers for cars, trucks and ships also rely on the same compressor principle. Without this often-overlooked piece of machinery, modern industrial society simply wouldn't exist. Five decades ago, FVV founded the Centrifugal Compressor Research expert group in recognition of this fact. Since then, the industrial and scientific communities have been working together not only to conduct fundamental collective research, but also to investigate practice-relevant phenomena such as flow processes, noise generation and dissipation and new impeller designs.

There is plenty still to discover. Over the years and decades, legal and technical framework conditions and requirements have evolved. While classic aerodynamics has been almost completely explored, the field of acoustics – which is far more difficult to study and optimise – is now taking centre stage. As before, boosting efficiency remains a key focus: »It is important to remember that even the smallest increase in efficiency can save a huge amount of energy – and $CO_2$, if you're working with fossil fuels – over the service life of a 5-megawatt machine,« says Dr. Matthias Schleer, Chairman of the FVV Centrifugal Compressor Research expert group.



Photos: Andreas Schmitter

In 2011, the group decided to build a new centrifugal compressor test bench at the Institute of Jet Propulsion and Turbomachinery at RWTH Aachen University. Even with ever faster high-performance computers and improved simulation methods, physical experiments at the test bench are still vital: »Numbers are only one side of the coin when it comes to acquiring new knowledge. Conducting experiments is the only way to calibrate, trim and verify your calculations,« explains Professor Peter Jeschke, Head of the Institute of Jet Propulsion and Turbomachinery (IST) at RWTH Aachen University, who was responsible for managing the construction and commissioning of the new test bench.

With a drive power of two megawatts, an impeller diameter of 400 millimetres and space for up to 100 sensors, the centrifugal compressor test bench is one of the largest and most cutting-edge facilities of its kind in Europe. There are only a few other comparable test benches on this scale in the world. FVV and its member companies invested three million euros in the project. For five years, experts from RWTH Aachen University developed the required components together with partners from the turbomachinery industry, built the test bench and installed the measurement technology. Since the test bench was commissioned in 2016, the researchers have used it to study a variety of topics: in addition to conducting aerodynamic and acoustic tests on various centrifugal compressor configurations, they have also been busy developing methods to predict flow instabilities that limit the usable operating range.

»Conducting experiments is the only way to calibrate, trim and verify your calculations.«

For many years, it was standard practice to leave large turbomachines running constantly for weeks or even months on end. But this is changing as our use of renewable energy increases: turbomachines are now operated flexibly and started up and shut down multiple times a day, or are run with partial loads more frequently. Using the centrifugal compressor test bench in Aachen, the scientists on one of the project teams are investigating how the operating range of a compressor can be expanded so that the energy consumption is optimised at as many operating points as possible. This can be achieved, for example, by installing a variable guide wheel in the intake section; this wheel is then used to adjust the inflow angle of the air flowing towards the impeller.

New methods, materials and calculation process generate new findings, which in turn can be used to develop more efficient, quieter compressors. But research takes time; most programmes last a number of years. Changing the test bench configuration can take months, and training new staff is just as time-consuming as installing new measuring points. However, throughout all of this work, one principle takes precedence above all else: »We have to evaluate the data correctly. We must recognise any interference or errors; inaccurate calibration prior to testing can also generate unusable measurement data,« says IST Head Jeschke. To satisfy these high standards of care and precision, the FVV test bench has, up to now, only been operated once a week wherever possible. Over the next few years, research and science will increasingly shift their focus to addi-

When the new centrifugal compressor test bench at RWTH Aachen University was commissioned in 2016, it enabled scientists to conduct research under real-life conditions. The research spectrum was extended to include experimental projects such as:

→ »Design and Implementation of the FVV Industrial Compressor [1279]« // **FUNDING:** FVV // **PROJECT MANAGEMENT:** Dr. Matthias Schleer (Howden Turbo) // **RTD PERFORMER:** Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University

→ »Circumferentially Inhomogeneous Centrifugal Compressor Flow [1337]« // **FUNDING:** BMWi/AiF (20454 N) // **PROJECT MANAGEMENT:** Dr. Thomas Hildebrandt (NUMECA) // **RTD PERFORMER:** Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University

→ »Radial Compressor with Wide Operating Range [1354]« // **FUNDING:** BMWi/AiF (20494 N) // **PROJECT MANAGEMENT:** Dr. Matthias Schleer (Howden Turbo) // **RTD PERFORMER:** Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University

→ »Acoustic Emission into Discharge Pipes II [1383]« // **FUNDING:** DFG (258517910) and FVV // **PROJECT MANAGEMENT:** Dr. Irhad Buljina (MAN Energy Solutions) // **RTD PERFORMER:** Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University and Institute of Flow Mechanics and Technical Acoustics (ISTA), TU Berlin

→ »Centrifugal Compressor in Flexible Operation [1443]« // **FUNDING:** BMWi/AiF (03EE5067) and FVV // **PROJECT MANAGEMENT:** Dr. Matthias Schleer (Howden Turbo) // **RTD PERFORMER:** Institute of Jet Propulsion and Turbomachinery (IST), RWTH Aachen University

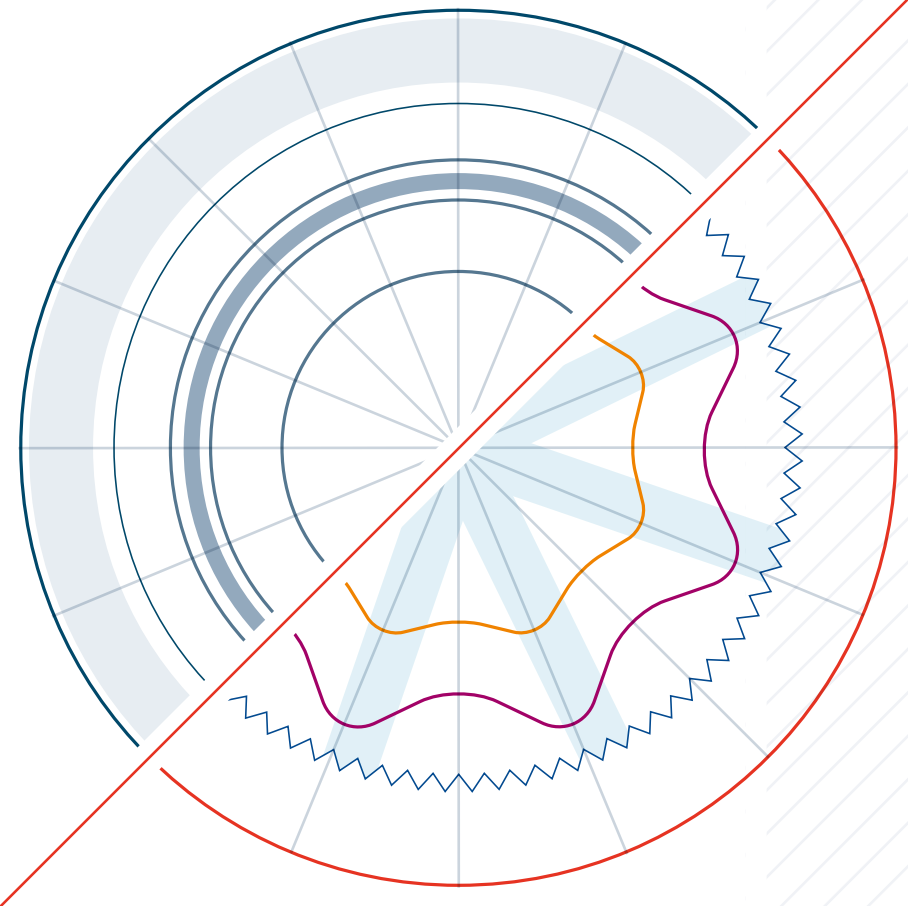
## 1968 – 2021
## Centrifugal Compressor Research

→ To mark the anniversary of the Centrifugal Compressor Research expert group, FVV is releasing a special publication summarising all the research projects of the past ten years.

→ It also looks ahead to the key topics for future projects.

tive manufacturing processes, which can be used to achieve complex impeller geometries [→ page 68]. Material sciences will also move into the spotlight, as the impellers are exposed to extreme loads at maximum speed.

The team in Aachen is by no means out of touch with what's going on outside the scientific realm: practical research conducted with industry partners regularly generates results that are soon rolled out in real industrial products. In one project, the team created a highly efficient compressor wheel. Acoustic investigations in pressure lines laid the foundations for a measurement process that provides more accurate results in a far simpler, more cost-effective way than before. This measurement process is currently being applied and tested in experiments as part of an ongoing research project. IST Head Jeschke is convinced that the new process will replace the previous DIN standard – a result that will benefit not only FVV member companies, but also wider society. Expert group Chairman Schleer outlines the specific benefits: »Most members of the group would not be able to generate these kinds of results on their own.« After all, many smaller engineering firms and SMEs play an active role in FVV's centrifugal compressor research alongside major companies. »Thanks to Industrial Collective Research, the companies can take these results and use them to boost their own competitiveness.« And this approach isn't set to change any time soon. //



# **Components** from a printer

Pistons produced using additive manufacturing have the potential to reduce fuel consumption and emissions. In an FVV project, researchers are designing two piston variants for 3D printing; these designs will then be printed, machined and put to the test in experiments. In two further projects, the team will determine the material characteristics and identify ways to improve the durability of additively manufactured parts.

»The complex geometries required would be virtually impossible to produce with traditional cast or forged pistons.«

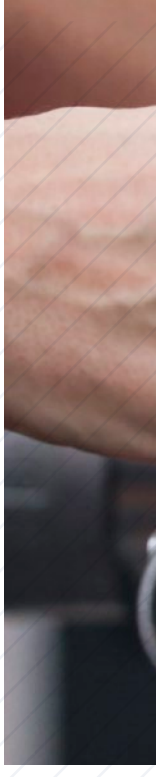
**Printing instead of casting //** Heavy-duty vehicles for long-distance or nonroad applications need powerful and durable engines. In this segment, high-volume diesel engines will remain the only viable option for a number of years yet, even if significant progress is being made on the development of battery-powered electric powertrains or fuel cells. However, these vehicles will only be able to comply with future $NO_x$ and $CO_2$ limits if they are fitted with sophisticated exhaust gas purification equipment or internal engine systems. In a spray-guided, diffusive combustion process, the piston shape and bowl have a significant impact on carburation and, by extension, on the combustion process and the emissions generated. »This is why the combustion chamber design takes priority if you're looking to optimise the combustion process,« says Dr. Reza Rezaei, who heads the Advanced Engineering and Model-Based Development for Commercial Vehicles team at IAV in Gifhorn.

In FVV's Innovative HD Combustion System Design project, which started in 2019, researchers from TU Darmstadt, the Leibniz University in Hanover and the Karlsruhe Institute of Technology (KIT) are investigating two piston variants with complex combustion chamber geometries produced using additive manufacturing methods. The complex geometries required would be virtually impossible to produce with traditional cast or forged pistons, explains project coordinator Rezaei: »Our piston bowl is no longer rotationally symmetrical, but asymmetrical with a complex geometry to optimise carburation and combustion.« To reduce wall heat losses from the pistons, they are also equipped with special internal cooling channels that would be impossible to create using traditional methods.

High combustion pressures and temperatures require a robust and durable material. The researchers opted for Inconel, a nickel-based alloy that is ideal for high-temperature applications and is also used in rocket engines. Suppliers process the material using selective laser melting. So does the component go straight into the engine, hot off the printer? Rezaei explains that it's not that simple: »The machining of the pistons is a challenge for the suppliers; they need to gain some experience first.«

Reza Rezaei describes a unique feature of the project: »The institutes in Darmstadt and Hanover were relying partly on the industry's design processes, so there were regular sessions with experts to bring industrial experience into the process.« Daimler Truck, Scania, Volvo Truck and a number of other FVV members have shown an interest in the project and are supporting the researchers; the test engine was supplied by Daimler. From October 2021, two piston variants will be installed in the single-cylinder test engine at the KIT's Institute of Internal Combustion Engines in Karlsruhe in preparation for a series of experiments. The CFD simulations of injection, carburation and combustion conducted in advance of the tests showed promising results. In parallel to the experiment, the second piston variant will be designed and produced using additive manufacturing. »This variant has a number of new features, including the special cooling channels to reduce heat losses,« says Rezaei.

While internal tests at IAV showed that additively manufactured pistons can withstand peak pressures of over 200 bar, there is a lack of robust data on the high-temperature service life of the components. To address this, researchers at TU Darmstadt are currently working with colleagues from the University of Stuttgart to develop a special process as part of another FVV project. This is an important undertaking, as it is very time-consuming and costly to ascertain key material values using the current methods. This is partly because additive manufacturing processes can be used to achieve a wide range of microstructural characteristics, given the large number of process parameters, cooling conditions that vary between locations, and the unique geometrical features of each component. The local mechanical material characteristics therefore vary accordingly – sometimes even between different locations on the same workpiece. It would not be financially feasible to conduct the large number of tests required to fully investigate the impact of all parameters, and doing so would also undermine the benefits of an agile development process. With this in mind, the project aims to develop a concept to evaluate these components based on sample test processes.



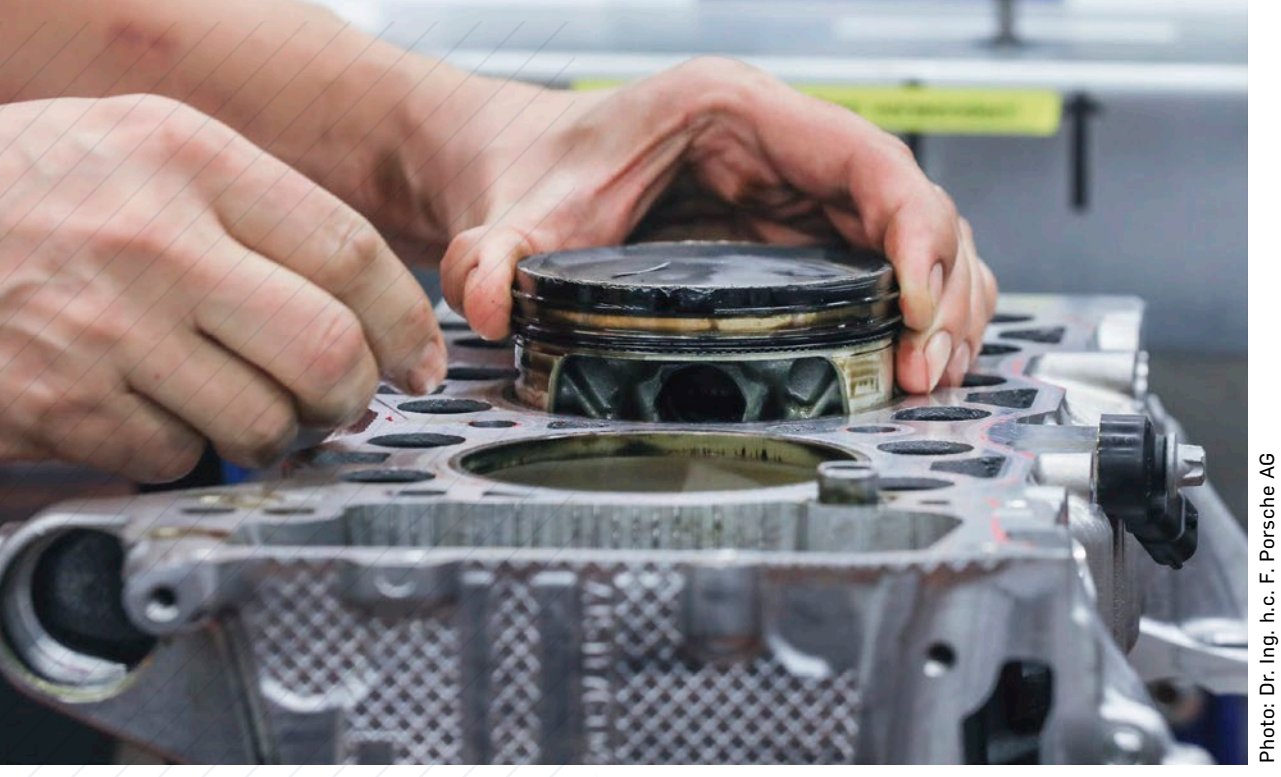


Photo: Dr. Ing. h.c. F. Porsche AG

Photo: B. Bode, Prof. Dr. R. Lachmayer, IPeG, LUH

Additively manufactured pistons have already been put to the test in race conditions in a project by Mahle and Porsche (image above). A research project initiated by FVV is now also looking at commercial vehicle pistons with complex geometries (image below).

»Additively manufactured components are an important building block of the smart production processes of the future.«

Another project is focussing on increasing fatigue strength. In the ›Additively Manufactured High-pressure Components‹ project commencing in October 2021, researchers from TU Darmstadt and the MFPA Weimar materials research and testing facility will study the scientific and technical background to manufacturing technologies and material and component characteristics, and develop calculation methods to improve and calculate the fatigue strength of these components. TU Darmstadt will also carry out tests on cyclical transient material characteristics, fatigue strength and crack propagation. Among other aspects, researchers at MFPA Weimar will focus on the optimisation of the construction process and heat treatment, the fatigue strength of component samples, microstructure and damage characterisation and topographical and surface analysis.

The autofrettage technique is one of the options being considered to improve fatigue strength. With this process, pipes or drilled holes are subjected to enormous internal pressure, causing the inside to yield plastically. The compressive residual stresses that remain in the part when the pressure is released then increase its fatigue strength. Preliminary investigations have shown that autofrettage can double or even triple the fatigue resistance of additively manufactured internal high-pressure parts. This process can significantly expand the range of applications for additively manufactured components to include structures that are exposed to internal pressure – including the cooling channels in pistons. A special heat treatment also harbours the potential to increase component strength.

Across all of these projects, the researchers are certain of one thing: additively manufactured components are an important building block of the smart production processes of the future. Industrial Collective Research helps SME suppliers in particular to support the climate neutrality and digitalisation transformation. //

The additive manufacturing of components and structures is an interdisciplinary topic in FVV's Industrial Collective Research. The key to success here is utilising design freedom.

→ »Innovative HD Combustion System Design [1368]« // **PLANNING GROUP:** PG 3 Combustion CI // **FUNDING:** FVV // **PROJECT MANAGEMENT:** Dr. Reza Rezaei (IAV) // **RTD PERFORMERS:** Thermo-Fluids & Interfaces, TU Darmstadt / Institute of Internal Combustion Engines, KIT Karlsruhe / Institute for Product Development and Equipment Construction, Leibniz University, Hanover

→ »LPBF High-Temperature Lifetime [1401]« // **PLANNING GROUP:** PG T Turbomachinery // **FUNDING:** BMWi/AiF (21220 N) // **PROJECT MANAGEMENT:** Dr. Roland Herzog (MAN Energy Solutions) // **RTD PERFORMERS:** Institute for Materials Testing, Materials Science and Strength of Materials, University of Stuttgart / Center for Structural Materials, TU Darmstadt

→ »Additively Manufactured High-pressure Components [M1220]« // **PLANNING GROUP:** PG 4 Strength & Tribology // **FUNDING:** BMWi/AiF (applied for) // **PROJECT MANAGEMENT:** Stefan Zimmermann (Woodward L'Orange) // **RTD PERFORMERS:** Institute for Steel Construction and Mechanics of Materials, TU Darmstadt / Material Research and Testing Institute (MFPA), Bauhaus-Universität Weimar

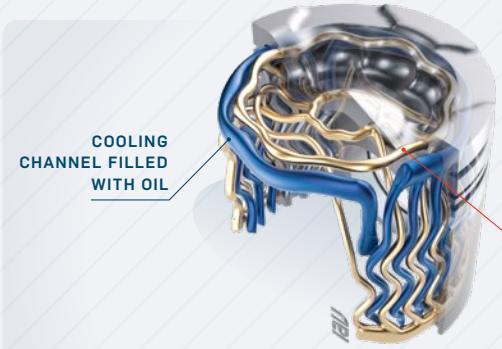
Photos: IAV GmbH

## Bowl geometry and cooling channel design

**Series pistons**
can only be made cost-effectively in conventional forms.

**3D-printed pistons**
can also be produced profitably in innovative shapes.


The cross-section reveals that the innovative shape increases the **injection spray length** by around 25 %.




Great potential for **sodium cooling channels:** innovative shapes allow a higher surface temperature and reduce wall heat losses.

