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Communication in Times of Crisis

Researchers at the TU Darmstadt are experimenting with technologies designed to empower the civilian population in times of crisis. They aim at establishing basic communications and means to share information, thus facilitating human cooperation and mutual aid even following wide-spread power and Internet outages.

Simple and robust signalling technology proves reliable in a crisis

Photo: Katrin Binner

By Boris Hänßler

Unknown hackers launched a malware attack on the Ukrainian national power grid in late 2016. The malicious software interfered with the control system and caused an hour-long power outage in parts of Kiev. In the last year, other hackers set their sights on the Domain Name Service (DNS) owned by Dyn, a US American service provider, knocking out several websites, including Netflix and Amazon for multiple hours. These are just two of the many examples that expose the vulnerability of today's high-tech society; and the German federal government regards attacks on our critical infrastructure as a latent danger.

Natural disasters or major emergencies can also isolate a region from the power grid and Internet, which is why the German Federal Office for Civil Protection and Disaster Assistance advises citizens to stockpile food supplies for crisis situations. However, the population at large dismisses this risk. What would happen if the power supply system and Internet really were to fail? Most people no longer have battery operated radios, and would be completely cut off from all information sources. "Despite our increasing dependence on infrastructure-based networks", warns Matthias Hollick, Professor on Security in Mobile Networks at the TU Darmstadt, "no backup plans exist. Civil protection and disaster assistance has even seen budget cuts in recent years. The authorities and armed forces are able to operate their communication networks for a considerable time, even in the absence of external power supply. In contrast, the civilian population would be mostly disconnected from any means of communications."

"How can we maintain communications using smartphones and existing sensors?"

That's why Hollick and his colleagues founded "Networked Infrastructureless Cooperation for Emergency Response" (NICER), an interdisciplinary research centre at the TU Darmstadt. Its core team consists of eleven professors, three post-doctoral researchers, sixteen research associates and six associate staff members. NICER is a joint project involving the Universities of Kassel and Marburg and receives some 4.5 million Euro in funding from the federal state of Hesse within the LOEWE programme. The basic idea is to network the population by means of infrastructureless information and communication technologies. To achieve this objective, NICER is focused on three key themes: the establishment of autonomous communication islands, the construction of bridges between the islands, and the operation of an overall network with special applications for use in crisis situations.

"We work on the basis of two possible scenarios", Hollick explains: "a major power outage across a vast area of the country, and a complex crisis situation such as the Fukushima Daiichi nuclear disaster. How can we maintain communications in such situations utilizing mobile devices such as smartphone and tablets? How could existing sensor systems be utilised to obtain a shared situation report?" One problem, according to Hollick, is the sheer volume of data that needs to be managed in a crisis situation. Everyone involved will want to communicate to check that their families are safe and well, to find out about the developing situation or to request assistance. Is there anyone with a pump who might be able to help in the event of a flood? Who has any spare blankets, medical supplies or food? "The general population possesses ample resources", says Hollick, "yet, they need to coordinate the distribution process".

That's why the researchers want to establish communication islands. An island may be an urban district or a village. All mobile devices within the island would be able to communicate with one another without the need for any underlying infrastructure. Moreover, in case of large-scale disasters, there may be several such islands all existing independently of one another. Additional bridges would then need to be established to enable communications between islands. For example, a mobile device carried by a resident of one island who happens to travel to another island could

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function as a bridge between the two areas. It would store information destined for recipients in the other island and physically carry it there, thus enabling the exchange of information over longer distances.

One difficulty in setting up the islands is the fact that cellular base stations, which function as central coordination nodes, would no longer work. Mobile devices can only communicate directly over short distances and therefore depend on other devices that act as forwarding and distribution nodes. Data traffic management is particularly challenging following this loss in coordination capabilities. Still, to enable the prioritisation of specific data types, devices need to be able to exchange status information. Hollick's group has developed a robust, ultra-low-lateny forwarding mechanism for such status information exchanges, in which the signal emitted from a given device is picked up and broadcast simultaneously by all devices in the immediate vicinity. The message propagation can be compared with the ring waves formed when throwing a stone into a pond. The collaboration of the involved devices needs to be precise enough for the emitted signals to overlap constructively – a level of precision that the researchers also want to achieve on standard commercial devices.

