hoch³ FORSCHEN

SCIENCE QUARTERLY

Spring 2019

TECHNISCHE UNIVERSITÄT DARMSTADT

Imprint

Publisher
President of TU Darmstadt,
Karolinenplatz 5,
64289 Darmstadt,
Germany

Editor
Corporate Communication
Jörg Feuck (Editor-in-chief)
Ulrike Albrecht (Graphic Design)
Patrick Bal (Images)

Conceptual design
conclouso GmbH & Co. KG, Mainz,
Germany

Photography (title)
Katrin Binner

Circulation
5.000

Next issue
17th of June 2019

Service for readers
presse@pvw.tu-darmstadt.de

Newsletter subscription
www.tu-darmstadt.de/newsletter

ISSN
2196-1506

Would you like to receive the next issue of hoch³FORSCHEN? Please send an E-Mail to:
presse@tu-darmstadt.de

The laboratory inside the microscope

Darmstadt researchers led by Leopoldo Molina-Luna observe the tiniest of electronic components in action. Not only can their electron microscope image individual atoms; it can also produce, heat and electronically control the sample.

At the top of the sample holder, there is a laboratory of microscopic size where temperature and electric field can be controlled.

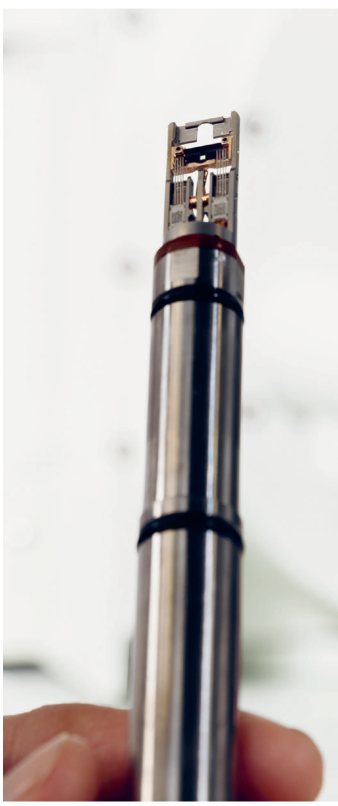

Photo: Katrin Binner

By Christian Meier

Although the two control boxes at the bottom of the room-sized electron microscope are hardly noticeable amongst the numerous screens and cables, they make all the difference for Leopoldo Molina-Luna. They serve as an upgrade that turns the microscope into an entire laboratory for nanotechnology. The physicist wants more than just to observe the world of individual atoms. He wants to manipulate it. 'The goal is to understand what actually happens on the nanoscale,' says Molina-Luna, expert in electron microscopy at the Department of Materials and Earth Sciences. When they use the term 'nano-level', scientists are referring to an order of magnitude in which objects measure only a few nanometres - no more than one hundred thousandth of a millimetre. In this minuscule universe, an influenza virus is already a giant. However, technology has been able to contract into this world for some time. The smallest elements of a computer chip, for example transistors, measure only a few nanometres. Billions of them fit on a fingernail-sized chip.

'Electron microscopy has made tremendous progress in recent years.'

Nanoelectronics wants to break new ground, such as components with a similar reminder function as brain cells or storage media with gigantic capacity in the tiniest space. For this, different materials must be added to layers that are only a few nanometres thin: custom work in the invisible microcosm.

Although you can see such diminutive components in the electron microscope, you only glimpse snapshots. However, Molina-Luna wants to watch the tiny electronic components while they are at work. He wants to observe how individual atoms behave during the switching process. Such a component consists of a thin insulator slice between two metal layers, not unlike a sandwich. When electrical voltage is applied, a conductive bridge forms between the metals, a so-called filament, which can be interrupted again by changing the applied voltage. These two different states allow the storage of data if one encodes one state as 0 and the other as 1.

'At least, that is the model concept,' says Molina-Luna. 'Until now, it could only be tested indirectly, because classical measurement methods are macroscopic.' Current methods measure the current flow at a certain voltage, a phenomenon collectively caused by tens of billions of particles. 'But electron microscopy has made tremendous progress in recent years,' says Molina-Luna. The electron microscope has become a 'multidimensional' instrument.

The development of so-called Micro-Electro-Mechanical Systems (MEMS) helped. These are complex electromechanical devices of microscopic size. Molina-Luna's cooperation partner, the Dutch company DENSsolutions, has shrunk a test lab down to a few millimetres and fixed it on a sample holder. This chip can be inserted into an electron microscope. This now allows the Darmstadt researchers to heat samples within the microscope and apply different electrical voltages. The sample holder is very stable, emphasizes Molina-Luna. It allows very high magnifications, up to 25-million times. At the same time, the sample holder serves as a production site: The Darmstadt researchers have synthesized nanoparticles on it. The powder was mixed with the solvent, the solvent could evaporate, and a sintering process took place after introducing the holder in the microscope, which produced the 'new' nanoparticles.