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 take a look at our event recommendations for 2022 and save the dates of the FVV Spring & Autumn Conferences:

Spring – 31 March / 01 April 2022

Autumn – 06 / 07 October 2022

See you there!

**Multiply your benefits and join our 2022 partnership events:**

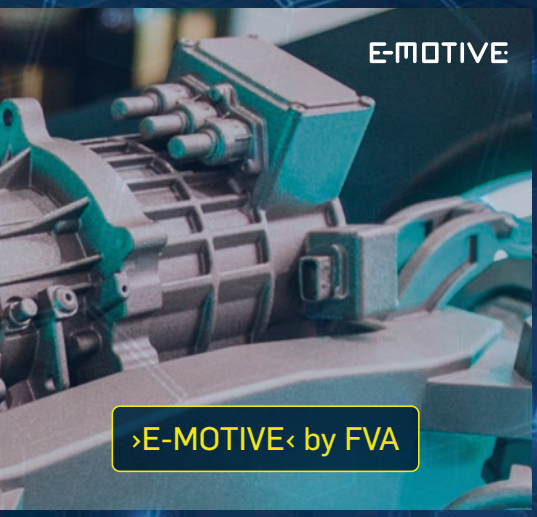
Ideas sometimes need time and a fertile place to grow. Such as our partnership meetings and conferences. Face-to-face discussions between manufacturers and suppliers, designers and scientists, leading engineers from industry, renowned researchers and outstanding young talents from Germany, Europe and around the world not only promote mutual understanding, but also ensure a swift and efficient transfer of research results from science to industrial practice.

**Photos:**
›The Powertrain of Tomorrow‹: AVL
FVV Prime Movers: Charles Yunck
›P2X Conference‹: style-photography, iStock
Rest: operator

Background: Horsepowermini, Adobe Stock

FVV PrimeMovers.
Networking Events.


›CIMAC Congress‹




›E-MOTIVE‹ by FVA



›P2X Conference ‹


›Stuttgart International Symposium‹


›Powertrains and Energy Systems of Tomorrow‹

# FVV PrimeMovers.
# Publications.

## MTZ / ATZ – PROJECT REPORTS

→ **MTZ 11 / 2020:** Model-predictive airpath control for a gasoline engine // Project: Controls for High-Load Exhaust Gas Recirculation [1265] › Engines › PG 1 › Materials

→ **ATZ heavyduty 02 / 2020:** Deposit forming tendency of Diesel fuels in injectors // Project: JFTOT Diesel II [1285] › Engines › PG 4 › Materials

→ **MTZ 01 / 2021:** Investigations on the deposit formation and decomposition from urea in SCR systems // Project: AdBlue Deposits [1262] › Engines › PG 6 › Emissions

→ **MTZ 02 / 2021:** Thermal influence on the overall TC system with consideration of the coupled bearings // Project: Thermally Influenced TC Bearing Friction [1238] › Turbomachinery › PG T › Development tools

→ **MTZ 04 / 2021:** Optimisation of the engine water jacket from concept to production-ready level // Project: Accurate Temperature Management [1266] › Engines › PG 1 › Development tools

→ **MTZ 05-06 / 2021:** CNG DI combustion processes in combination with high-load EGR and the Miller process // Project: CNG-DI-Engine at λ=1-Operation with Highload-EGR [1202] › Engines › PG2 › Efficiency

## MTZ / ATZ – RESEARCH PRIORITIES

→ **MTZ 07-08 / 2020:** »We have to consider the return on investment« // Priority: Life-cycle $CO_2$ Emissions in the Mobility Sector

→ **MTZ 09 / 2020:** Engine research in international cooperations // Priority: International Industrial Collective Research

→ **MTZ 03 / 2021:** Spark-ignition engines – fundamental research for sustainable individual mobility // Priority: Combustion technology

→ **ATZheavyduty 01 / 2021:** Hydrogen as a platform technology // Opinion: Dietmar Goericke (Managing Director of FVV)

## OTHER PUBLICATIONS

→ **FutureFuels Blog 09 / 2020:** There is not one single solution for $CO_2$ neutrality in the mobility sector // Project: Life-cycle $CO_2$ Emissions in the Mobility Sector [1365]

→ **Aachen Colloquium 2020:** Climate Protection in Road Transport Requires a Comprehensive Approach – A Meta Analysis of $CO_2$-Life Cycle Studies // Project: Life-cycle $CO_2$ Emissions in the Mobility Sector [1365]

→ **International Vienna Motor Symposium 2021:** Taking a Systemic View // Project: Life-cycle $CO_2$ Emissions in the Mobility Sector [1365]

→ **ZSW Media Advisory 02/2021:** Groundbreaking for the HyFaB Research Factory for Hydrogen and Fuel Cells // Project: FVV Generic Fuel Cell Stack [1366]

BEV
Turbo-charging
Hybrid power-trains
Internal combustion engines
Diesel engines
Thermo-dynamics


Car-to-X C2X
Automated driving
HiL, SiL, MiL
RDE
Chassis technology
Lighting technology


## 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.

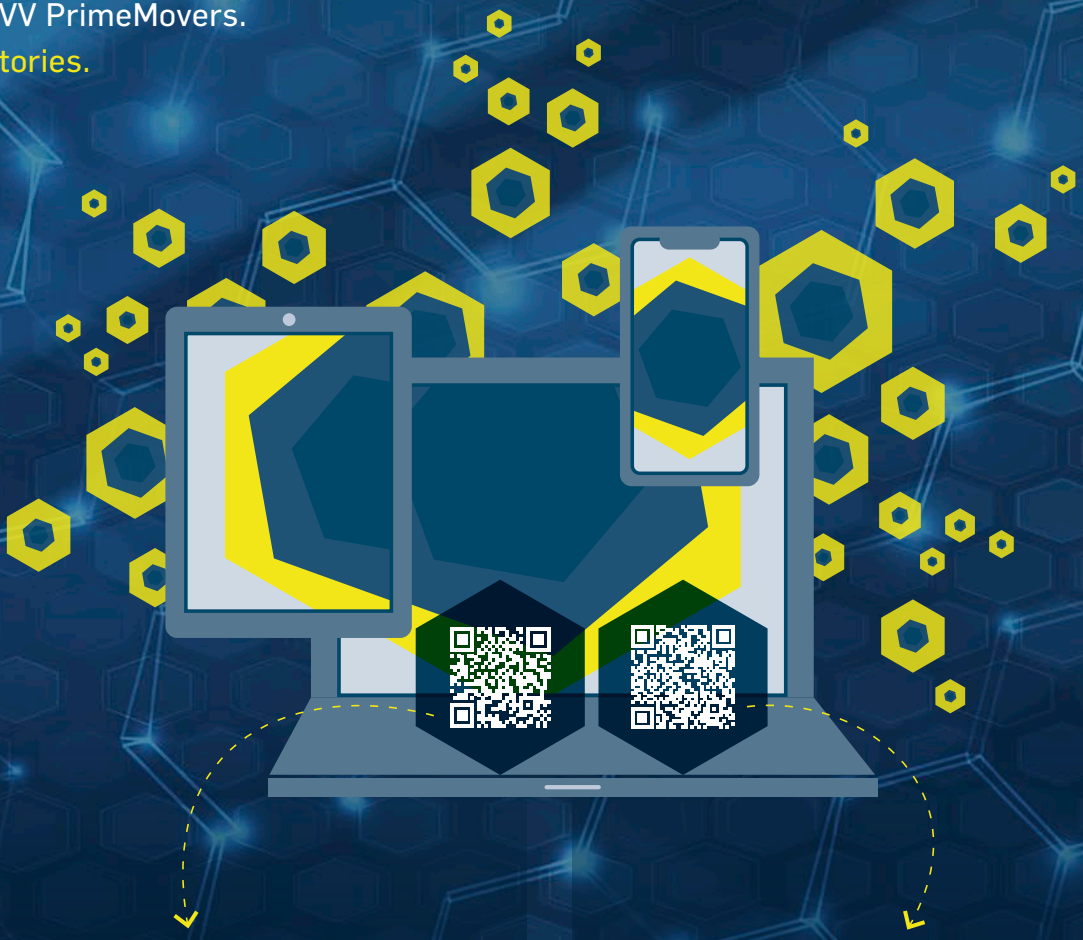
www.MTZ-magazine.com

## 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.

www.ATZ-magazine.com

# FVV PrimeMovers.
# Stories.



## FVV Innovation Stories

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

www.PrimeMovers.de/en

## FVV 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.

www.fvv-net.de/en | Media | Newsletter

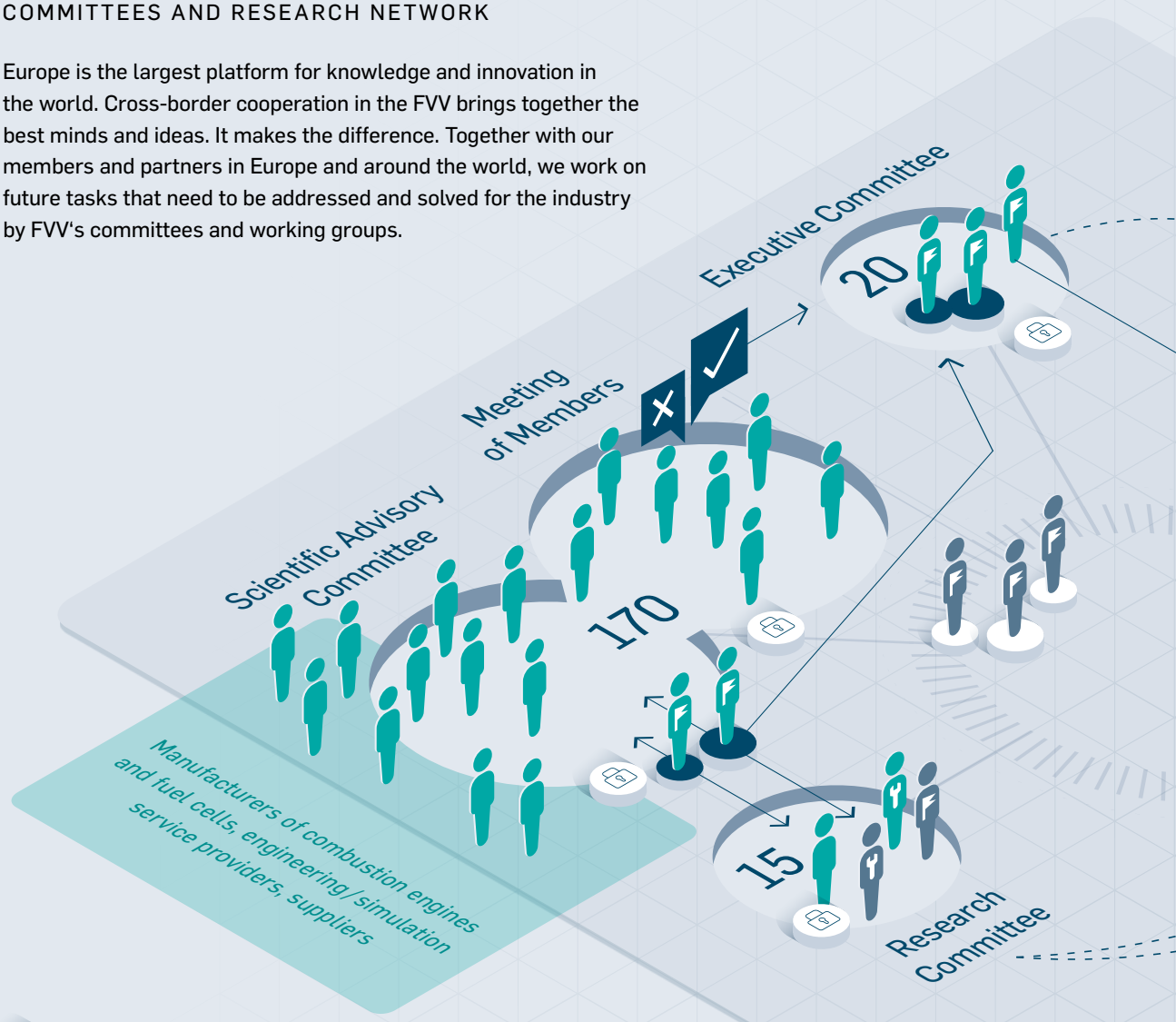
FVV ANNUAL REPORT

# 2020/2021

# Structure of the association

## COMMITTEES AND RESEARCH NETWORK

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



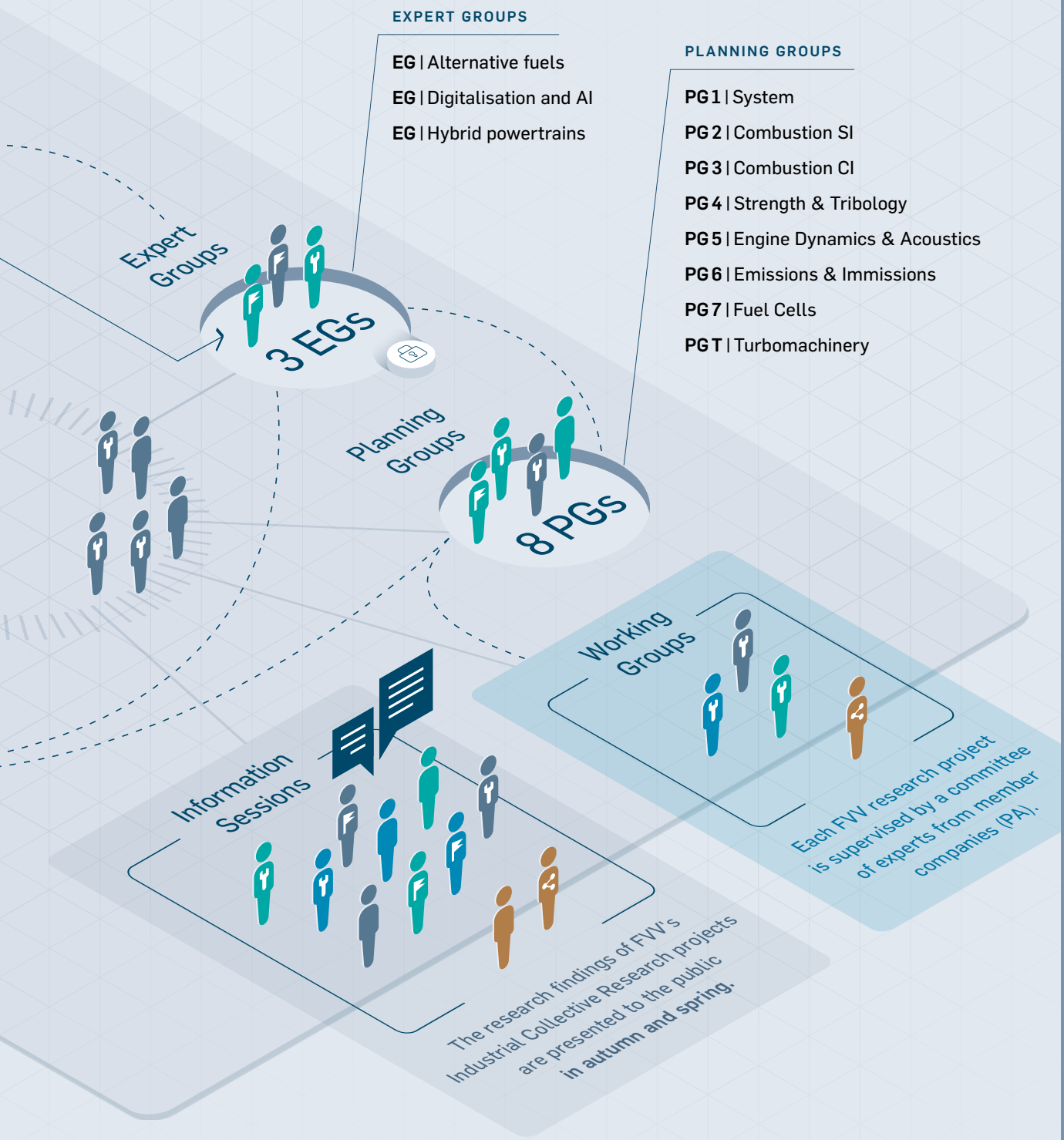

APPOINTED/ELECTED REPRESENTATIVES

MEMBERS: MANAGEMENT, COORDINATION, TEAM

FVV: MANAGEMENT, COORDINATION, TEAM

RTD PERFORMERS: MANAGEMENT, COORDINATION, TEAM

EXTERN: COOPERATION, PERSON


EXPERT GROUPS
EG | Alternative fuels
EG | Digitalisation and AI
EG | Hybrid powertrains
PLANNING GROUPS
PG 1 | System
PG 2 | Combustion SI
PG 3 | Combustion CI
PG 4 | Strength & Tribology
PG 5 | Engine Dynamics & Acoustics
PG 6 | Emissions & Immissions
PG 7 | Fuel Cells
PG T | Turbomachinery
Expert Groups
3 EGs
Planning Groups
8 PGs
Working Groups
Each FVV research project is supervised by a committee of experts from member companies (PA).
Information Sessions
The research findings of FVV's Industrial Collective Research projects are presented to the public in autumn and spring.

# Members

## MEMBER COMPANIES AND THEIR REPRESENTATIVES

| | COMPANY | LOCATION (HEADQUARTERS) | REPRESENTATIVE (SCIENTIFIC ADVISORY COMMITTEE) |
|---|---|---|---|
| A | Aalberts Surface Treatment GmbH | Kerpen | Uwe Franz |
| | ABB Turbo Systems AG | Baden (CH) | Dr. Dirk Bergmann |
| | AeroDesignWorks GmbH | Köln | Georg Kröger |
| | Afton Chemical GmbH | Hamburg | Walter Kudlich |
| | AIP GmbH & Co. KG | Haldenwang | Christian Hartmann |
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| | AM Metals GmbH | Halsbrücke | Dr. Florian Wendt |
| | ANSYS Germany GmbH | Otterfing | Dr. Wolfgang Bauer |
| | APL GmbH | Landau | Dr. Marcus Gohl |
| | Aramco Overseas Company B.V. | Den Haag (NL) | Dr. Patrick Gastaldi |
| | ↑ ARTECO NV | Sint-Denijs (BEL) | Dr. Serge Lievens |
| | ASG Analytik-Service Gesellschaft mbH | Neusäss | Dr. Thomas Wilharm |
| | Atlanting GmbH | Aachen | Raimund Vedder |
| | Atlas Copco Energas GmbH | Köln | Dr. Hauke Wittich |
| | AUDI AG | Ingolstadt | Dr. Christian Brenneisen |
| | AVAT Automation GmbH | Tübingen | Frank Ganssloser |
| | AVL Deutschland GmbH | Mainz-Kastel | Dr. Moritz Frobenius |
| | AVL List GmbH | Graz (AT) | Prof. Dr. Peter Prenninger |
| B | B&B-AGEMA GmbH | Aachen | Dr. Karsten Kusterer |
| | BASF Catalysts Germany GmbH | Hannover | Andrzej Bucholc |
| | Bayerische Motorenwerke AG | München | Robert Mirlach |
| | Benteler Automobiltechnik GmbH | Paderborn | Dr. Fabian Fricke |
| | Bertrandt Projektgesellschaft mbH | Ehningen | Matthias Rühl |
| | BMTS Technology GmbH & Co. KG | Stuttgart | N. N. |
| | ⟳ BorgWarner Ludwigsburg GmbH | *Group membership BorgWarner Turbo Systems GmbH* | |
| | BorgWarner Turbo Systems GmbH | Kirchheimbolanden | Dr. Stefan Münz |
| | Bosch Engineering GmbH | Abstatt | Nico Kappel |
| C | ↑ Cataler Corporation Europe | Düsseldorf | Dr. Carsten Stoecker |
| | Caterpillar Energy Solutions GmbH | Mannheim | Dr. Sebastian Ohler |
| | Caterpillar Motoren GmbH & Co. KG | Kiel | Andreas Banck |
| | CFturbo GmbH | Dresden | Dr. Oliver Velde |
| | ↓ Clariant Produkte (Deutschland) GmbH | Bruckmühl-Heufeld | |