To ensure that the collaboration also functions in an energy-efficient manner, the NICER researchers have been re-engineering various mobile devices in their "Emergency Response Lab" to increase their performance. For instance, each device is equipped with a so-called firmware, which is the software empowering the processors of the radio module. Under standard operating conditions, the firmware forwards incoming data packets either to the operating system or application software. After processing, they are dispatched to the intended recipient again via the firmware and radio module. "However", Hollick explains, "if we succeed in managing the communications on the radio module processors, we could cut out several steps. Simple data packets could be processed in fractions of milliseconds, whereas using the operating system would take orders of magnitude longer. That's a significant gain if we are operating hundreds of devices." Confining the processing to the radio module also saves power, as it is no longer necessary to power up the main processor. This would extend the battery life of the devices in question – important when the power grid is down. In order to be able to utilise the firmware in this way, mobile devices would simply require a standardised emergency operating mode, which would kick in during crisis situations. The scientists are also looking into ways of utilising the various data available within a given island to produce a shared situation report: what sensors are available? Which of them would need to be queried to produce an accurate overview of the situation without overloading the network? Signal processing experts and robotics researchers are jointly investigating how to process this sensor data. To this end they build on the communication mechanisms for interaction with the rescue robots, which could be deployed in particular challenging environments such as for instance nuclear facilities following an accident.

Last, but not least, the services that should be available within each island are also a subject of research – Apps that, for example, provide citizens with situational updates or information about relief resources. The researchers are developing ways of operating the Apps distributed across the emergency network, thus making them resilient to infrastructure outages but also to the failure of individual devices. Hollick concludes: "We're hoping that solutions based on the NICER research will soon be available to everybody. This facilitates that the affected population has the means to help themselves under catastrophic circumstances literally in its hands – namely by making use of the mobile devices they own already."

The author is a technology journalist.

Photo: Katrin Binner

Professor Matthias Hollick is a researcher and teacher at the Department of Computer Science

Surgical Robots with a Deft Touch

An abdominal surgery robot developed at the TU Darmstadt should take the strain off surgeons and increase the treatment success rate. The artificial assistant works with a particularly sensitive touch thanks to its innovative sensor technology.

Photo: Katrin Binner

The FLEXMIN robot and some of the project team (from left to right): Dr. Christian Hatzfeld, Professor Roland Werthschützky, Johannes Bilz, and Professor Helmut F. Schlaak

By Uta Neubauer

Whether it's self-driving cars, autonomous vacuum cleaners or humanoid mechanical entities at the hotel reception desk, robots are finding their way into our daily lives. "They are also increasingly in demand in the field of medicine", says Dr. Christian Hatzfeld, a post-doctoral candidate at the TU Darmstadt's Department of Mensuration and Sensor Engineering. As part of the FLEXMIN project, which is funded by the German Research Foundation, he and his colleagues are developing a robot to perform minimally invasive abdominal surgery specifically for the removal of rectal tumours. Minimally invasive surgery usually involves inserting the surgical instruments and a miniature camera into the body through minor incisions. By contrast, no incision is required for the Darmstadt system. The plan is to introduce the instrument attachment into the body cavity via the anus, i.e., via a natural orifice. "That is easier and safer for the patient", Hatzfeld explains, "because not making an incision speeds recovery and leaves no scar."

The surgical robot is operated by the surgeon using remote control technology. The surgeon tracks the procedure from a control panel and screen that shows the operation magnified and in real time. He or she can manually move the surgical instruments that have been inserted into the body via a number of pin-like grips and clamps. As the surgeon's relatively clumsy hand movements are converted to ultra precise movements at the robot end, the instruments can be accurately manoeuvred, opened and closed inside the body. In addition, the artificial aids also provide physical relief for surgeons: whereas minimally invasive surgical operations without robotic support sometimes require them to work bent over in cramped conditions for hours at a time, often resulting in muscular stress pain, the FLEXMIN provides them with a comfortable seating position. Another benefit: it will be possible, in future, to integrate auto pilot functionality with which standard tasks can be executed. The robot will then perform routine tasks, such as inserting and tying off surgical sutures, autonomously, again lessening the workload for surgeons.

Moreover, the system will also eliminate handshaking and other disruptive effects. Beating heart surgery is also feasible. The cardiac pulsations – according to the vision – could be compensated for by appropriate counter movements by the robot. The surgeon would then conduct the operation via an artificially stabilised screen image of a non-beating heart. As Professor Mario Kupnik, who has headed up the Department of Measurement and Sensor Technology for the past two years, emphasises: "robots enable surgical interventions that were previously impossible, and this functionality is also convincing physicians." Kupnik inherited the FLEXMIN project from his predecessor Professor Roland Werthschützky, who continues to provide support for the project.

Robots are already used for certain surgical interventions, especially prostatectomies, in many hospitals. However, current systems do have one drawback: They are unable to discern whether or not a tissue is

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soft and, therefore, – by contrast with an experienced surgeon – cannot feel the transition between nodular diseased tissue and healthy tissue. Nor are the artificial aids able to tell how hard they can pull a piece of tissue without damaging it. "The use of robots removes the direct contact between man and tool", Dr. Hatzfeld explains: "Yes, the surgeons sees what is happening on the screen, but receives no haptic feedback."

Even whilst working on his doctoral thesis at the TU Darmstadt, Hatzfeld was looking into haptic force perception and corresponding sensors, which provide artificial entities with a sense of touch of a sort. Thanks to the integration of sensors calibrated to match human cognition, the Darmstadt operation robot should now be able to sense things that not even the surgeon would notice. For example, the first fibres to rip in human tissue tend to tear in specific frequency ranges. An off-the-shelf vibration sensor is able to pick up these frequencies and issue an early warning of impending tissue damage. Other sensors that have been developed in the course of the project are able to amplify the forces working on a surgical instrument such that they can be felt by the operator and the control panel.

"... we are able to achieve extremely complex tasks via an existing orifice."

Another feature of the Darmstadt surgical intervention system is its exquisite sensitivity to operator input, which far outstrips anything achieved by previous robots. "In terms of our implementation of the sophisticated precision micro-mechanical elements and actuation component, we have pushed the very limits of technology", says Helmut F. Schlaak, Head of the Department of Microtechnology and Electromechanical Systems. The sophisticated robotic engineering systems were developed by his staff, whereby the Darmstadt-based engineers were able to benefit from a facility unique to their department, namely their own precision engineering workshop. Their specialists helped to design and manufacture the components for the robot, of which there is currently only a single example in existence. The advent of robots in surgery will usher in a new era in telemedicine, for in tomorrow's world it will make no difference whether the surgeon is sitting at the operating panel in the same room as the patient or somewhere in a completely different continent. "Specialists can be brought in via special data links to assist with particularly complicated procedures", Kupnik explains, but emphasises that robots will never render the presence of a surgeon in the operating theatre completely obsolete, as somebody will always need to be able to intervene in an emergency. The current thinking is that a surgeon would do the preparation and follow-up work for the operation on site and that the online specialist would only take over for the critical part. This would make it possible to carry out specialised operations, for which patients currently have to travel long distances, even in crisis regions and rural hospitals.

In relation to medical questions, the researchers at the TU Darmstadt are collaborating with the "Surgical Technology and Training" research group led by PD Dr. med. Andreas Kirschniak at the Eberhard Karls Universität Tübingen. The medical experts at Tübingen have tested the Darmstadt surgical robots in pilot projects in which they have, for example, succeeded in removing gall bladders from pig livers. "The foundations have been laid", says Kupnik: "Now it's all about finding commercial partners." Hatzfeld is optimistic, as robotics is considered a key issue in the health sector: "If a medical engineering company were to invest in our system and drive its development, and if everything goes smoothly with the approval process, then it could be in the operating theatre within a decade." It may also be found elsewhere by then, as the findings and insights gained through the FLEXMIN project are transferable.

"What's special about our system", Kupnik concludes, "is that we are able to achieve extremely complex tasks via an existing orifice without having to be present." Robots with a deft touch and sophisticated micro-mechanics are also needed for industrial plant servicing and other tasks. Experts would gladly make way for their robotic colleagues under certain circumstances, particularly when the tasks in hand are highly dangerous involving, for example, bomb disposal or repairs at nuclear power facilities.

The author is a science writer and holds a doctorate in Chemistry.