↑ new member ↓ resigned member

| | COMPANY | LOCATION (HEADQUARTERS) | REPRESENTATIVE (SCIENTIFIC ADVISORY COMMITTEE) |
|---|---|---|---|
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| | Corning GmbH | Wiesbaden | Dr. Thorsten Boger |
| | Coryton Advanced Fuels Ltd. | Stanford-le-Hope (GB) | Arne Gimmini.<br>Ben Lampertz |
| | CTWe GmbH | Henfenfeld | Daniel Büschelberger |
| | Cutting-Edge Nanomaterials UG | Waldenbuch | Dr. Seyed Schwan Hosseiny |
| D | DAF Trucks N.V. | Eindhoven (NL) | Bram Hakstege |
| | Daido Metals Co., Ltd. | Inuyama, Aichi (JP) | Minoru Hanahashi |
| | Daimler Truck AG | Stuttgart | Dr. Volker Schmeißer |
| | ⟳ Delphi Technologies | *Group membership BorgWarner Turbo Systems GmbH* | |
| | Delta JS AG | Zürich (CH) | Dr. Joachim Schmied |
| | DERC GmbH | Oberroth | Mario Kornprobst |
| | DEUTZ AG | Köln | Taghi Akbarian,<br>Dr. Heiner Bülte |
| | Dr. Ing. h.c. F. Porsche AG | Weissach | Dr. André Casal Kulzer |
| E | ↑ eCon Engineering Germany GmbH | Kirchheimbolanden | Uwe Tomm |
| | ELGAN Diamantwerkzeuge GmbH & Co. KG | Nürtingen | Hans-Peter Böhm |
| | Emission Partner GmbH & Co. KG | Saterland | Dr. Klaus-Dieter Zanter |
| | Engineering Center Steyr GmbH & Co. KG | Sankt Valentin (AT) | Ronald Penzinger |
| | EnginOS GmbH | Ostfildern | Christine Burkhardt |
| | Erbslöh Aluminium GmbH | Velbert | |
| | ERC Additiv GmbH | Buchholz | Dr. Martin Müller |
| | ETAS GmbH | Stuttgart | Thorsten Huber |
| | Evonik Industries AG | Darmstadt | Michael Seemann |
| | Exothermia SA | Pylaia (GR) | Dr. Alexis Manigrasso,<br>Dr. Konstantinos Michos |
| F | Faurecia Emissions Control Technologies, Germany GmbH | Augsburg | Emmanuel Jean |
| | Federal-Mogul Burscheid GmbH | Burscheid | Thomas Bastuck |
| | Federal-Mogul Nürnberg GmbH | Nürnberg | Klaus Lades |
| | Federal-Mogul Valvetrain GmbH | Barsinghausen | Frank Zwein |
| | Federal-Mogul Wiesbaden GmbH | Wiesbaden | Dr. Uwe Lehmann |
| | FEV Europe GmbH | Aachen | Christof Schernus |
| | FKFS Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart SdbR | Stuttgart | Hans-Jürgen Berner |

| | COMPANY | LOCATION (HEADQUARTERS) | REPRESENTATIVE (SCIENTIFIC ADVISORY COMMITTEE) |
|---|---|---|---|
| | Ford-Werke GmbH | Köln | Dr. Ulrich Kramer |
| | ↓ FPT Motorenforschung AG | Arbon (CH) | |
| | Freyberger engineering GmbH | Köln | Dr. Christian Töpel |
| | FUCHS SCHMIERSTOFFE GMBH | Mannheim | Dr. Manfred Harperscheid |
| | FVTR GmbH | Rostock | Dr. Martin Reißig |
| G | Gamma Technologies Inc. | Westmont (US) | Jan Böbel, Dr. Thomas Morel |
| | Garrett Advancing Motion Inc. | Rolle (CH) | Jean-Sebastien Roux |
| | GE Power AG | Mannheim | Dr. Michael Ladwig |
| | Gehring Technologies GmbH | Ostfildern | Gerhard Flores |
| | GF Casting Solutions AG | Schaffhausen (CH) | Ilias Papadimitriou |
| | ↓ GIE. RE. PSA – Renault | Guyancourt Cedex (FR) | |
| | Gleitlagertechnik Essen GmbH | Essen | Dr. Stefan Verstege |
| | Gleitlagertechnik Weißbacher GmbH | Alpen | Dr. Christoph Weißbacher |
| | ↓ GM Global Technology Operation LLC | Pontiac (US) | |
| | GTW Technik s.r.o. | Třemošná (CZ) | Jiri Sujanec |
| H | Haltermann Carless Deutschland GmbH | Hamburg | Dr. Jens Schaak |
| | HEAD acoustics GmbH | Herzogenrath | Prof. Dr. Klaus Genuit |
| | Heinzmann GmbH & Co. KG | Schönau | Anton Gromer |
| | Hengst SE | Münster | Ingo Brunsmann |
| | Heraeus Deutschland GmbH & Co. KG | Hanau | Dominik Sperzel |
| | Hitachi Automotive Systems, Ltd. | Chiyoda-ku (JP) | Yoshihito Yasukawa |
| | HJS Emission Technology GmbH & Co. KG | Menden | Klaus Schrewe |
| | ↓ hofer powertrain münchen GmbH | Lenting | |
| | Honda R&D Europe (Deutschland) GmbH | Offenbach | Dr. Michael Fischer |
| | Howden Turbo GmbH | Frankenthal | Dr. Matthias Schleer |
| I | IAV GmbH | Berlin | Marc Sens |
| | IAVF Antriebstechnik GmbH | Karlsruhe | Dr. Peter Berlet |
| | ↑ IBIDEN Ceram GmbH | Frauental | Dr. Irene Begsteiger |
| | IFP Energies nouvelles | Rueil-Malmaison Cedex (FR) | Bruno Walter |
| | IHI Charging Systems International GmbH | Heidelberg | Dr. Jan Ehrhard |
| | Industrial Analytics Berlin GmbH | Berlin | Dr. Richard Büssow |
| | ↓ Ingenieurbüro Dr. Linnhoff | Haltern am See | |

↑ new member ↓ resigned member

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

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

↑ new member ↓ resigned member

| | COMPANY | LOCATION (HEADQUARTERS) | REPRESENTATIVE (SCIENTIFIC ADVISORY COMMITTEE) |
|---|---|---|---|
| S | Scania CV AB | Södertälje (SE) | Johan Linderyd |
| | Schaeffler AG | Herzogenaurach | Dr. Michael Elicker |
| | Schaeffler Engineering GmbH | Werdohl | Lars Pfützenreuter |
| | SEG Automotive Germany GmbH | Stuttgart | Dr. Dieter Eppinger |
| | Shell Global Solutions (Deutschland) GmbH | Hamburg | Dr. Ingo Mikulic |
| | Siemens Energy Global GmbH & Co. KG | Duisburg | Olaf Bernstrauch |
| | Siemens Industry Software GmbH | Köln | Dr. Helge Tielbörger |
| | Steinbeis Transferzentrum Bauteilfestigkeit und -sicherheit, Werkstoff- und Fügetechnik (BWF) | Esslingen | Dr. Stephan Issler |
| | Subaru Corporation | Tokio (JP) | Daisuke Yamada |
| T | TEC4FUELS GmbH | Herzogenrath | Dr. Klaus Lucka |
| | Tenneco GmbH | Edenkoben | Frank Terres |
| | ↑ TESONA GmbH & Co. KG | Hörselberg / Hainich | Heiko Lantzsch |
| | TheSys GmbH | Kirchentellinsfurt | Peter Ambros |
| | TotalEnergies SE | Berlin | Peter Scholl |
| | Toyota Motor Corporation | Aichi (JP) | Ashish Kamat, Paul Decker-Brentano |
| | Turbo Science GmbH | Darmstadt | Dr. Sebastian Leichtfuß |
| U | ↓ Umicore AG & Co. KG | Hanau | |
| V | VEMAC GmbH & Co. KG | Aachen | Axel Koblenz |
| | Vitesco Technologies Emitec GmbH | Lohmar | Rolf Brück |
| | ↓ Vitesco Technologies GmbH | Regensburg | |
| | Volkswagen AG | Wolfsburg | Dr. Ekkehard Pott |
| | Volvo Car Corporation | Göteborg (SE) | Ragnar Burenius |
| | VOLVO Powertrain AB | Göteborg (SE) | Ulla Särnbratt |
| W | Winterthur Gas & Diesel Ltd. | Winterthur (CH) | Dr. Wolfgang Östreicher |
| | Woodward L'Orange GmbH | Stuttgart | Dr. Michael Willmann |
| | WTZ Motorentechnik GmbH | Dessau-Roßlau | Dr. Christian Reiser |
| Z | ZF Friedrichshafen AG | Schweinfurt | N.N. |

# Committees

## EXECUTIVE COMMITTEE AND MANAGEMENT

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

| MANAGEMENT |
|---|
| Dietmar Goericke, *Managing Director* |
| Martin Nitsche, *Deputy Managing Director* |
| Matthias Zelinger, *Deputy Managing Director* |

## SCIENTIFIC ADVISORY COMMITTEE

| REPRESENTATIVE | COMPANY | LOCATION (HEADQUARTERS) |
|---|---|---|
| Dr. Ekkehard Pott, ***Chairman*** | Volkswagen AG | Wolfsburg |
| Dr. Dirk Hilberg, ***Deputy Chairman*** | Rolls-Royce Deutschland Ltd. & Co. KG | Oberursel |

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

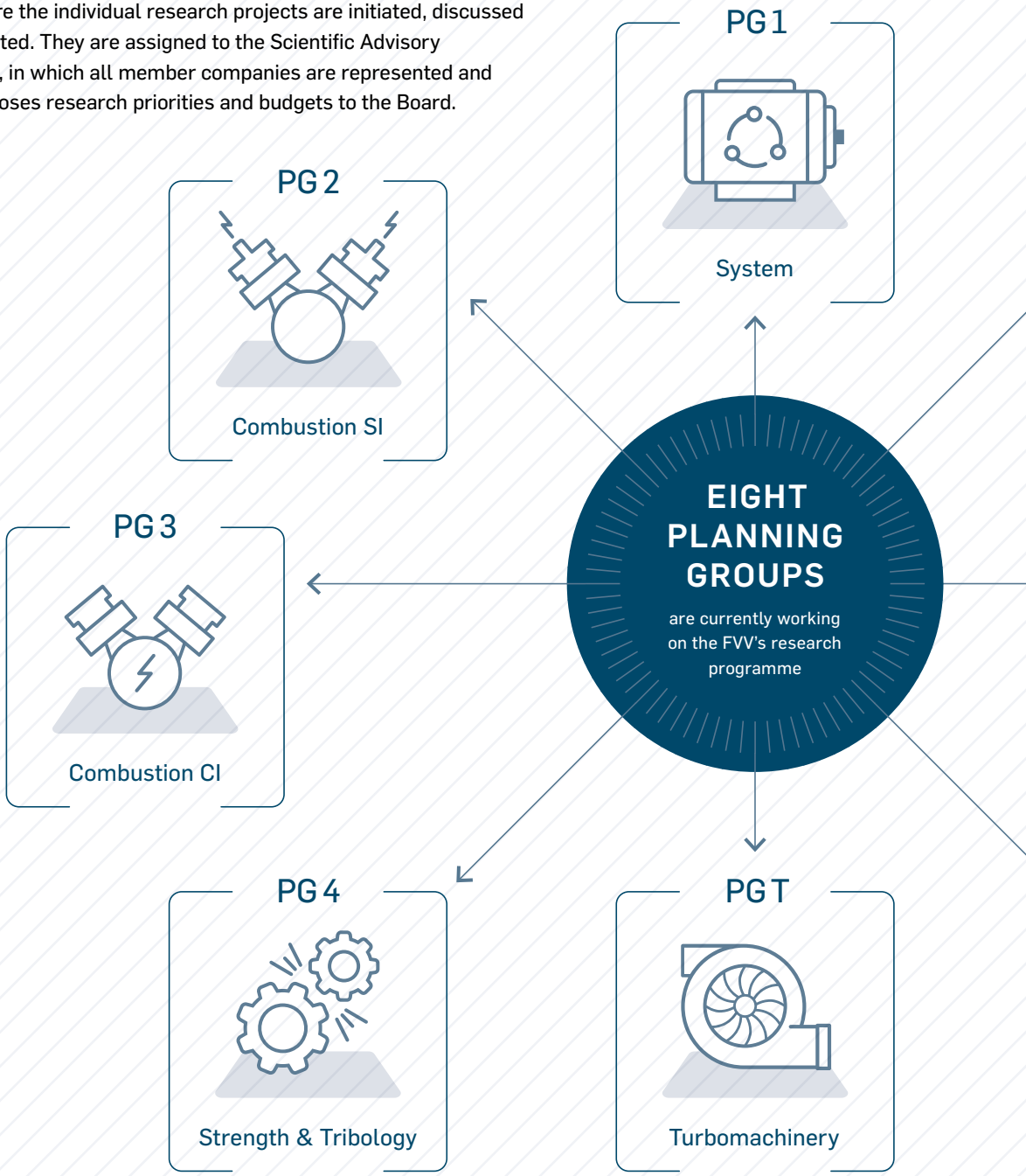
### Research Committee

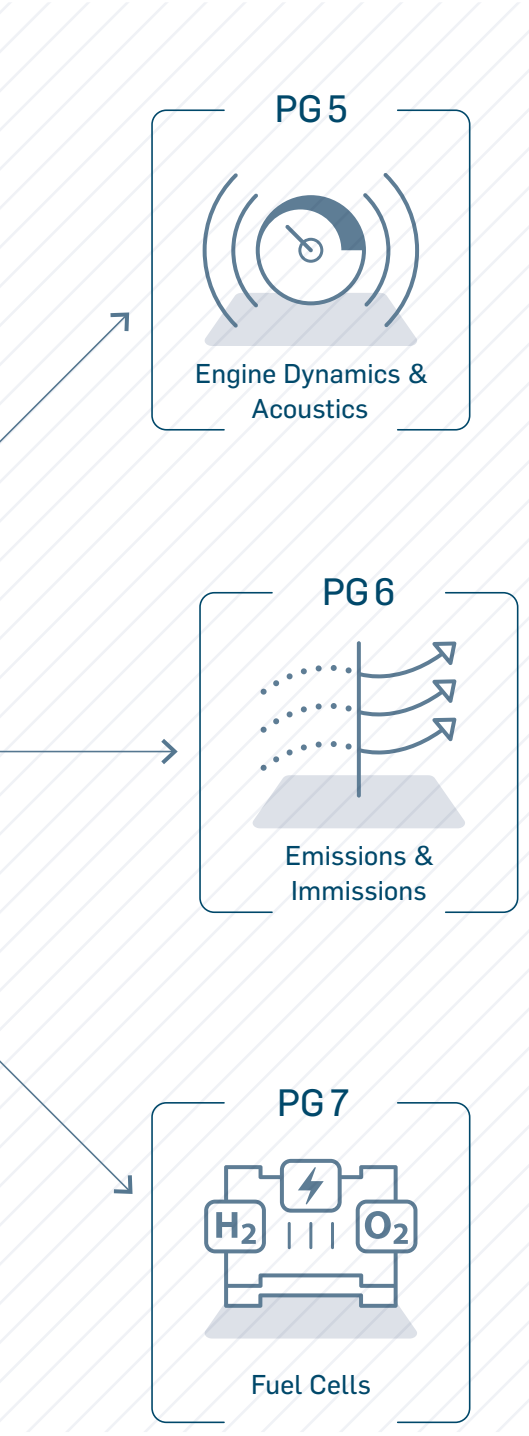
| | | |
|---|---|---|
| Prof. Dr. Christoph Brands | Schaeffler Technologies AG & Co. KG | Herzogenaurach |
| Paul Decker-Brentano | TOYOTA GAZOO Racing Europe GmbH | Köln |
| Arndt Döhler | Opel Automobile GmbH | Rüsselsheim |
| Dr. Dieter Eppinger | SEG Automotive Germany GmbH | Stuttgart |
| Dr. Volker Formanski | Bayerische Motorenwerke AG | München |
| Markus Kolczyk | MANN+HUMMEL GmbH | Ludwigsburg |
| Dr. Ulrich Kramer | Ford-Werke GmbH | Köln |
| Dr. Andreas Kufferath | Robert Bosch GmbH | Stuttgart |
| Dr. André Casal Kulzer | Dr. Ing. h.c. F. Porsche AG | Weissach |
| Dr. Peter Riegger | Rolls-Royce Solutions GmbH | Friedrichshafen |
| Dr. Volker Schmeißer | Daimler Truck AG | Stuttgart |
| Marc Sens | IAV GmbH | Berlin |
| Dr. Christian Weiskirch | TRATON SE | München |

# Coordination and knowledge transfer

## PLANNING GROUPS (PG)

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






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

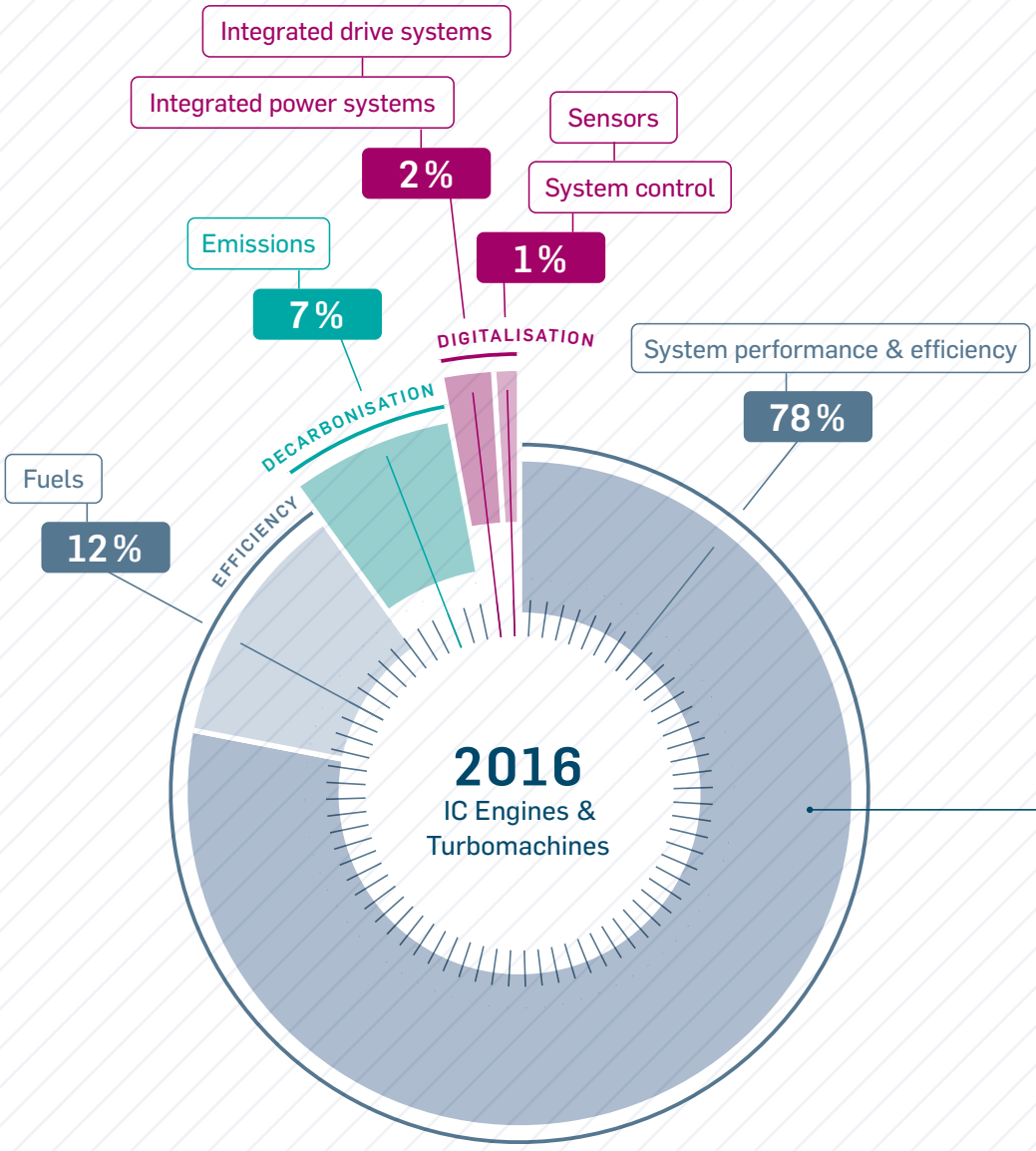
THEMIS enables more than 15,000 users, 6,000 of whom are members of the FVV research network, to exchange information on equal terms. Members can use the platform to jointly draw up ideas for new research projects, take part in project and committee work online, organise meetings and contacts, manage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