Medicine Meets Engineering

The Departments Microtechnology and Electromechanical Systems (Professor Helmut F. Schlaak) as well as Measurement and Sensor Technology (Professors Mario Kupnik and Roland Werthschützky) have been conducting long-term research into medical robot systems and measurement technology. The strategic Rhine-Main Universities Alliance (TU Darmstadt, Goethe University Frankfurt, and Johannes Gutenberg University Mainz) is providing an additional boost to the field of medical engineering. The teaching hospital facilities at the Universities of Frankfurt and Mainz in combination with the engineering sciences at the TU Darmstadt should strengthen the Rhine-Main region's profile as a centre of medical engineering excellence.

Current publications relating to the FLEXMIN Project:

C. Hatzfeld, C. Neupert, S. Matich et al: *A Teleoperated Platform for Transanal Single-Port Surgery: Ergonomics and Workspace Aspects, IEEE WorldHaptics Conference,* Fürstenfeldbruck, 2017.

S. Matich, C. Neupert, A. Kirschniak, H. F. Schlaak, P. P. Pott: *3-D force measurement using single axis force sensors in a new single port parallel kinematics surgical manipulator,* IEEE/RSJ IROS, Daejeon, 2016, 3665-3670.

C. Neupert, S. Matich, N. Scherping, M. Kupnik, R. Werthschützky, C. Hatzfeld: *Pseudo-Haptic Feedback in Teleoperation,* IEEE Trans. on Haptics, Vol. 9, No. 3, 397-408, July-Sept. 1 2016.

Sensitive Energy Cables in the Underground

The trouble-free operation of the energy distribution grid presents a challenge in the era of renewable energy sources. Researchers demonstrate how grid operators can operate and expand underground cabling in a more efficient manner.

By Jutta Witte

The test site for buried electric cables in the South Hessian town of Griesheim is a technically ambitious experimental facility. 90 temperature sensors, 16 water tension sensors and 20 moisture sensors combine to measure interactions between power cables and soil in which they are embedded – including clay, loam, sand and an artificial liquid soil – under varying loads and changing environmental conditions. The data is automatically recorded, read out and forwarded to the scientists for analysis. The interdisciplinary team from the Department of Geothermal Science and Technology and the High Voltage Laboratories at the TU Darmstadt is primarily interested in the effective thermal conductivity of the various cable bedding materials. "This is the crucial parameter for determining the extent of the load to which a cable system can be subjected", explains Professor Ingo Sass, who heads up the Department of Geothermal Science and Technology.

If cables dissipate heat in the course of conducting electrical power, the surrounding bedding substance dries and its thermal conductivity is reduced. These interactions are by no means trivial, for excessive thermal loading lowers the durability of the electrical insulation of the cable material . Extreme cases can result in outages and concomitant power supply bottlenecks. The hydraulic conditions of the surrounding soils have a strong influence on the moisture content of a cable trench fill material. In particular, the scientists also want to know the extent to which short term load spikes, of the kind that result from volatile energy sources such as wind and solar, can adversely affect the cable load capacity. The successful collation of reliable thermal conductivity data and development of corresponding analytical and forecasting processes would enable power grid operators to optimise their use of existing cabling systems and to undertake the expensive expansion of the national grid, which the energy transition has made necessary, in a more cost effective manner. And this is the starting point for the research alliance: "We want to create the foundational technologies that will make it possible to utilise cables more efficiently than it would normally be possible", says Sass.

Cables used for the transmission of medium and low voltage electrical power are usually installed underground in germany. According to Professor Volker Hinrichsen, Head of the High Voltage Laboratories, the existing cabling stocks have grown organically since wide-area power distribution began in the early 20th century. There are practically no reliable diagnostic tools, which can shed light on the condition of these cabling systems. The standards pertaining to supply security, in particular, are worded in such a conservative manner that they are, *de facto,* always oriented on a worst case scenario. The thinking among experts is, therefore, that the majority of cabling systems are currently operating far below their theoretical thermal loading capacity of 70 to 90 degrees centigrade at the cable conductor. "And", says Hinrichsen, "it is these resource that we are now trying to access."

Experts consider the intelligent use of existing cable routes as part of a "smart grid", based on an understanding of their thermal properties, to be a fast and relatively less costly alternative to a lengthy and expensive expansion of the grid. In their estimation it ought to be possible to increase the current load levels by ten to twenty per cent with the aid of an intelligent operations management system. Yet, the challenges are complex. "There are thousands of different soils", Ingo Sass explains, "and they have thousands of different thermal properties." Within the distribution area supplied by one major Bavarian distribution grid operator alone, researchers have identified 39 of the main soil types, each of which has a heterogeneous constitution. The extent to which soils can differ at different locations is exemplified by a sandy soil whose thermal properties can undergo a radical transformation, but only after it loses an excess of 80 per cent of its moisture content.

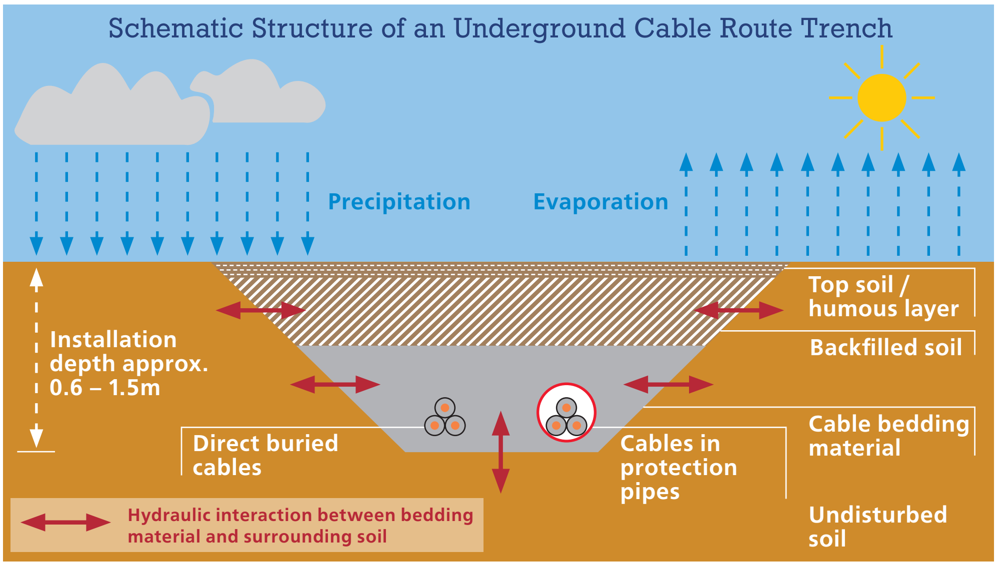

Illustration: Ulrike Albrecht, Template AGT

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Photo: Katrin Binner

Professor Volker Hinrichsen (left) and doctoral candidate Constantin Balzer at the test site

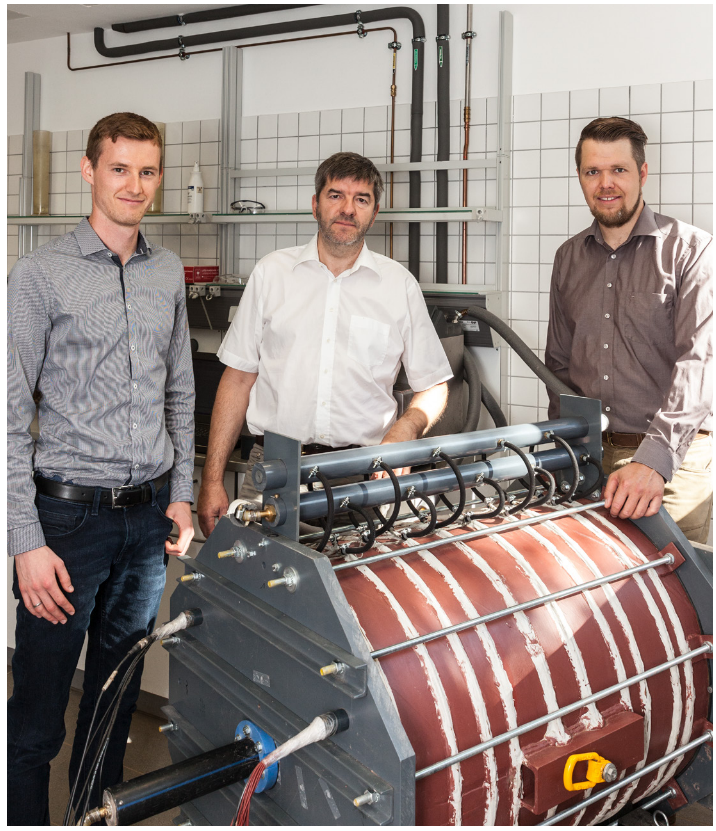

Photo: Sandra Junker

Professor Ingo Sass, Christoph Drefke (right) and Markus Schedel (left) in the lab