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

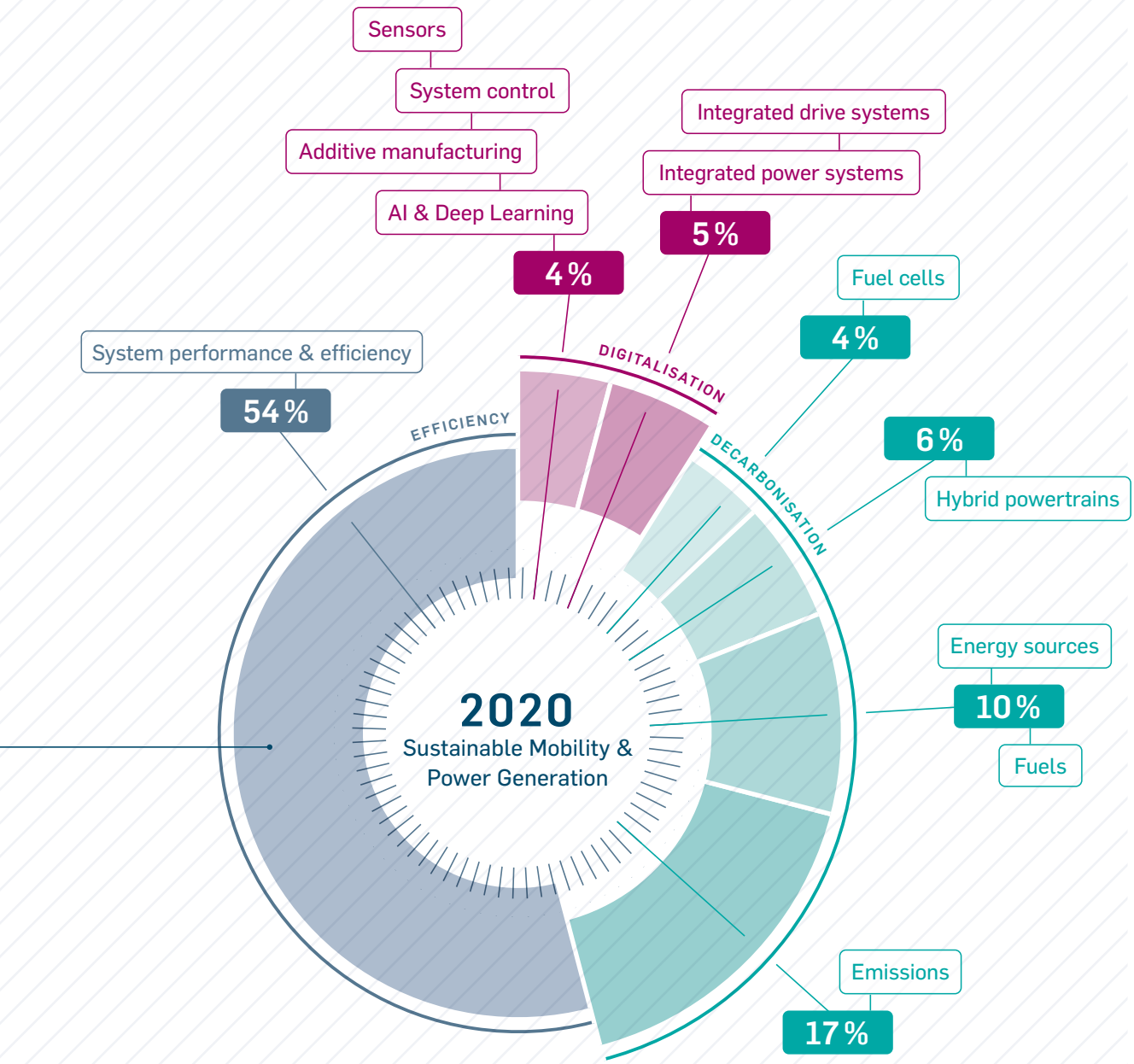
# Research priorities

EFFICIENCY, DECARBONISATION & DIGITALISATION

Collectively we create knowledge-based insights that are available to each of our network partners. In addition to the fundamental standard topics, the FVV is installing new research priorities to support a climate-neutral, resource-efficient and competitive industry.

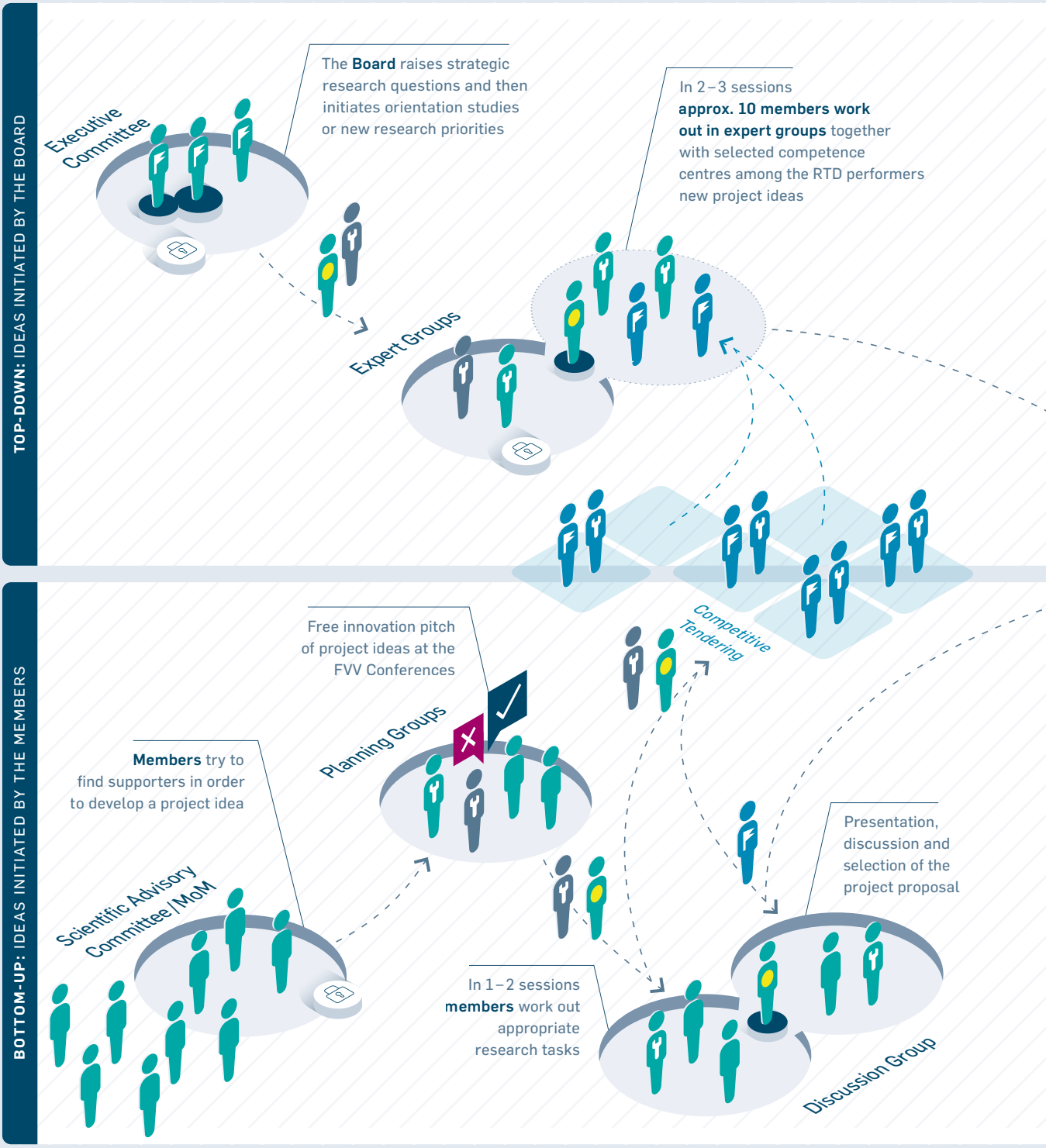


→ Climate neutrality is at the core of the transformation [→ page 8]. This vision can only be achieved through the use of $CO_2$-neutral energy sources and efficient energy converters. FVV is deploying both new research programmes [→ page 28] and modern digital methods such as artificial intelligence to make this happen.

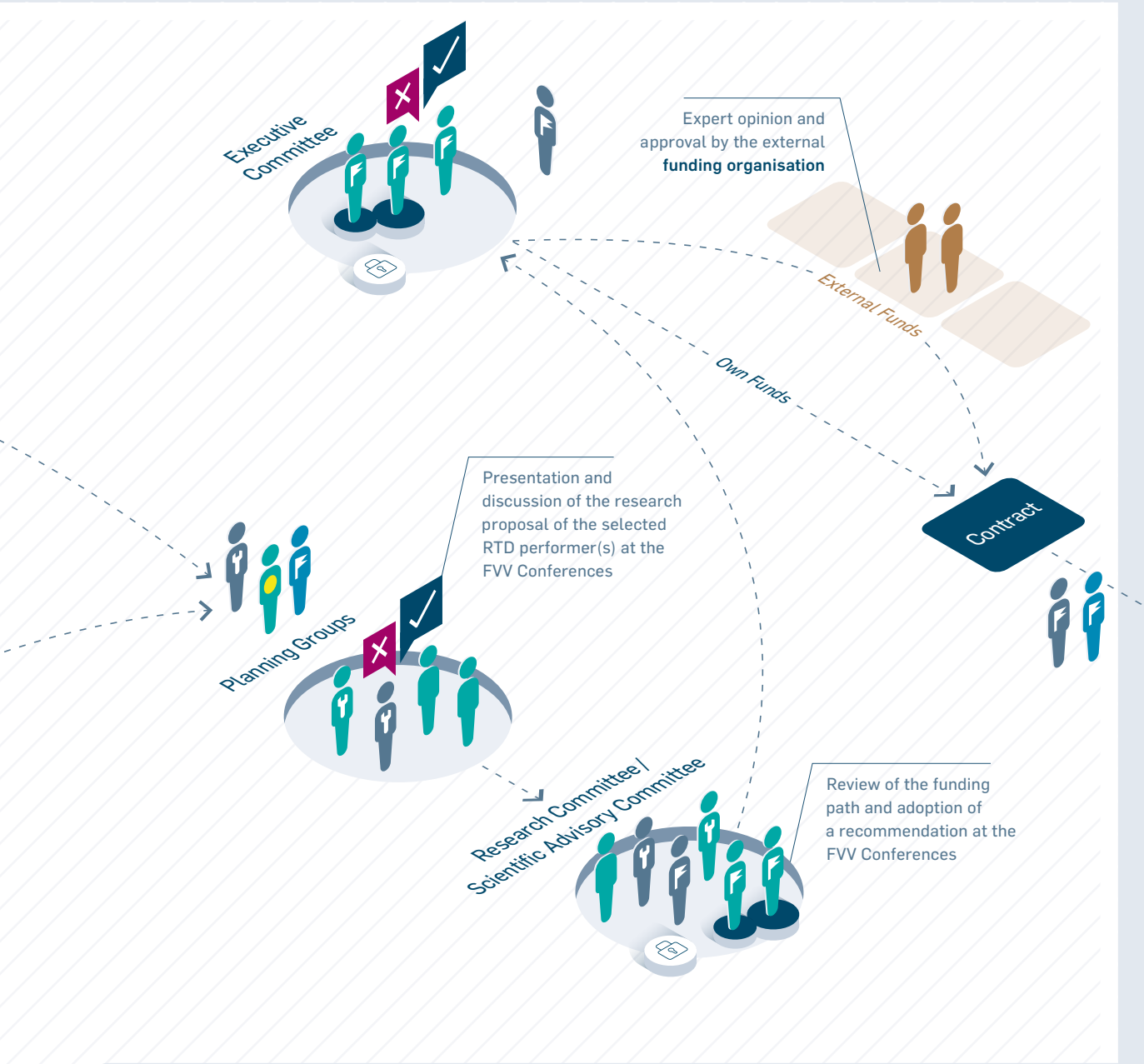


# Life cycle of a research project

## DEVELOPMENT OF A NEW RESEARCH IDEA



## APPROVAL OF THE PROPOSAL




APPOINTED/ ELECTED REPRESEN-TATIVES

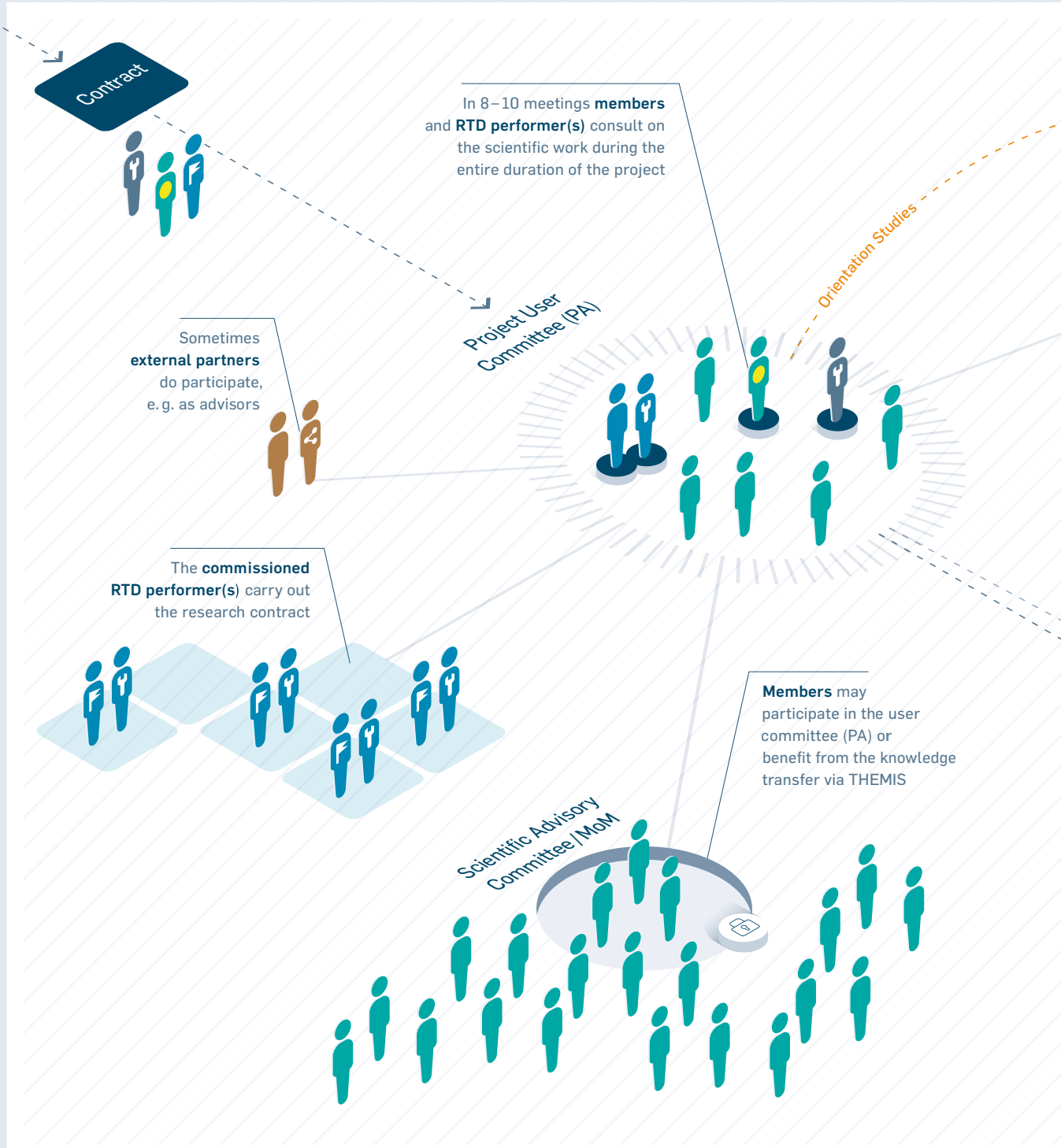
**MEMBERS**
TD: MENTOR
BU: INITIATOR
MANAGEMENT
COORDINATION
TEAM

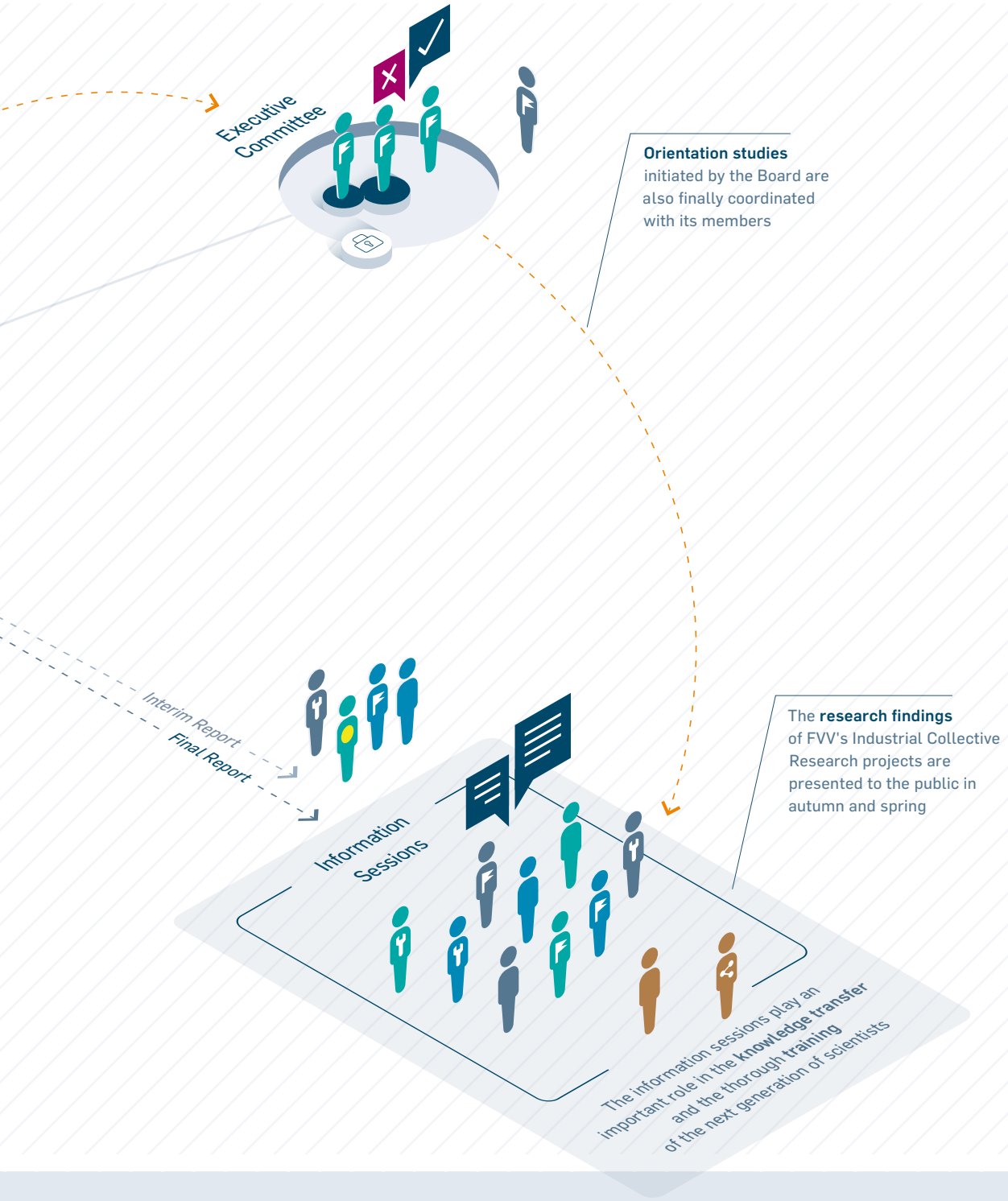
**FVV**
MANAGEMENT
COORDINATION
TEAM

**RTD PERFORMERS**
MANAGEMENT
COORDINATION
TEAM

**EXTERN**
COOPERATION
PERSON

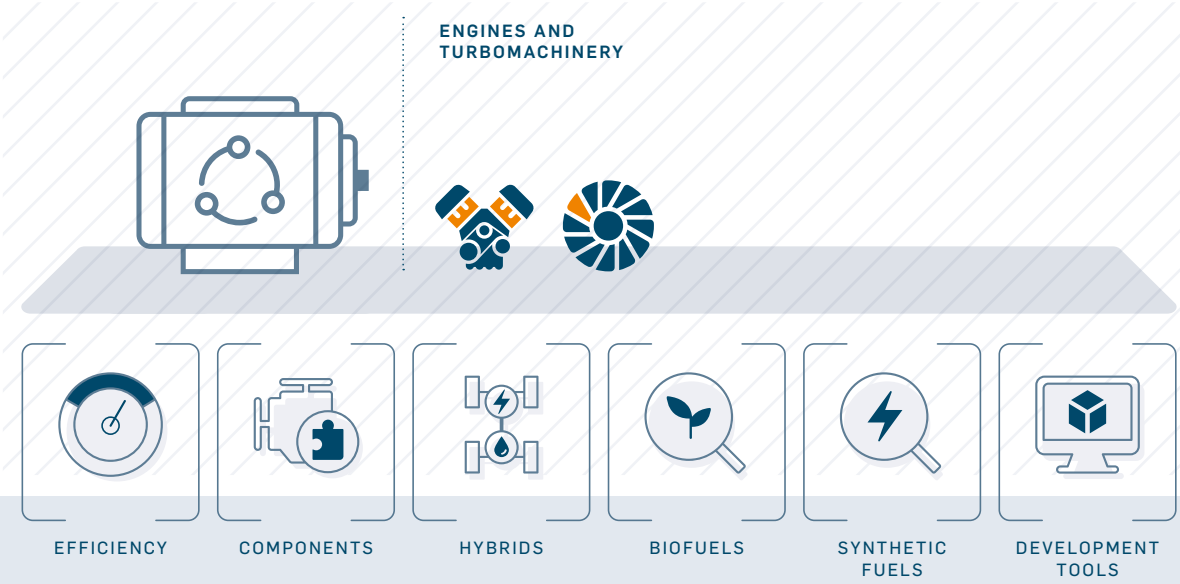
## IMPLEMENTATION OF A RESEARCH PROJECT




Executive Committee
Orientation studies initiated by the Board are also finally coordinated with its members
Interim Report
Final Report
Information Sessions
The research findings of FVV's Industrial Collective Research projects are presented to the public in autumn and spring
The information sessions play an important role in the knowledge transfer and the thorough training of the next generation of scientists