Based on laboratory analyses of well over a hundred soil samples, the scientists are now able to describe the processes that take place in different soils and bedding materials in precise detail, and can model the results from the cable test site with the aid of numerical simulations. The laboratory experiments provide insights into the ways in which the effective thermal conductivity of a given bedding material changes as a function of the hydraulic conditions of the surrounding soil and a cable's capacity to dissipate heat. To this end, researchers use the dissipated heat from buried cables to desiccate different bedding materials and soils in a targeted manner and under predefined conditions, and precisely measure the development of thermal and hydraulic properties over time.

The results of the field tests and laboratory experiments are then fed into numerical models. These can help to produce an even better understanding of the physical processes, to better quantify the parameters involved, and to correct experimental concepts where necessary. They also enable the transfer of fundamental research findings to any given cable route and the soil conditions in which it operates. The calculations form the basis for tools that can be used online which will then be integrated into intelligent plant management systems in medium and low voltage distribution grids. This would relieve grid operators of the need to permanently monitor the cables using costly temperature sensors of the kind currently deployed throughout high and maximum voltage cable grids. Instead, they would be able to identify highly stressed sections of their cabling systems in advance and either reduce the load temporarily or else install improved bedding materials in these hot spots for long-term stress relief.

The author is a science writer and holds a doctorate in History.

The Alliance

An interdisciplinary collaborative research alliance was founded in 2012 and includes the Department of Geothermal Science and Technology and the High Voltage Laboratories at the TU Darmstadt in addition to a Bavarian distribution grid operator. The research project comprises three distinct aspects: laboratory-based analyses of soil samples under predefined boundary conditions; measurements taken in the cable test site under real-life conditions, and modelling the results using numerical simulations.

Substantial project activities are being conducted under the auspices of doctoral candidates Constantin Balzer of the High Voltage Laboratories as well as Christoph Drefke and Markus Schedel of the Department of Geothermal Science and Technology.

The research is funded, *inter alia,* as part of the DFG Graduate School of Excellence Energy Science and Engineering (GSC 1070). The Forum for Interdisciplinary Research at the TU Darmstadt also contributed some initial funding.

Options for the Diesel Engine

Synthetic fuels, such as oxymethylene ether, could prepare Diesel vehicles to play a major role in the drive train mix of tomorrow. Scientists at the TU Darmstadt are carrying out research into the practical viability of alternative fuels.

By Jutta Witte

Professor Christian Beidl, Head of the Institute for Internal Combustion Engines and Powertrain Systems at the TU Darmstadt, does not consider the current debate on internal combustion engines and electric motors as competing drive train systems to be particularly expedient. Instead, the expert favours an open contest between technologies, which considers the system as a whole, because, he believes, the Diesel engine will continue to play a crucial role in the drive scenarios of tomorrow – particularly in long-distance transport.

"It is not the engines as energy converters that are the problem", Beidl emphasises, "but rather the fuels". For many years, his team has been conducting research into new non-fossil-based fuels for Diesel engines, designed not only to reduce nitrogen oxide and particulate matter pollution levels, but also as a sustainable solution to the CO_2 problem. The main challenge that this entails is to resolve a conflict that is typical for Diesel engines, namely that engines with a high degree of efficiency tend to generate high temperatures which, in turn, results in a high nitrogen oxide output. The established way to reduce temperature peaks within the combustion chambers is to include a return feed of virtually anoxic exhaust gases. However, the lower the oxygen levels, the more soot particles are formed there. "Therefore", Beidl explains, "to resolve this conundrum we need to inhibit the formation of soot." Experiments conducted on industrial drive system and car engines as well as on a single-cylinder research engine have already shown that the use of oxymethylene ether is the ideal way to achieve this objective. The researchers have performed basic experiments and carried out realistic driving simulations for various operating modes and driver profiles under differing environmental conditions, in the course of which they focussed on emissions, process controls and various exhaust gas aftertreatment concepts. They have been able to demonstrate that oxymethylene ether enables soot-free combustion whilst increasing the efficiency level of the motor, but that it also reduces energy density due to its high oxygen content.

Thus, the optimum adaptation of Diesel engines to this synthetic fuel, according to Beidl, will require more in-depth research in combination with technological progress. However, the basic engine technology will not change. "We now know that oxymethylene ether fuels have some outstanding properties", says Beidl, who is also excited about the technical process chain involved in the production of the new fuel. As oxymethylene ether consists, among other things, of hydrogen, which can be synthesised from surplus electrical energy, one can imagine possible solutions which would both absorb peak loads and help to improve the distribution and storage of electricity from regenerative power sources.

In terms of introducing oxymethylene ether, Beidl currently imagines two possible scenarios. In one scenario, the oxymethylene ether would be deployed as a fuel supplement – comparable with ethanol – such that it would penetrate the entire market via existing infrastructure. Another scenario would involve its niche application in ships, locomotives and agricultural vehicles. However, for a long time to come, crude-oil-based fuels and their production is likely to remain significantly more cost effective than synthetic fuels, which are currently only available at the laboratory scale. Yet, Beidl views attempts to resolve the CO_2 issue by means of electric drive systems alone as short sighted: "We want to show that oxymethylene ether represents a socially relevant parallel development path."

The author is a science writer and holds a doctorate in History.

Oxymethylene ether (OME) is a methyl and trioxane-based synthetic molecule which forms chains of one to seven elements. It is used as a precursor for novel C1 fuels because it contains none of the carbon-carbon bonds typically found in fossil fuels and which are responsible for the formation of soot particulates. In addition to carbon, oxymethylene ether comprises hydrogen and a high level of oxygen, is colourless, combustible and has a high energy density.

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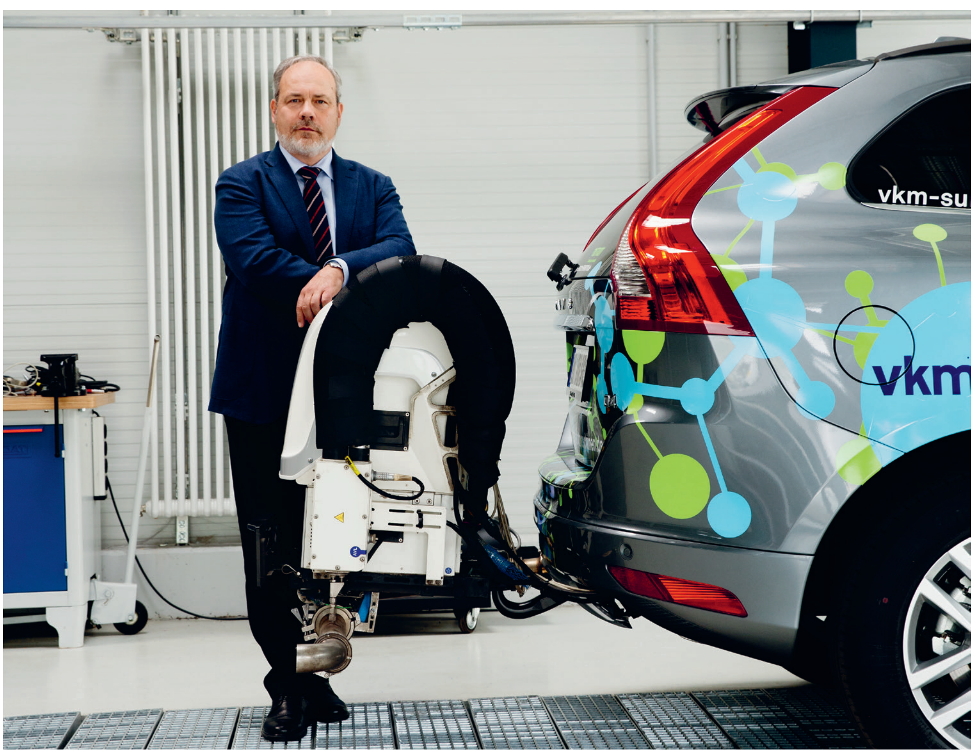

Photo: Katrin Binner

Professor Christian Beidl with the world's first oxymethylene ether powered research vehicle