# System

PLANNING GROUP 1




**COORDINATOR**

Dr. Peter Riegger,
Rolls-Royce Solutions

**PROJECT MANAGEMENT**

Ralf Thee, FVV

**PG1 ONLINE**

FVV

THEMIS

**RESEARCH PRIORITIES**

Planning group 1, ›System‹, is dedicated to the following topics:

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

And tackles the following lines of research / focuses:

- → System analysis of new technologies, alternative powertrains and fuels
- → Recovering lost energy
- → (Ultra-low) temperature management
- → Control, regulation, sensors
- → Turbocharging
- → Large and nonroad engines

## PG 1 | RESEARCH PROJECTS

| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Planned projects** | |
| **M0521** | Pre-Ignited Flame Propagation in Gas Engines | **Dr. Markus Wenig,** Winterthur Gas & Diesel |
| **M1021** | Data-based Monitoring of Powertrain Components | **Dr. Christian Jörg,** Hitachi Astemo Europe |
| **M1320** | On-Board Emission Conformity Monitoring (OBECOM) // CORNET | **Dr. Heike Többen,** Eberspächer Exhaust Technology |
| **M1321** | Condensate Formation in Exhaust Systems | **Dirk Vierkotten,** Pierburg |
| **M1521** | Distributed Thermal Hybrid Powertrain Testing // FVV-EM | **Dr. Marcus Gohl,** APL Automobil-Prüftechnik Landau |
| **M1620** | AI Route Optimisation // BMWi/AiF | **Dr. Markus Wenig,** Winterthur Gas & Diesel |
| **M1621** | AI4Fuels | **Dr. Michael Bippes,** Volkswagen |
| **M1820** | Maneuvering with Hybrid Ships // BMWi/AiF | **Dr. Udo Schlemmer-Kelling,** FEV Europe |
| **M1920** | Hybrid Drives for Alternative Fuels // BMWi/AiF | **Dr. Udo Schlemmer-Kelling,** FEV Europe |
| **M1921** | Axial Turbine T/C for Lean Burn Concepts | **Marc Sens,** IAV |
| **M3220** | Ejector-Bypass TC // BMWi/AiF | **Dr. Tom Steglich,** IAV |
| **M3320** | New Hydrogen Storage Concept | **Kathrin Giefer,** Ford-Werke |
| | **Ongoing projects** | |
| **1312** | 48V Mild Hybrid with Semi-Homogeneous Diesel Combustion // BMWi/AiF // 01-01-2018 to 31-05-2022 | **Dr. Achim Lechmann,** IAV |
| **1321** | Working Cycle Dissolved Turbine Efficiency in Turbochargers // FVV-EM, DFG // 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 28-02-2022 | **Prof. Peter Prenninger,** AVL List |
| **1342** | Sensor Concept for E-Fuels // FVV-EM // 01-02-2019 to 28-02-2022 | **Dr. Bernd Becker,** IAV |
| **1355** | Powertrain 2040 // FVV-EM // 01-04-2019 to 30-09-2021 | **Dr. Thorsten Schnorbus,** FEV Europe |
| **1382** | Lubrication Large Bore Engines II // FVV-EM // 01-05-2020 to 30-04-2022 | **Dr. Tobias C. Wesnigk,** M. JÜRGENSEN |
| **1384** | $H_2$ in the Gas Network // FVV-EM // 01-01-2020 to 31-12-2021 | **Dr. Dietrich Gerstein,** DVGW<br>**Dr. Ulrich Kramer,** Ford-Werke |
| **1385** | T/C for Lean Burn Concepts // FVV-EM // 01-04-2020 to 31-10-2021 | **Marc Sens,** IAV |

↓ Continue on the next page

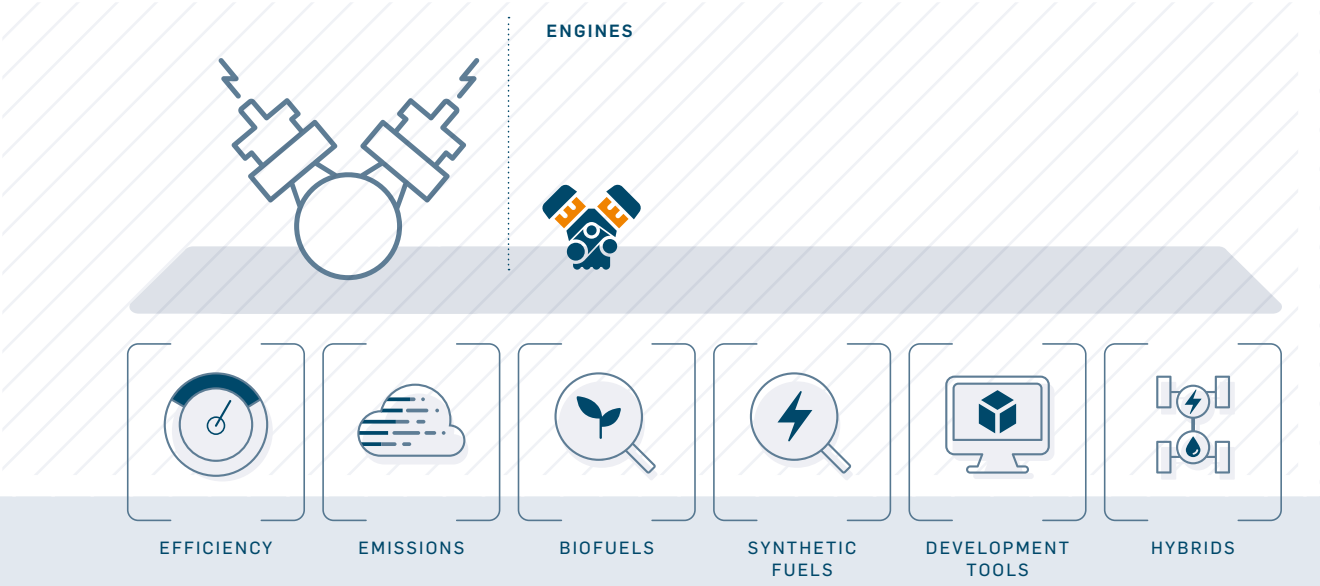
| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| **1394** | Modelling of Pre-ignition in Gas Engines // FVV-EM, CORNET // 01-04-2020 to 31-03-2022 | **Dr. Markus Wenig,** Winterthur Gas & Diesel |
| **1407** | Zero Impact Vehicle Emissions (Conceptual Study) // FVV-EM // 01-09-2020 to 31-08-2021 | **Prof. Dr. Kurt Kirsten,** APL Automobil-Prüftechnik Landau |
| **1410** | SocioMotion // FVV-EM // 01-11-2020 to 31-10-2021 | **Prof. Dr. Thomas Garbe,** Volkswagen |
| **1428** | Modular Hybrid Powertrain // FVV-EM // 01-01-2021 to 31-12-2022 | **Dr. Veit Held,** Opel Automobile |
| **1429** | $CO_2$-neutral Long-haul Heavy-duty Powertrains 2050 II // FVV-EM // 01-04-2021 to 31-03-2023 | **Herbert Schneider,** ISUZU MOTORS |
| **1433** | HyFlex ICE // FVV-EM // 01-03-2021 to 28-02-2023 | **Marc Sens,** IAV |

## Completed projects

| | | |
|---|---|---|
| **1305** | Exhaust Gas Aftertreatment Before Turbine // FVV-EM // 01-05-2018 to 30-06-2021 | **Dr. Frank Bunar,** IAV |
| **1314** | TC Model Parameterisation // BMWi/AiF // 01-01-2018 to 30-06-2020 | **Dr. Panagiotis Grigoriadis,** IAV |
| **1316** | Exhaust Gas Composition at Low Temperatures // FVV-EM, FVV-EM // 01-07-2018 to 31-10-2020 | **Dr. Michael Becker,** Pierburg |
| **1327** | Lubrication Large Bore Engines I // FVV-EM // 01-09-2018 to 31-10-2020 | **Dr. Tobias C. Wesnigk,** M. JÜRGENSEN |
| **1363** | Method Hybrid Testing // FVV-EM // 01-07-2019 to 30-06-2021 | **Dr. Marcus Gohl,** APL Automobil-Prüftechnik Landau |
| **1430** | $CO_2$ Effects from Electricity Demand // FVV-EM // 01-10-2020 to 31-03-2021 | |

# Combustion SI

PLANNING GROUP 2




**COORDINATOR**

Dr. André Casal Kulzer, Porsche

**PROJECT MANAGEMENT**

Ralf Thee, FVV

**PG2 ONLINE**

FVV

THEMIS

**RESEARCH PRIORITIES**

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

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

And tackles the following lines of research / focuses:

- → Combustion modelling/simulation
- → Combustion processes and fuel preparation
- → Water injection
- → Wall heat transfer
- → Knocking and pre-ignition
- → Particle formation in the combustion chamber
- → Downsizing concepts

## PG 2 | RESEARCH PROJECTS

| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Planned projects** | |
| **M0120** | Oil Input into Combustion II | **Dr. Eike Stitterich,** Hengst |
| **M0220** | DI$H_2$jet (DI Hydrogen Combustion Process) // CORNET, FVV-EM | **Michael Günther,** IAV |
| **M0221** | Engine Knock Intensity Modelling for Future Fuels | **Dr. André Casal Kulzer,** Porsche |
| **M0421** | Cold Start Optimisation for M-100 Methanol Engine | **Dr. Helmut Ruhland,** Ford Werke |
| **M0720** | Near-zero Emission Concept for $H_2$ DI Otto Engines // FVV-EM | **Dr. David Lejsek,** Robert Bosch<br>**Dr. Wolfgang Samenfink,** Robert Bosch |
| **M1221** | Prediction of Inhomogeneous $H_2$-SI Combustion | **Dr. Maximilian Brauer,** IAV |
| **M1319** | Oxyfuel Combustion Process for Stationary Gas Engines | **Marc Sens,** IAV |
| **M1721** | Initial Pre-ignition II | **Albert Breuer,** Ford-Werke |
| **M1821** | Renewable EN 228 Gasoline | **Rupali Tripathi,** Neste Oyj |
| **M2120** | Preferential Evaporation of Alternative Fuel Mixtures // BMWi/AiF | **Jérôme Munier,** Porsche |
| **M2520** | Test Bench Investigation Aged Gasoline Fuel | **Dr. Bernd Becker,** IAV |
| **M2920** | Innovative RDE Engine-out Emission Reduction | **Christine Burkhardt,** EnginOS<br>**Futoshi Yoshimura,** Nissan Motor |
| **M3720** | Mixture Preparation / Homogenization with $H_2$-DI // BMWi/AiF | **Michael Rieß,** IAV |
| **M4220** | Multicomponent Fuels / Wall Film Interaction // BMWi/AiF | **Jérôme Munier,** Porsche |
| **M4320** | Fuel Composition – RDE and Soot Formation // FVV-EM | **Dr. Christian Töpel,** Freyberger engineering<br>**Dr. Lars Menger,** BMW |
| | **Ongoing projects** | |
| **1343** | Spray Modelling for DI Gasoline Engines // FVV-EM<br>// 01-01-2019 to 31-12-2021 | **Dr. Christian Jörg,** Hitachi Astemo Europe |
| **1348** | Fuel Composition for $CO_2$ Reduction // FVV-EM<br>// 01-03-2019 to 28-02-2022 | **Nozomi Yokoo,** Toyota Motor Corporation<br>**Dr. Yoshihiro Okada,** Toyota Motor Corporation<br>**Terutoshi Tomoda,** Toyota Motor Corporation |
| **1349** | Influencing Wall Heat Losses in SI Engines // BMWi/AiF, FVV-EM<br>// 01-01-2019 to 30-09-2021 | **Dr. Thorsten Unger,** Porsche |
| **1357** | Homogenisation Model SI Engines II // BMWi/AiF<br>// 01-07-2019 to 31-03-2022 | **Marc Sens,** IAV |
| **1367** | Water Injection in Spark-Ignition Engines II // FVV-EM<br>// 01-10-2019 to 31-03-2022 | **Dr. André Casal Kulzer,** Porsche |

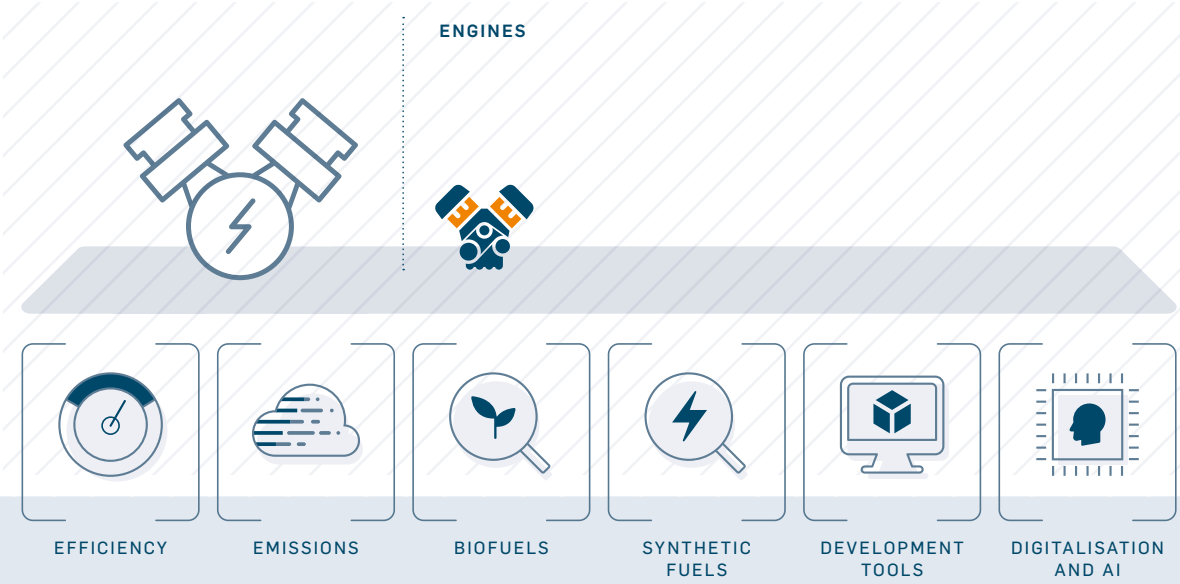
| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| **1370** | Fast Knocking Prediction for Gasoline Engines // FVV-EM // 01-10-2019 to 30-09-2021 | **Dr. Michael Fischer,** Tenneco |
| **1374** | Fuel Influence on Particulate Characteristics // BMWi/AiF // 01-09-2019 to 31-08-2021 | **Dr. Wolfgang Samenfink,** Robert Bosch |
| **1387** | Benchmark Platform for Scale Resolving Simulations // BMWi/AiF // 01-01-2020 to 30-06-2022 | **Kathrin Giefer,** Ford-Werke |
| **1426** | Heuristic Search and Deep Learning // BMWi/AiF // 01-11-2020 to 30-04-2023 | **Dr. Aras Mirfendreski,** TOYOTA GAZOO Racing Europe |
| **1431** | SACI Combustion System with Active Pre-Chamber // FVV-EM // 01-01-2021 to 30-06-2023 | **Dr. André Casal Kulzer,** Porsche |
| **1434** | ICE2030 // FVV-EM // 01-02-2021 to 31-01-2023 | **Arndt Döhler,** Opel Automobile |
| **1435** | Modelling Turbulence // FVV-EM, CORNET // 01-01-2021 to 31-12-2022 | **Dr. David Lejsek,** Robert Bosch |

## Completed projects

| | | |
|---|---|---|
| **1260** | Thermodynamics Top Land Volume // BMWi/AiF, FVV-EM // 01-01-2017 to 30-04-2021 | **Oliver Dingel,** IAV |
| **1281** | Pilot Injection Gas Engine // BMWi/AiF // 01-08-2017 to 31-03-2021 | **Dr. Martin Schenk,** BMW |
| **1283** | Oil Input into Combustion // FVV-EM, BMWi/AiF // 01-08-2017 to 31-01-2020 | **Dr. Eike Stitterich,** Hengst |
| **1307** | ICE2025+: Ultimate System Efficiency // FVV-EM, FVV-EM // 01-03-2018 to 31-10-2020 | **Arndt Döhler,** Opel Automobile |
| **1311** | Gas Pulsation and Turbochargers Interaction // BMWi/AiF // 01-01-2018 to 30-06-2021 | **Marc Sens,** IAV |
| **1313** | Engine Knock Model // BMWi/AiF // 01-01-2018 to 30-11-2020 | **Dr. André Casal Kulzer,** Porsche |
| **1317** | Spray Diagnostics of Gasoline E-Fuels // FVV-EM // 01-08-2018 to 31-03-2020 | **Dr. Eberhard Kull,** Vitesco Technologies |
| **1328** | Initial Pre-ignition // CORNET, FVV-EM // 01-05-2018 to 31-12-2020 | **Albert Breuer,** Ford-Werke |
| **1336** | PostOxidation // CORNET, FVV-EM, BMWi/AiF // 01-10-2018 to 28-02-2021 | **Christine Burkhardt,** EnginOS<br>**Yoshihiro Imaoka,** Nissan Motor |
| **1395** | Experimentally Validated LES Models for Wall Heat Transfer in Otto Engines // CORNET, FVV-EM // 01-01-2020 to 31-03-2021 | **Gabriel Dilmac,** Porsche |

# Combustion CI

PLANNING GROUP 3




**COORDINATOR**

Dr. Christian Weiskirch, TRATON

**PROJECT MANAGEMENT**

Ralf Thee, FVV

**PG3 ONLINE**

FVV

THEMIS

**RESEARCH PRIORITIES**

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

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

And tackles the following lines of research / focuses:

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

## PG 3 | RESEARCH PROJECTS

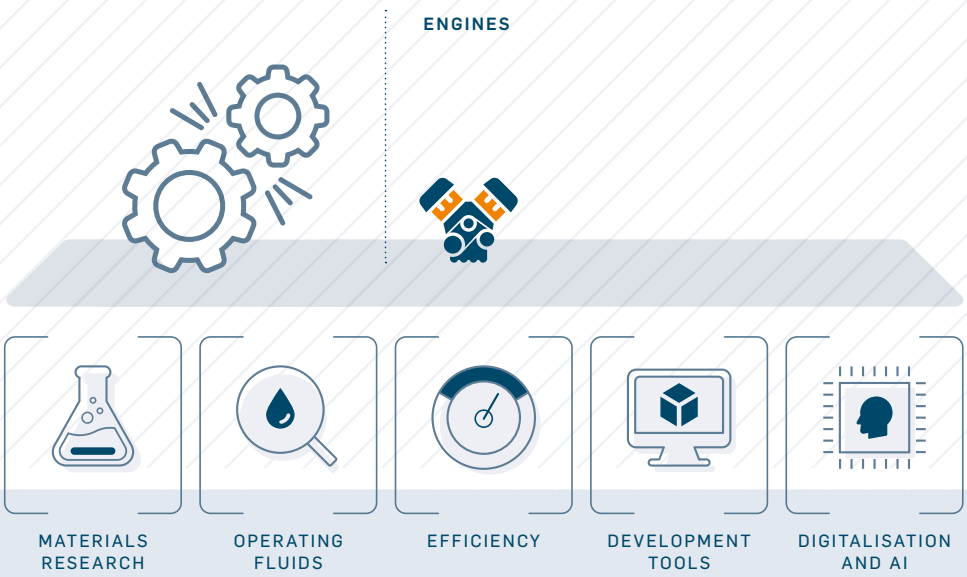
| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Planned projects** | |
| **M0621** | Power Density Hydrogen CI Engine | **Dr. Markus Wenig,** Winterthur Gas & Diesel |
| **M1120** | $NH_3$ Combustion Process for Large Engines // BMWi/AiF | **Christian Kunkel,** MAN Energy Solution |
| **M1121** | MePICS – Methanol Pilot Injection Combustion System | **Dr. Kai Deppenkemper,** FEV Europe |
| **M1919** | Diesel Engine Process Chain // BMWi/AiF | **Dr. Wolfgang Bauer,** MAN Truck & Bus |
| **M2219** | AI Integration into the Development Toolchain // BMWi/AiF | **Amodio Palma,** Winterthur Gas & Diesel |
| **M2818** | DME Fuel Properties | **Dr. Werner Willems,** FORD Research and Innovation Center Aachen |
| **M3020** | Gas Injection High-pressure COmbustion (GIHPCO) // CORNET | **Ingmar Berger,** Woodward L'Orange<br>**Dr. Michael Willmann,** Woodward L'Orange |
| **M3120** | HyCE Truck // CORNET, BMWi/AiF | **Dr. Reza Rezaei,** IAV<br>**Prof. Gennadi Zikoridse,** Argomotive<br>**Dr. Martin Lammert,** Emission Partner<br>**Dr. Jörg Spengler,** INTERKAT Catalyst |
| **M3319** | $CO_2$ Reduction by Shorter Burn Duration // BMWi/AiF | **Dr. Patrick Gastaldi,** Aramco Fuel Research Center |
| | **Ongoing projects** | |
| **1318** | Air Insulation Diesel engine // FVV-EM // 01-07-2018 to 31-12-2021 | **Dr. Patrick Gastaldi,** Aramco Fuel Research Center |
| **1346** | Potentials of Airpath Variabilities for HD Gas Engines // FVV-EM // 01-01-2019 to 31-12-2021 | **Dirk Weberskirch,** MAN Truck & Bus |
| **1352** | PremixedDiesel // BMWi/AiF, FVV-EM, CORNET // 01-01-2019 to 31-12-2021 | **Dr. Simon Schneider,** MAHLE International |
| **1368** | Innovative HD Combustion System Design // FVV-EM // 01-07-2019 to 28-02-2022 | **Dr. Reza Rezaei,** IAV |
| **1403** | eSpray // FVV-EM, CORNET // 01-06-2020 to 31-05-2022 | **Dr. Uwe Leuteritz,** Liebherr-Components Deggendorf |
| **1405** | Closed-cycle Hydrogen CI Engine // FVV-EM // 01-09-2020 to 31-10-2021 | **Dr. Markus Wenig,** Winterthur Gas & Diesel |
| **1408** | Cold Start Emission Reduction // FVV-EM // 01-09-2020 to 28-02-2023 | **Dr. Maximilian Brauer,** IAV |
| **1442** | Hydrogen Combustion and Comparison PFI/DI concepts // FVV-EM // 01-04-2021 to 31-03-2023 | **Dr. Reza Rezaei,** IAV |

↓ Continue on the next page

| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Completed projects** | |
| **1235** | Modelling Emissions of Diesel Engine Combustion with Variable Valve Timing // FVV-EM // 01-08-2016 to 29-02-2020 | **Matthias Diezemann,** IAV |
| **1275** | VVT for Diesel LNT Rich Purge // BMWi/AiF // 01-04-2017 to 31-03-2021 | **Christine Burkhardt,** EnginOS |
| **1280** | Propeller Operation with Four-stroke Dual-fuel Engines II // FVV-EM // 01-09-2017 to 28-02-2021 | **Dr. Philipp Henschen,** MAN Energy Solutions |
| **1284** | RCCI in Heavy Duty Engines // CORNET, FVV-EM, BMWi/AiF, FVV-EM // 01-08-2017 to 30-06-2020 | **Dr. Ingo Mikulic,** Shell Global Solutions |
| **1287** | Diesel Combustion Chamber Insulation // CORNET, FVV-EM, FVV-EM // 01-09-2017 to 29-02-2020 | **Dr. Maximilian Brauer,** IAV |
| **1310** | HC/CO Model // BMWi/AiF // 01-01-2018 to 31-07-2020 | **Dr. Markus Wenig,** Winterthur Gas & Diesel |
| **1320** | Spray Diagnostics of Future Diesel Fuels // FVV-EM // 01-02-2019 to 31-07-2020 | **Dr. Uwe Leuteritz,** Liebherr-Components Deggendorf |
| **1338** | Water Injection on Diesel Engines // BMWi/AiF // 01-11-2018 to 31-10-2020 | **Dr. Peter Bloch,** Robert Bosch |

# Strength & Tribology

PLANNING GROUP 4




**COORDINATOR**

Dr. Dieter Eppinger,
SEG Automotive Germany

**PROJECT MANAGEMENT**

Max Decker, FVV

**PG4 ONLINE**

FVV

THEMIS

**RESEARCH PRIORITIES**

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

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

And tackles the following lines of research / focuses:

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

## PG 4 | RESEARCH PROJECTS

| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Planned projects** | |
| **M0119** | Gaseous $H_2$ Inhibitors | **Patrick Fayek,** Robert Bosch<br>**Angelika Schubert,** Robert Bosch |
| **M0321** | Dedicated Piston Bore Interface Layout for $H_2$-ICEs | **Dr. Mirko Plettenberg,** AVL List |
| **M0419** | Corrosion Loads due to new Drive Concepts | **Regina Franke-Hörth,** SEG Automotive Germany |
| **M0420** | Base Engine Components for $H_2$ ICEs | **Dr. Daniel Hrdina,** MAHLE International |
| **M0519** | TMF Al-additiv // BMWi/AiF | **Dr. Florian Rödl,** Porsche |
| **M0520** | Machine Learning – MLμσ // BMWi/AiF | **Dr. Michael Berg,** IAV |
| **M0618** | Oil Circuit and Tribosystems of Hybrid Engines with Water Injection // FVV-EM | **Dr. Peter Berlet,** IAVF Antriebstechnik |
| **M0819** | Fatigue Characterisation of Copper | **Christoph Germann,** SEG Automotive Germany |
| **M1220** | Additively Manufactured High-pressure Components // BMWi/AiF | **Stefan Zimmermann,** Woodward L'Orange<br>**Dr. Wolfgang Scheibe,** Heinzmann |
| **M1420** | Rheology of Novel Unconventional Fluids | **Klaus Meyer,** Robert Bosch |
| **M1819** | Wear Prediction and Wear Simulation | **Dr. Martina Weise,** IAV |
| **M2315** | VALOEKO // BMBF | **Dr. Arnim Robota,** Federal-Mogul Burscheid |
| | **Ongoing projects** | |
| **1377** | Shaft Bores // BMWi/AiF // 01-11-2019 to 28-02-2022 | **Stefan Roth,** MAN Energy Solutions |
| **1379** | Tribomaps Friction Enhancing Laser Structures // BMWi/AiF // 01-12-2019 to 31-05-2022 | **Dr. Anton Stich,** AUDI |
| **1393** | Fretting Fatigue Strength Assessment // BMWi/AiF // 01-01-2020 to 31-03-2022 | **Dr. Reiner Böschen,** Rolls-Royce Solutions |
| **1396** | Fuel Oil Flow Measurement // CORNET // 01-01-2020 to 31-12-2021 | **Motoichi Murakami,** Toyota Motor Corporation<br>**Dr. Marcus Gohl,** APL Automobil-Prüftechnik Landau |
| **1402** | Exhaust Gas Effected Tribosystems // BMWi/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 // 01-09-2020 to 31-08-2021 | **Jan Becker,** Porsche |

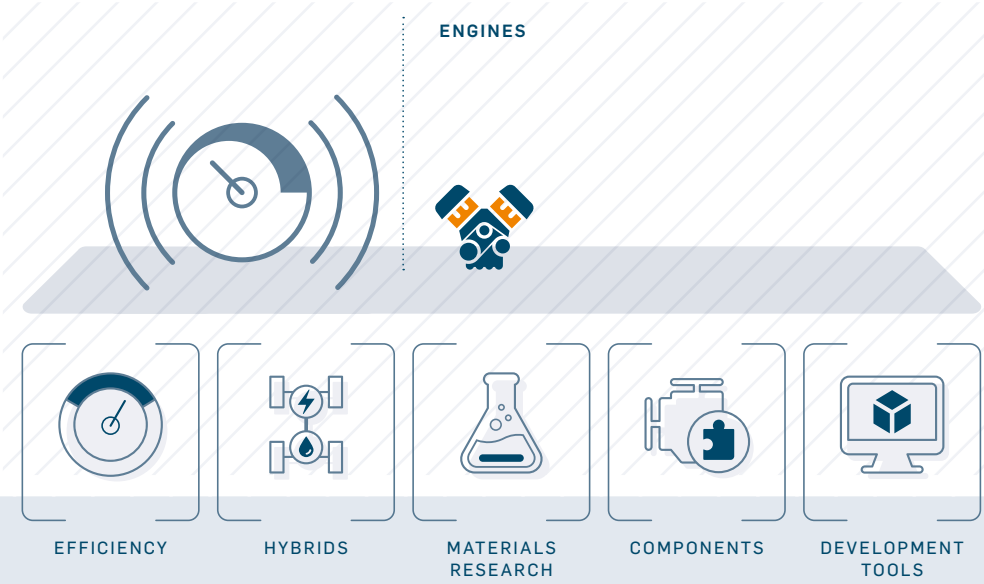
| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| **1441** | Lifetime Model Winding Insulation // BMWi/AiF // 01-03-2021 to 31-08-2023 | **Dr. Zeljana Beslic,** SEG Automotive Germany |
| **M3420** | Flow Erosion II // BMWi/AiF // 01-06-2021 to 30-11-2023 | **Jens Strassmann,** Volkswagen |

## Completed projects

| | | |
|---|---|---|
| **1276** | Piston Pin Bearing II // FVV-EM, BMWi/AiF, FVV-EM, FVV-EM // 01-04-2017 to 30-06-2020 | **Dr. Rolf-Gerhard Fiedler,** MAHLE International |
| **1277** | Tribological Fluid Models II // BMWi/AiF // 01-04-2017 to 31-03-2020 | **Klaus Meyer,** Robert Bosch |
| **1289** | High-pressure Components made of Ultra-high-strength Steels // BMWi/AiF // 01-11-2017 to 30-04-2021 | **Dr. Wolfgang Scheibe,** Heinzmann |
| **1309** | Firing Friction Measurement Methodology // FVV-EM, FVV-EM // 01-04-2018 to 31-03-2021 | **Tai Ono,** SUBARU |
| **1323** | Flow Erosion // BMWi/AiF // 01-08-2018 to 30-04-2021 | **Jens Strassmann,** Volkswagen |
| **1350** | Fatigue Influence Braze Quality // BMWi/AiF // 01-01-2019 to 30-06-2021 | **Prof. Dr. Matthias Türpe,** MAHLE International |
| **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

**PG5 ONLINE**

FVV

THEMIS

**RESEARCH PRIORITIES**

Planning group 5, ›Engine Dynamics & Acoustics‹, is dedicated to the following topics:

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

And tackles the following lines of research / focuses:

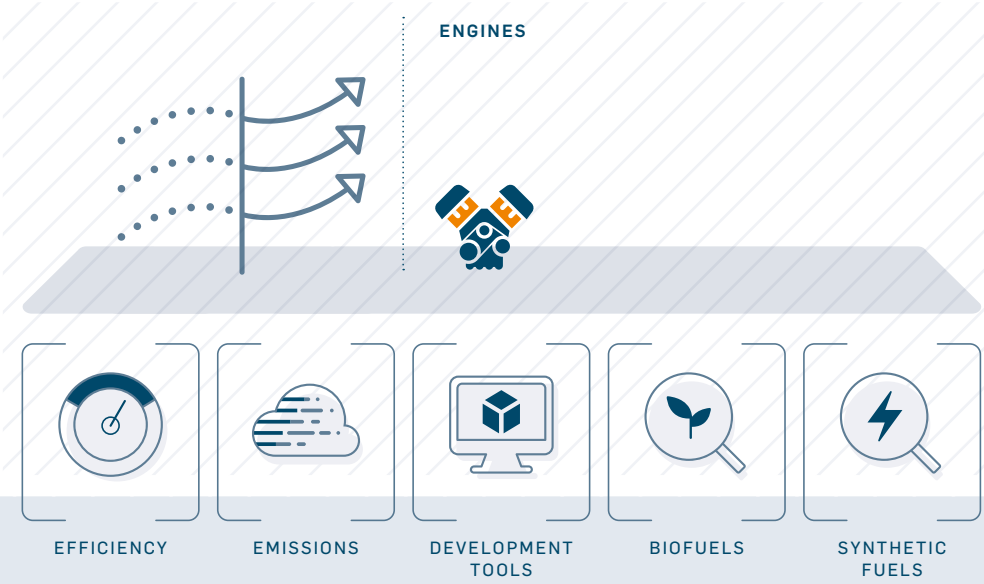
- → Acoustic behaviour of powertrain components
- → Interferences
- → Vibration damping
- → Detecting acoustic phenomena in conventional and new powertrain variants

## PG 5 | RESEARCH PROJECTS

| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Planned projects** | |
| **M0620** | Dissonance (Part-)Electric Powertrains | **Rainer Weber,** Vitesco Technologies |
| **M3719** | Transfer Path Analysis by Means of Deep Learning // BMWi/AiF | **Dr. Matthias Wegerhoff,** HEAD acoustics |
| **M3819** | Exterior Noise of Electric Vehicles | **Dr. Stefan Heuer,** MAN Truck & Bus |
| **M3820** | Acoustic of Hydrogen Piston Engines // BMWi/AiF | **Dr. Stefan Heuer,** MAN Truck & Bus |
| **M3920** | NVH-Behaviour of Fuel Cell Vehicles // BMWi/AiF | **Dr. Stefan Heuer,** MAN Truck & Bus |
| **M4119** | E-Motor Eccentricity Tolerance for NVH in HEV // FVV-EM | **Hans Johannesson,** Volvo Car |
| **M4219** | NVH-optimised Elastomeric Drive Bearings // BMWi/AiF | **Hans Johannesson,** Volvo Car |
| | **Ongoing projects** | |
| **1369** | Interference Noise in the Vehicle Compartment with Electrified Drives // FVV-EM // 01-09-2019 to 31-08-2021 | **Dr. Stefan Heuer,** MAN Truck & Bus |
| | **Completed projects** | |
| **1304** | Perceptional NVH-Aspects of Downspeeding // FVV-EM // 01-03-2018 to 31-12-2020 | **Dr. Sebastian Lucas,** Volkswagen<br>**Dr. Harald Stoffels,** Ford-Werke |
| **1306** | Prediction Diesel Roughness with TPA // FVV-EM // 01-06-2018 to 31-05-2021 | **Dr. Bernd Philippen,** HEAD acoustics<br>**Roland Kühn,** Daimler |
| **1340** | Interior Noise Hybrid Powertrains // FVV-EM // 01-01-2019 to 30-06-2021 | **Rainer Weber,** Vitesco Technologies |
| **1361** | Acoustic Transmission Loss in Turbochargers II // FVV-EM // 01-07-2019 to 31-05-2020 | **Bernd Müller,** Porsche |

# Emissions & Immissions

PLANNING GROUP 6




**COORDINATOR**

Dr. Volker Schmeißer,
Daimler Truck

**PROJECT MANAGEMENT**

Max Decker, FVV

**PG6 ONLINE**

FVV

THEMIS

**RESEARCH PRIORITIES**

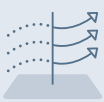
Planning group 6, ›Emissions & Immissions‹, is dedicated to the following topics:

- → Emissions for new powertrain concepts
- → Alternative fuels
- → Fluctuating operating strategies and their effects
- → New materials in components that come into contact with exhaust gas

And tackles the following lines of research / focuses:

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

## PG 6 | RESEARCH PROJECTS



| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Planned projects** | |
| **M0121** | $H_2$-DeNOx II // BMWi/AiF | **Dr. Frank Bunar,** IAV |
| **M1019** | TWC Reaction under High-frequency Lambda Switching // CORNET, BMWi/AiF | **Toshihiro Mori,** Toyota Motor Corporation |
| **M1421** | Laughing-gas Aftertreatment on Ammonia Engines | **Dr. Daniel Peitz,** HUG Engineering |
| **M1519** | Residual Emissions on the Road to Zero Impact // BMWi/AiF | **Dr. Harald Beck,** MAN Truck & Bus |
| **M2019** | Exhaust Gas Condensates of Future Fuels – Composition and Impact on EATS | **Dr. Andreas Jäger,** IAVF Antriebstechnik<br>**Dr. Bernhard Lüers,** FEV Europe |
| **M2020** | CCS on the Decarbonisation of Marine Propulsion Systems // CORNET, FVV-EM | **Klaus Meyer,** Robert Bosch |
| **M2320** | FaconSCR Model // BMWi/AiF | **Dr. Harald Beck,** MAN Truck & Bus |
| **M2420** | High-temperature $H_2$-DeNOx for $H_2$ DI Otto Engines | **Dr. Frank Bunar,** IAV |
| **M2616** | Generation of RDE Test Scenarios // BMWi/AiF | **Florian Rass,** Honda R&D Europe |
| **M2620** | Exhaust Gas Radial Distribution Measurement | **Nikos Symeonidis,** Toyota Motor Europe |
| **M2720** | Oxygen Storage II // FVV-EM | **Jeremias Bickel,** Robert Bosch |
| **M2918** | Predictive EATS in RDE Cycles (PEARC) | **Dr. Bernhard Lüers,** FEV Europe |
| | **Ongoing projects** | |
| **1324** | CFD Analysis of Particle Formation // BMWi/AiF // 01-07-2018 to 30-09-2021 | **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<br>**Andreas Döring,** MAN Energy Solutions |
| **1372** | Cold Start CNG Catalyst // BMWi/AiF // 01-08-2019 to 31-12-2021 | **Dr. Michael Fischer,** Tenneco |
| **1391** | Cleaning Mechanisms in the Exhaust Path // BMWi/AiF // 01-01-2020 to 31-12-2021 | **Raimund Vedder,** Atlanting |
| **1398** | TWC Impact on Particulate Properties // BMWi/AiF // 01-03-2020 to 28-02-2022 | **Dr. Julie Le Louvetel-Poilly,** Toyota Motor Europe |
| **1400** | Deposits from AdBlue II // CORNET, FVV-EM // 01-04-2020 to 31-03-2022 | **Raimund Vedder,** Atlanting |
| **1412** | Zero Impact Tailpipe Emission Powertrains // FVV-EM // 01-09-2020 to 31-08-2022 | **Dr. Frank Bunar,** IAV |

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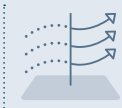
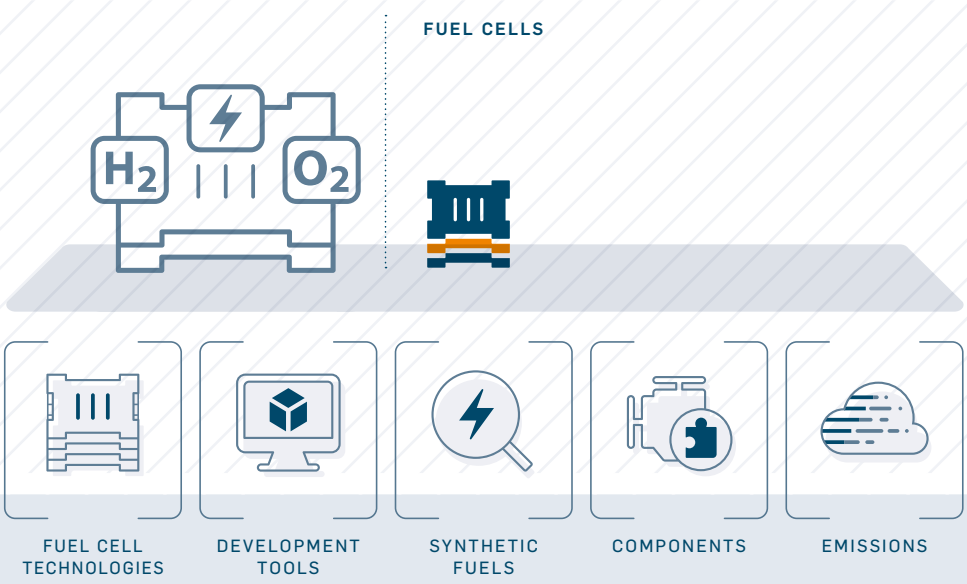


| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Completed projects** | |
| **1268** | Ash Behaviour in Open-pore Filters // BMWi/AiF // 01-03-2017 to 29-02-2020 | **Dr. Bernhard Lüers,** FEV Europe |
| **1292** | Ash Behaviour in Wall-flow Filters // BMWi/AiF // 01-12-2017 to 30-11-2020 | **Dr. Bernhard Lüers,** FEV Europe |
| **1294** | 2030+ Requirements on Emission Control Systems – MD/HD // FVV-EM // 01-02-2018 to 31-07-2020 | **Dr. Claus Görsmann,** Johnson Matthey<br>**Dr. Uwe Zink,** BASF Catalysts Germany |
| **1315** | Oxygen Storage // FVV-EM // 01-07-2018 to 30-09-2020 | **Jeremias Bickel,** Robert Bosch |
| **1319** | $H_2$-DeNOx // FVV-EM // 01-06-2018 to 31-12-2020 | **Dr. Frank Bunar,** IAV |
| **1333** | FaconSCR // FVV-EM // 01-11-2018 to 31-10-2020 | **Dr. Harald Beck,** MAN Truck & Bus<br>**Dr. Andreas Roppertz,** Emission Partner |
| **1359** | $NO_2$ with Diesel E-Fuels // BMWi/AiF, FVV-EM // 01-05-2019 to 31-03-2021 | **Dr. Bernhard Lüers,** FEV Europe |

# Fuel Cells

PLANNING GROUP 7




**COORDINATOR**

Dr. Volker Formanski,
BMW

**PROJECT MANAGEMENT**

Martin Nitsche, FVV

**PG7 ONLINE**

FVV

THEMIS

**RESEARCH PRIORITIES**

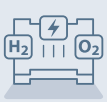
Planning group 7, ›Fuel Cells‹, is dedicated to the following topics:

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

And tackles the following lines of research / focuses:

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

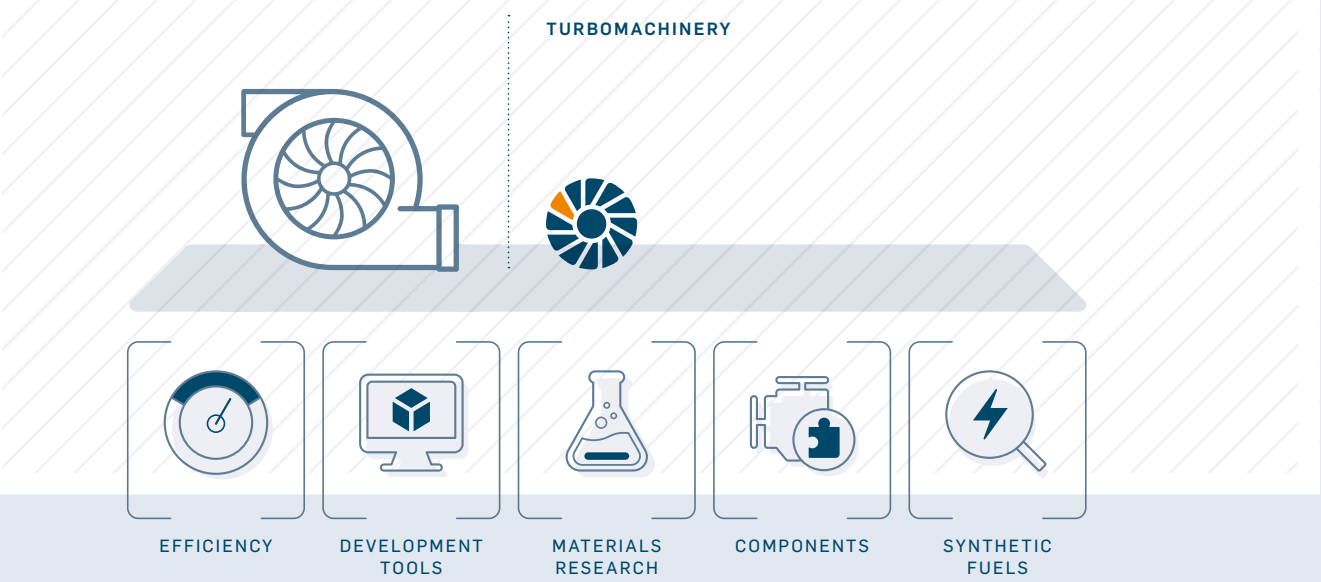
## PG 7 | RESEARCH PROJECTS




| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| | **Planned projects** | |
| **M0217** | Innovative FC Air Supply // BMWi/AiF | **Dr. Oliver Berger,** Volkswagen |
| **M0517** | Simulation/Balance of Plant // FVV-EM | **Stefan Rothgang,** Pierburg |
| **M0721** | Minimally invasive Diagnostics for Liquid-water Morphology | **Sarah Städtler,** AUDI |
| **M0817** | Integrated Fuel Cell Simulation // FVV-EM | **Stefan Bohatsch,** Volvo Car |
| **M0921** | Model Development of Fuel Cell PEM Membranes | **Marius Zubel,** FEV Europe |
| **M1717** | Simulation/Vehicle Hybridisation // BMWi/AiF | **Dr. Thorsten Schnorbus,** FEV Europe |
| **M1917** | Methodology for SoH Detection // BMWi/AiF | **Richard Schauperl,** AVL List |
| **M2317** | Fuel Cells Air Contaminations (Study) // FVV-EM | **Markus Kersting,** IAV |
| **M2519** | Cooling Fuel Cells II // BMWi/AiF | **Dr. Markus Kaiser,** nexiss |
| **M4120** | Cleaning of Dielectric Cooling Fluids | **Dr. Michael Harenbrock,** MANN+HUMMEL |
| | **Ongoing projects** | |
| **1406** | Energy Recovery in Fuel Cell Applications // FVV-EM // 01-09-2020 to 31-08-2022 | **Dr. Dirk Jenssen,** Volkswagen |
| **1411** | FC Cold Start // FVV-EM // 01-09-2020 to 31-08-2022 | **Dr. Stefan Kaimer,** Ford-Werke |
| | **Completed projects** | |
| **1295** | Cathode Air Quality Requirements for LT-PEM Fuel Cells // FVV-EM // 15-01-2018 to 31-12-2020 | **Dr. Michael Harenbrock,** MANN+HUMMEL |
| **1298** | Fuel Cell System Simulation – Membrane Water Management // FVV-EM // 01-01-2018 to 31-01-2020 | **Dr. Helge Tielbörger,** Siemens Industry Software |
| **1362** | Corrosion Products and Contaminations in the Fuel Cell Hydrogen System // FVV-EM // 01-08-2019 to 31-12-2020 | **Dr. Christian Lucas,** Volkswagen |
| **1366** | Generic Fuel Cell Stack // FVV-EM // 01-09-2019 to 30-06-2020 | **Dr. Jan Haußmann,** Schaeffler Technologies |

# Turbomachinery

PLANNING GROUP T




**COORDINATOR**

Dr. Dirk Hilberg,
Rolls-Royce Deutschland

**PROJECT MANAGEMENT**

Dirk Bösel, FVV

**PGT ONLINE**

FVV

THEMIS

**RESEARCH PRIORITIES**

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

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

And tackles the following lines of research / focuses:

- → Aerodynamics of turbomachines
- → 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** | |
| **1444** | Modelling of Metal-graphite Composites // BMWi/AiF | **Dan Roth-Fagaraseanu,** Rolls-Royce Deutschland |
| **836 II** | Alternative Metals for Plain Bearings // BMWi/AiF | |
| **T0118** | Flexible HP-Turbines // DFG, FVV-EM | **Christoph Lyko,** Rolls-Royce Deutschland |
| **T0121** | Stability of IN718 at High Service Times // BMWi/AiF | **Dr. Dirk Kulawinski,** Siemens Energy<br>**Dr. Torsten Neddemeyer,** Siemens Energy |
| **T0219** | Thermal Effects and Rotor Stability for Foil Bearings // BMWi/AiF | **Dr. Joachim Schmied,** Delta JS |
| **T0220** | Sensitivity and Probabilistic (ComDynA_SP) // BMWi/AiF | **Dr. Andreas Hartung,** MTU Aero Engines |
| **T0221** | Optimization with Frequency Domain Based Methods // FVV-EM | **Dr. Stephan Behre,** MTU Aero Engines |
| **T0321** | Acoustoelastically Coupled Compressors // BMWi/AiF | **Klaus Steff,** Siemens Energy |
| **T0419** | Thermo-mechanically Induced Stress Gradients // BMWi/AiF | **Frank Vöse,** MTU Aero Engines |
| **T0420** | Modelling of Primary Atomisation Using SPH // FVV-EM | **Dr. Ruud L.G.M. Eggels,** Rolls-Royce Deutschland |
| **T0421** | Time Dependent Crack Closure // FVV-EM, DFG | **Henning Almstedt,** Siemens |
| **T0521** | Simulation-Crack Behavior Coarse-Grain II // BMWi/AiF | **Markus Fried,** MTU Aero Engines |
| **T0618** | Hot Gas Ingestion into Wheel Cavities // BMWi/AiF | **Dr. Marco Konle,** MTU Aero Engines |
| **T0621** | Reduced-order Model for Rim Seal Design // BMWi/AiF | **Dr. Karsten Kusterer,** B&B-AGEMA |
| **T0719** | Industrial Application of Unsteady Flow Solvers // BMWi/AiF | **Dr. Stephan Behre,** MTU Aero Engines |
| **T0721** | Nonlinear Dynamic Contact Identification // FVV-EM, DFG | **Dr. Andreas Hartung,** MTU Aero Engines |
| **T0818** | Lubricant Oil Supply Model for Axial Plain Bearings // BMWi/AiF | **Michael Bottenschein,** Voith Hydro Holding |
| **T0820** | Inverse Dynamic Analysis // DFG, FVV-EM | **Dr. Andreas Hartung,** MTU Aero Engines |
| **T0919** | AI-based Material Data Analysis // BMWi/AiF | **Alexander Schult,** Rolls-Royce Deutschland |
| **T0920** | Creep-fatigue Crack behavior of welded joints II // AVIF | **Dr. Shilun Sheng,** Siemens Energy |
| **T1019** | Aerodynamics of Tandem Stators III // BMWi/AiF | **Dr. Henner Schrapp,** Rolls-Royce Deutschland |
| **T1119** | Thermal TC Bearing Interaction // BMWi/AiF, FVV-EM | **Uwe Tomm,** BorgWarner Turbo Systems |
| **T1120** | Contact Mistuning // BMWi/AiF | **Dr. Andreas Hartung,** MTU Aero Engines |
| **T1419** | Mixing Processes of Jet in Crossflow Configurations in Combustors // BMWi/AiF | **Dr. Marco Konle,** MTU Aero Engines |
| **T1420** | Aeroelastic Cascade DELTA II // CORNET | **Dr. Sabine Schneider,** Rolls-Royce Deutschland |
| **T1519** | Calculation Model for Wet Compression // DFG, FVV-EM | **Christoph Biela,** Siemens |

| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| **T1603** | Qualification of Lead-free Multilayer Plain Bearings | **Marc Witte,** Rickmeier |
| **T1618** | Smart Hybrid Plain Bearings | **Sebastian Wolking,** SAINT-GOBAIN PERFORMANCE PLASTICS PAMPUS |
| **T1619** | Correlation-Framework for NDE Data with Defects // BMWi/AiF | **Dr. Christian Amann,** Siemens Energy Global |
| **T1629** | Process Media-lubricated Plain Bearings // BMWi/AiF | **Dr. Christoph Weißbacher,** GTW Gleitlagertechnik Weißbacher |
| **T1918** | Combined Dynamical Analyses (ComDynA): Validation // BMWi/AiF | **Dr. Andreas Hartung,** MTU Aero Engines |

## Ongoing projects

| | | |
|---|---|---|
| **1232** | Secondary Flow Influence // FVV-EM // 01-10-2016 to 31-12-2021 | **Dr. Stephan Behre,** MTU Aero Engines |
| **1270** | Self-excited Combustion Dynamics in Multiburner Systems (ROLEX) // FVV-EM // 01-05-2017 to 31-10-2021 | **Dr. Michael Huth,** Siemens |
| **1273** | Radial Turbine Temperature Field II // BMWi/AiF // 01-04-2017 to 31-03-2022 | **Dr. Tom Heuer,** BorgWarner Turbo Systems Engineering |
| **1325** | Crack Behaviour Multiaxial (ARIMA) // BMWi/AiF // 01-10-2018 to 31-03-2022 | **Dr. Andreas Fischersworring-Bunk,** MTU Aero Engines |
| **1326** | Stress Relaxation Behaviour II // BMWi/AiF // 01-04-2018 to 31-03-2022 | **Dr. Martin Reigl,** GE Power |
| **1329** | HT-Threshold Calculation Methods // BMWi/AiF // 01-10-2018 to 31-03-2022 | **Frank Vöse,** 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 |
| **1351** | TMF Crack Path Calculation for Turbocharger Hot Parts // BMWi/AiF // 01-02-2019 to 30-09-2022 | **Dr. Andreas Koch,** Rolls-Royce Solutions |
| **1353** | Wheel-space Sealing II // BMWi/AiF // 01-04-2019 to 30-09-2021 | **Dr. Karsten Kusterer,** B&B-AGEMA |
| **1354** | Radial Compressor with Wide Operating Range // BMWi/AiF // 01-02-2019 to 31-07-2021 | **Dr. Matthias Schleer,** Howden Turbo |
| **1356** | Tilting Pad Bearing Dynamics // FVV-EM, BMWi/AiF // 01-03-2019 to 31-08-2021 | **Klaus Steff,** Siemens Energy |
| **1358** | Dynamic of Swirl and Jet Flames // FVV-EM // 01-04-2019 to 31-03-2022 | **Dr. Lukasz Panek,** Siemens |
| **1360** | Unsteady Tandem Flow // FVV-EM, DFG // 01-10-2019 to 30-09-2021 | **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 Global |

↓ Continue on the next page

| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| **1373** | Dynamics of TC Rotors with Coupled Bearings // BMWi/AiF // 01-10-2019 to 31-03-2022 | **Thomas Klimpel,** ABB Schweiz |
| **1375** | Brush Seals – Statistical Approach // FVV-EM // 01-12-2019 to 31-05-2022 | **Joris Versluis,** MTU Aero Engines |
| **1380** | Probabilistic Lifetime Model Comparison – Creep-Fatigue // AVIF // 01-01-2020 to 31-12-2022 | **Henning Almstedt,** Siemens |
| **1383** | Acoustic Emission into Discharge Pipes II // DFG, FVV-EM // 01-02-2020 to 31-07-2022 | **Dr. Irhad Buljina,** MAN Energy Solutions |
| **1386** | Turbo High Temperature Steel // BMWi/AiF // 01-02-2020 to 31-01-2023 | **Dr. Markus Dinkel,** Schaeffler Technologies |
| **1388** | Blade Forces and System Damping // BMWi/AiF // 01-01-2020 to 30-06-2022 | **Dr. Thomas Hildebrandt,** NUMECA |
| **1389** | Intentional Mistuning // BMWi/AiF // 01-01-2020 to 30-06-2022 | **Thomas Winter,** PBS Turbo |
| **1390** | Aluminum High Temperature Fatigue // BMWi/AiF // 01-01-2020 to 31-03-2023 | **Dr. Reiner Böschen,** Rolls-Royce Solutions |
| **1392** | Material Applications FeAl (WAFEAL) // BMWi/AiF // 01-01-2020 to 30-09-2022 | **Dan Roth-Fagaraseanu,** Rolls-Royce Deutschland |
| **1397** | Prediction of Gas Turbine Emissions // FVV-EM, DFG // 01-04-2020 to 31-03-2022 | **Dr. Ruud L.G.M. Eggels,** Rolls-Royce Deutschland |
| **1401** | LPBF High-Temperature Lifetime // BMWi/AiF // 01-05-2020 to 30-04-2023 | **Dr. Roland Herzog,** MAN Energy Solutions |
| **1421** | Dynamic of Swirl and Jet Flames II // DFG, FVV-EM // 01-12-2020 to 30-11-2023 | **Dr. Lukasz Panek,** Siemens |
| **1422** | Extended Operation Range of YSZ // FVV-EM, DFG // 01-11-2020 to 31-10-2023 | **Dr. Arturo Flores Renteria,** Siemens Energy |
| **1423** | Combined Dynamical Analyses (ComDynA): Analytics // BMWi/AiF // 01-10-2020 to 30-09-2022 | **Dr. Andreas Hartung,** MTU Aero Engines |
| **1424** | Fill Factor Influence // BMWi/AiF // 01-10-2020 to 31-03-2023 | **Dr. Christoph Weißbacher,** GTW Gleitlagertechnik Weißbacher |
| **1425** | Bidirectional Aeromechanical Coupling II // DFG, FVV-EM // 01-11-2020 to 31-10-2022 | **Dr. Andreas Hartung,** MTU Aero Engines |
| **1432** | Particle Transport in Compressor Casing Channels // FVV-EM // 01-03-2021 to 28-02-2022 | **Prof. Dr. Marius Swoboda,** Rolls-Royce Deutschland |
| **1437** | Squeeze Film Dampers II // BMWi/AiF // 01-01-2021 to 30-06-2023 | **Thomas Klimpel,** ABB Schweiz |
| **1438** | Heat Transfer Reduction at Turbine Casing Parts // FVV-EM // 01-07-2021 to 28-02-2022 | **Norbert Pieper,** Siemens Energy |
| **1439** | Fuel Cell Compressor Design // BMWi/AiF // 01-03-2021 to 31-08-2023 | **Dr. Thomas Hildebrandt,** NUMECA |
| **1440** | Constraint Effect in Component Design // BMWi/AiF // 01-03-2021 to 31-08-2023 | **Dr. Christian Amann,** Siemens Energy Global |

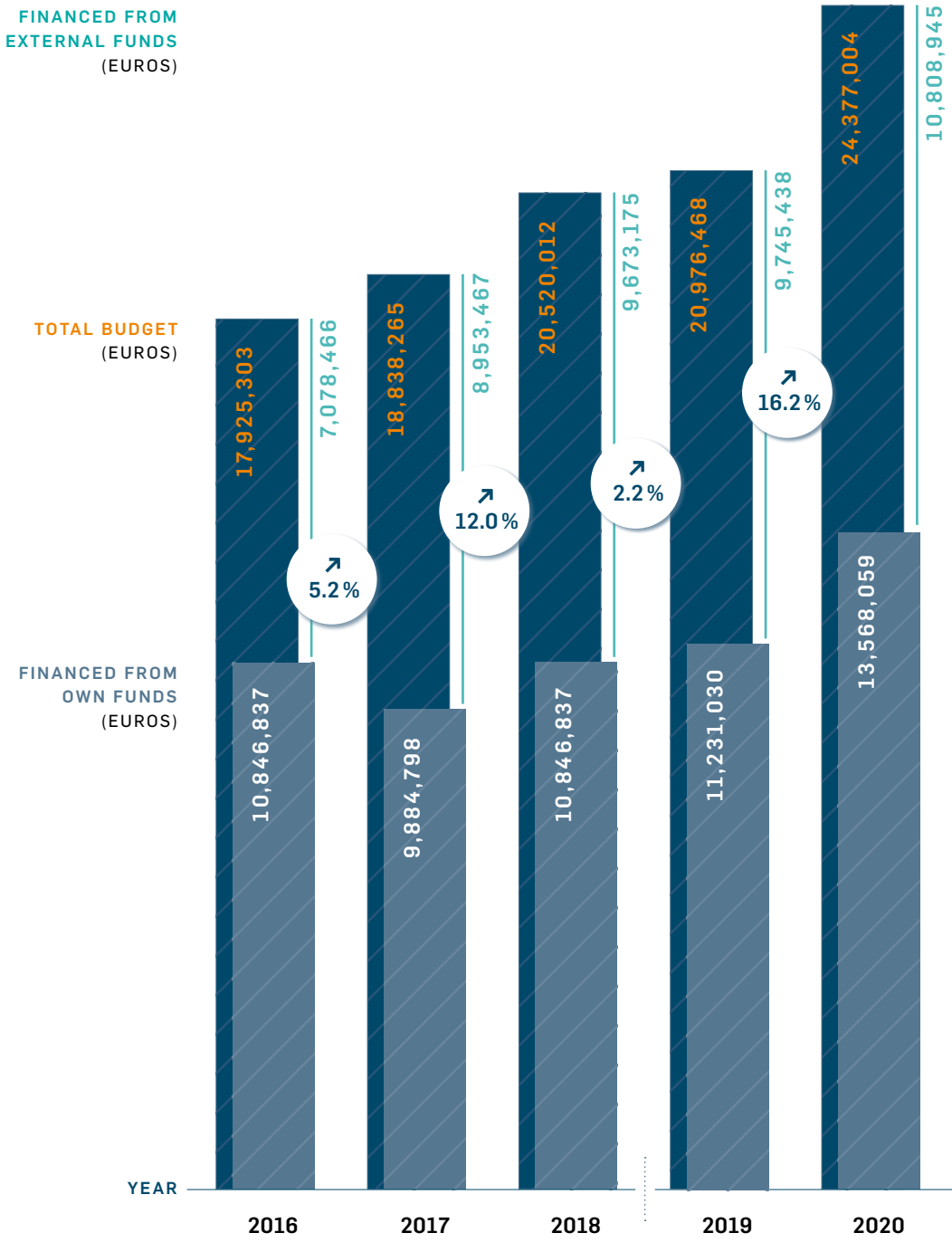
| NO | TITLE // FUNDING ORGANISATION // DURATION | PROJECT COORDINATOR |
|---|---|---|
| **1443** | Centrifugal Compressor in Flexible Operation // BMWi/AiF, FVV-EM // 01-03-2021 to 29-02-2024 | **Dr. Matthias Schleer,** Howden Turbo |
| **836 I** | Alternative Metals for Plain Bearings // BMWi/AiF // 01-06-2018 to 31-07-2021 | **Martin Limmer,** RENK |
| **847 I** | Microstructuring of Plain Bearing Surfaces // BMWi/AiF // 01-11-2018 to 31-10-2021 | **Dr. Oliver Alber,** MAN Energy Solutions |
| **880 I** | Material Qualification // BMWi/AiF // 01-11-2019 to 30-04-2022 | **Martin Limmer,** RENK |
| **915 I** | Plain Bearing Lubricant Qualification // BMWi/AiF // 01-11-2020 to 31-01-2023 | **Cornelia Recker,** Klüber Lubrication München |

## Completed projects

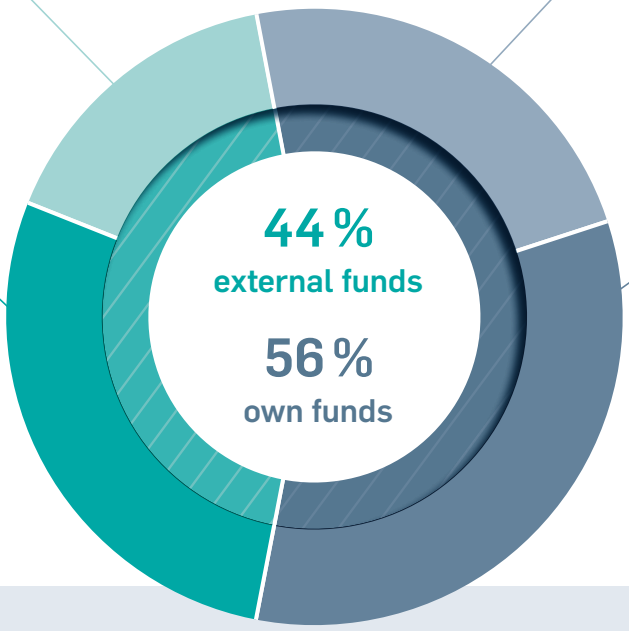
| | | |
|---|---|---|
| **1251** | Simulation-Crack Behaviour-Coarse Grain // BMWi/AiF // 01-11-2016 to 31-10-2020 | **Markus Fried,** MTU Aero Engines |
| **1252** | Failure Criteria for Plain Bearings II // FVV-EM, DFG // 01-12-2016 to 31-08-2020 | **Dr. Ümit Mermertas,** Siemens |
| **1259** | Thick-walled Castings II // AVIF // 01-01-2017 to 31-12-2020 | **Dr. Martin Reigl,** GE Power |
| **1261** | Aerodynamics of Tandem Stators II // BMWi/AiF // 01-01-2017 to 30-06-2021 | **Dr. Henner Schrapp,** Rolls-Royce Deutschland |
| **1279** | Design and Implementation of the FVV Industrial Compressor // FVV-EM // 01-07-2017 to 30-06-2021 | **Dr. Matthias Schleer,** Howden Turbo |
| **1288** | Lifing Methods, Multiaxial and Anisothermal (LEBEMAN) // BMWi/AiF // 01-09-2017 to 31-05-2021 | **Dr. Hartmut Schlums,** Rolls-Royce Deutschland |
| **1291** | Squeeze Film Dampers – Optimised Outer Bearing Support // BMWi/AiF // 01-09-2017 to 31-10-2020 | **Thomas Klimpel,** ABB Schweiz |
| **1299** | Notch Support Cast Steel // AVIF // 01-01-2018 to 31-12-2020 | **Henning Almstedt,** Siemens Energy Global |
| **1308** | Bidirectional Aeromechanical Coupling // FVV-EM, DFG // 01-06-2018 to 31-05-2020 | **Dr. Andreas Hartung,** MTU Aero Engines |
| **1330** | Metal-graphite Composites for Plain Bearings (MeGraV) // BMWi/AiF // 01-09-2018 to 31-12-2020 | **Dan Roth-Fagaraseanu,** Rolls-Royce Deutschland |
| **1331** | Aeroelastic Cascade DELTA // CORNET // 01-06-2018 to 30-04-2021 | **Dr. Sabine Schneider,** Rolls-Royce Deutschland |
| **1337** | Circumferentially Inhomogeneous Centrifugal Compressor Flow // BMWi/AiF // 01-12-2018 to 31-05-2021 | **Dr. Thomas Hildebrandt,** NUMECA |
| **1399** | Validation Thermally-induced Stress Gradients (TISG) // FVV-EM // 01-04-2020 to 30-09-2020 | **Frank Vöse,** MTU Aero Engines |
| **1427** | COMBROS-R/A Software Documentation in English // FVV-EM // 01-01-2021 to 30-04-2021 | **Klaus Steff,** Siemens Energy |

# 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 120.**

## YEAR-OVER-YEAR ANALYSIS

| | 2019 | 2020 | Change |
|---|---|---|---|
| MEMBERSHIP CONTRIBUTIONS | 6,429,950 | 7,983,185 | ↗ 24.2 % |
| IN-KIND CONTRIBUTIONS | 4,801,080 | 5,584,874 | ↗ 16.3 % |
| **TOTAL OWN FUNDS** | **11,231,030** | **13,568,059** | ↗ 20.8 % |
| BMWi/AiF | 6,658,718 | 6,929,079 | ↗ 4.1 % |
| OTHER SPONSORS | 3,086,720 | 3,879,866 | ↗ 25.7 % |
| **TOTAL EXTERNAL FUNDS** | **9,745,438** | **10,808,945** | ↗ 10.9 % |

# Research support

SPONSORS

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

A SELECTION
OF OUR SPONSORS

## BMWi/AiF –
### Federal Ministry for Economic Affairs and Energy/German Federation of Industrial Research Associations

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

www.aif.de/english

## DFG –
### German Research Foundation

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

www.dfg.de/en

## CORNET –
### COllective Research NETworking

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

www.cornet.online

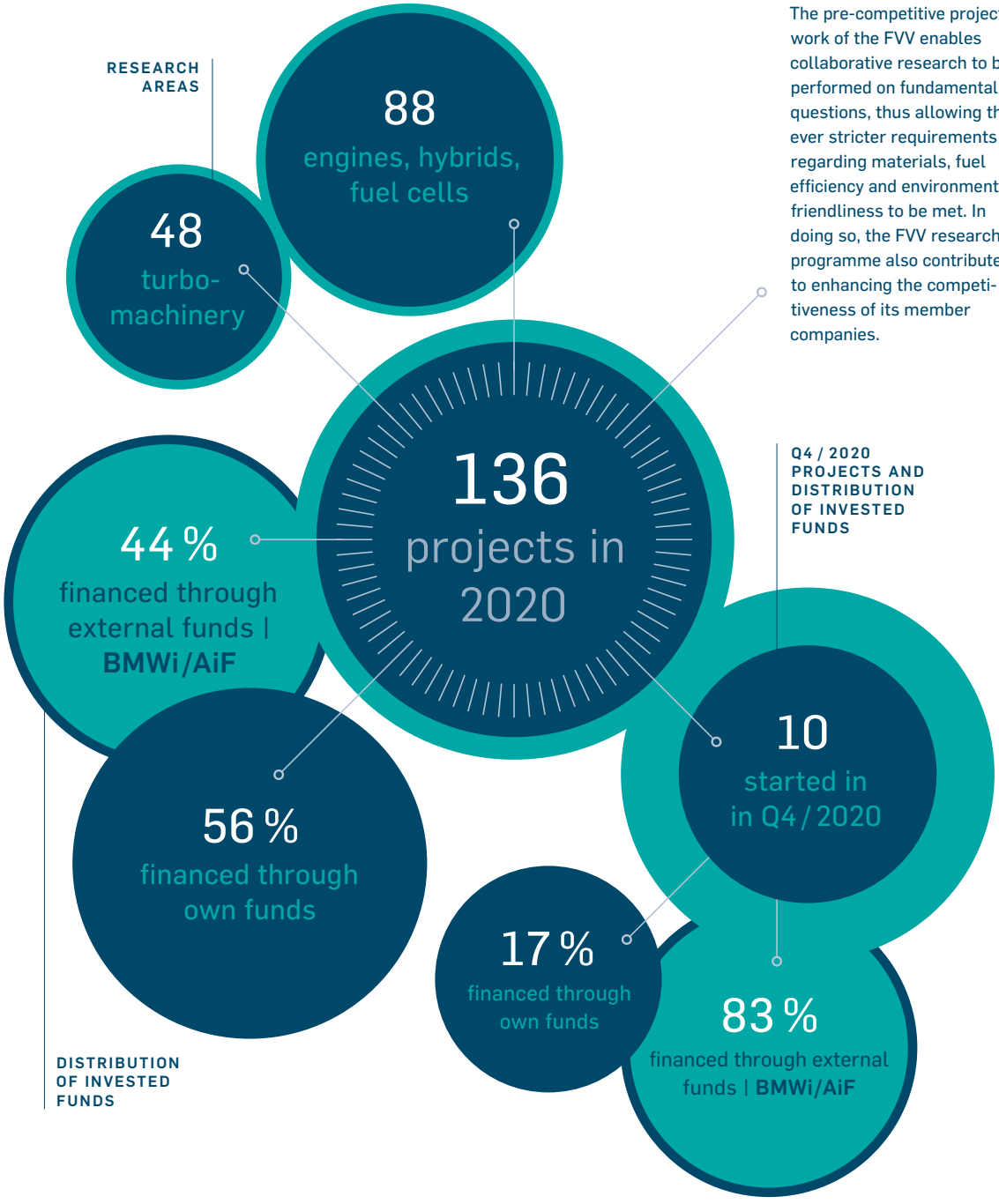
## AVIF –
### Research Association of the Working Group of the Iron- and Metal-Processing Industry

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

www.avif-forschung.de

# Realised projects

BREAKDOWN




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

# Research partners Engines

**DISTRIBUTION OF FUNDS** | BMWI/AIF AND OWN FUNDS

| LOCATION | EUROS | % |
|---|---|---|
| Stuttgart | 2,796,441 | 22.7 % |
| Aachen | 1,589,626 | 12.9 % |
| Darmstadt | 1,101,035 | 8.9 % |
| Karlsruhe | 1,081,716 | 8.8 % |
| Braunschweig | 771,651 | 6.3 % |
| Magdeburg | 576,273 | 4.7 % |
| Cottbus | 355,716 | 2.9 % |
| Hanover | 345,429 | 2.8 % |
| Berlin | 333,437 | 2.7 % |
| Dresden | 285,438 | 2.3 % |
| Freiberg | 251,352 | 2.0 % |
| Hamburg | 235,790 | 1.9 % |
| Zurich (CH) | 222,733 | 1.8 % |
| Munich | 219,096 | 1.8 % |
| Chemnitz | 203,036 | 1.7 % |
| Erlangen | 193,909 | 1.6 % |
| Coburg | 182,160 | 1.5 % |
| Duisburg | 175,158 | 1.4 % |
| Heidelberg | 148,950 | 1.2 % |
| Rostock | 140,219 | 1.1 % |
| Bremen | 138,690 | 1.1 % |
| Vienna (AT) | 115,044 | 0.9 % |
| Weimar | 109,530 | 0.9 % |
| Oldenburg | 100,097 | 0.8 % |
| Ulm | 99,710 | 0.8 % |
| Graz (AT) | 91,790 | 0.7 % |
| Jülich | 79,240 | 0.6 % |
| Freiburg | 67,345 | 0.6 % |
| Others < 60,000 € | 321,167 | 2.6 % |
| | **12,331,778** | |

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

## RTD PERFORMERS

# Research partners Turbomachinery

**DISTRIBUTION OF FUNDS** | BMWI/AIF AND OWN FUNDS

| LOCATION | EUROS | % |
|---|---|---|
| Aachen | 665,553 | 23.1 % |
| Darmstadt | 646,245 | 22.4 % |
| Berlin | 428,576 | 14.9 % |
| Stuttgart | 289,561 | 10.0 % |
| Clausthal | 161,528 | 5.6 % |
| Freiburg | 151,108 | 5.2 % |
| Karlsruhe | 119,030 | 4.1 % |
| Cottbus | 93,632 | 3.2 % |
| Bremen | 91,090 | 3.2 % |
| Munich | 65,250 | 2.3 % |
| Hanover | 55,783 | 1.9 % |
| Freiberg | 41,150 | 1.4 % |
| Dresden | 26,568 | 0.9 % |
| Bochum | 19,318 | 0.7 % |
| Wuppertal | 15,000 | 0.5 % |
| Braunschweig | 13,134 | 0.5 % |
| | **2,882,526** | |

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

# RTD PERFORMERS

# Annual statement of accounts

## BALANCE SHEET

| ASSETS SIDE | 31 DECEMBER 2020 EUROS | 31 DECEMBER 2020 EUROS | 31 DECEMBER 2019 EUROS | 31 DECEMBER 2019 EUROS |
|---|---|---|---|---|
| **A. Current assets** | | | | |
| I. Receivables and other assets | | | | |
| 01. Advance payments | 3,694,060.08 | | 2,765,042.77 | |
| 02. Other assets | 483,337.33 | | 35,860.25 | |
| | | 4,177,397.41 | | 2,800,903.02 |
| II. Cash on hand and bank balances | | 4,587,778.68 | | 7,375,920.50 |
| **B. Non-current assets** | | | | |
| I. Securities | | 1,082,113.61 | | 81,386.13 |
| | | 9,847,289.70 | | **10,258,209.65** |

| LIABILITIES SIDE | 31 DECEMBER 2020 EUROS | 31 DECEMBER 2020 EUROS | 31 DECEMBER 2019 EUROS | 31 DECEMBER 2019 EUROS |
|---|---|---|---|---|
| **A. Amount carried forward for research activities** | | | | |
| 01.a Own funds | 5,576,074.39 | | 7,204,300.19 | |
| 01.b Reserves of own funds | 224,000.00 | | 224,000.00 | |
| 02. External funds | 1,413,975.79 | | 17,658.97 | |
| | | 7,214,050.18 | | 7,445,959.16 |
| **B. Provisions** | | | | |
| 01. Provisions for pensions and similar obligations | 376,720.00 | | 281,820.00 | |
| 02. Other provisions | 147,503.03 | | 123,963.94 | |
| | | 524,223.03 | | 405,783.94 |
| **C. Liabilities** | | | | |
| 01. Liabilities to research institutes | 2,083,569.04 | | 2,363,231.85 | |
| 02. Other liabilities | 25,447.45 | | 43,234.70 | |
| | | 2,109,016.49 | | 2,406,466.55 |
| | | 9,847,289.70 | | **10,258,209.65** |

# CONFIRMATION OF AUDITOR

GGV

Wirtschaftsprüfungsgesellschaft
Steuerberatungsgesellschaft





**4. Schlussbemerkung und Bescheinigung**

Wir haben die Jahresrechnung unter Einbeziehung der Buchführung des Forschungsvereinigung Verbrennungskraftmaschinen e.V., Frankfurt am Main, bestehend aus der Vermögensübersicht zum 31. Dezember 2020 und der Ertrags- und Aufwandsrechnung für die Zeit vom 1. Januar bis 31. Dezember 2020, mit Ausnahme der zu statistischen Zwecken erfassten Sachleistungen der Mitglieder, geprüft.

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

Nach dem Ergebnis unserer Arbeiten erteilen wir der als Anlagen I und II beigefügten Jahresrechnung des Forschungsvereinigung Verbrennungskraftmaschinen e.V., Frankfurt am Main, für das Rechnungsjahr vom 1. Januar bis zum 31. Dezember 2020 die folgende Bescheinigung:

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

Frankfurt am Main, den 20. Mai 2021

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

GGV GmbH
Wirtschaftsprüfungsgesellschaft
Steuerberatunggesellschaft

Gäbler
Wirtschaftsprüfer

31. Dezember 2020 FVV

Achim Königstein, Opel Automobile GmbH, and Prof. Dr. Christoph Brands, Schaeffler Technologies AG & Co. KG, conducted the voluntary internal audit for the 2020 financial year on 27 August 2021. 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.



You may use the QR code to download an electronic copy of the FVV 2021 Annual Magazine or order the print version at kommunikation@fvv-net.de.

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

**→ www.fvv-net.de/en | Media**

PUBLISHER

Forschungsvereinigung
Verbrennungskraftmaschinen e.V.
Lyoner Strasse 18
60528 Frankfurt / M., Germany
www.fvv-net.de/en
www.primemovers.de/en

EDITION

11 | 2021

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EDITORIAL AND
PRINT LAYOUT DESIGN

Lindner & Steffen GmbH, Nastätten

TRANSLATION

fine Expression GbR, Darmstadt

PRINT

DFS Druck Brecher GmbH, Köln

PrimeMovers. 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. PrimeMovers. is completed by FVV's annual report.

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