Recently, researchers have observed an effect on such particles, which could facilitate new, super-dense storage media. With a core and a shell, the nanoparticles resemble cherries. The core consists of a different metal oxide than the shell (the core of sodium bismuth titanate, the shell of strontium-rich sodium bismuth titanate). When it is forced into a particle, mechanical stress builds up in its interior. Researchers controlled the strength of the stress by changing the proportion of strontium.

The mechanical stress leads to so-called flexoelectricity: Inside, the electrical charge carriers split

Information

Institute of Materials Science, Advanced Electron Microscopy

Dr. rer. nat. Leopoldo Molina-Luna

Phone: ++49(0)6151/16-22309

molina@aem.tu-darmstadt.de

www.mawi.tu-darmstadt.de/aem

Photo: Holger Menzel

The transmission electron microscope with open lock for insertion of the 'laboratory' (shown enlarged lower left).

into positive and negative charge centres, creating an electric dipole. Through flexoelectricity, this is retained even at high temperatures, something the Darmstadt researchers recently observed in this system for the first time anywhere in the world. Thanks to their microscope, they were able to elucidate the mechanism of flexoelectricity in the nanoparticle. The effect is shown in tiny patterns resembling fishbones. Researchers published the results in the renowned journal Nature Communications.

Because flexoelectricity is minimal in traditional materials, it has received little attention so far. However, it could be technically interesting, specifically if it could be switched on and off, because switching between two states could encode a bit and thus act as a memory. The TU researchers showed that this is possible: The polarization in their nanoparticles could be switched by applying electrical voltage, also inside the microscope. In addition to being used as memories, flexoelectric components could serve as sensors, actuators or energy converters.

With their success, the Molina-Luna team demonstrated how flexible the new microscopy method is. ' Such experiments help us to develop the chip even further,' says Molina-Luna. The extended form of microscopy will be applied to several classes of nanomaterials. Molina-Luna has received one of the prestigious ERC Starting Grants from the European Research Council for the project. The Darmstadt laboratory has the technology needed to prepare samples. With a beam of accelerated ions, Molina-Luna's team can cut very thin layers from components so that they can be examined using the electron microscope. Though the Darmstadt scientists see themselves as basic researchers, they are still looking for materials 'suitable for the application,' says Molina-Luna.

Molina-Luna regards extended electron microscopy as a complement to previous methods, such as the testing of samples with x-rays or electrical measurement. 'We contribute to the overall picture,' he says. Information on what is happening at the atomic level is frequently still lacking today. For example, regarding filament-based memories, one can now directly see the role that oxygen atoms play in forming a filament through an insulating layer. 'What is new is that we can now say how the switching process happens,' says the physicist. 'We want to refine the models,' he adds. But this does not complete the claims of the researchers: 'Ultimately, it's about developing better devices.'

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

At a glance

EU funding:
European Research Council (ERC) Starting grant: Functionality of Oxide-based devices under Electric-field: Towards Atomic-resolution Operando Nanoscopy (FOXON), budget approximately 1.8 million euros.

New department C
Advanced Electron Microscopy.
www.mawi.tu-darmstadt.de/aem

Publication:
Enabling nanoscale flexoelectricity at extreme temperature by tuning cation diffusion.
Molina-Luna, Leopoldo et. al. In: Nature Communications,
9 p. 4445. ISSN 2041-1723
https://www.nature.com/articles/s41467-018-06959-8

City without barriers

Many people do not feel at ease moving through their city. Martin Knöll and his team from the department of architecture are developing new approaches to urban planning. The various needs of pedestrians are the focus.

By Boris Hänßler

Leo is in his mid-20s and is studying history at TU Darmstadt. He has a physical disability, and as he speaks about his everyday life to architects and students, you can hear a pin drop. He says that he repeatedly missed the train at Luisenplatz in Darmstadt because, for example, a mother with a pushchair got in and there was no time for him to catch up. A mother with a child should have an easy time getting on a train, but so should Leo.

What does a complicated everyday life look like; how does it feel? A few TU students visit a blind group of friends to find out how blind people make their way around the city. Others put on an age simulator, a weighted suit with which they must drag themselves through the streets. 'We want every student to experience this,' says Martin Knöll, Assistant Professor and head of the Urban Health Games Research Group. 'That can be a huge boost of motivation for future architects and planners to also consider the needs of less mobile people.'

'From the three components of mobility, accessibility and health, we derive universal designs for public spaces.'

The health and well-being of people depends to a large extent on their spatial environment – for example, the road network, the building typology, their exercise habits or the pollutant concentration in the air. How important each of these factors is and how they work together is highlighted by Knöll and his team. 'From the three cornerstones of mobility, pedestrian accessibility and health, we derive universal designs for public spaces,' says Knöll. 'People should be able to feel good, move freely and stay healthy – everyone, with or without disabilities.'

City planners are interested in spatial design, surfaces, lighting, orientation, safety, freedom of movement and much more. There is no single standard for public space – every space requires a location-specific solution. However, planners can learn to look at it from the perspective of people with varying needs. At TU Darmstadt, this is an integral part of the curriculum and a focus of research. This may well make the TU institute of urban planning unique in Germany.

This is also why the organizers of the Frankfurt Book Fair came to Prof. Knöll two years ago. The fair attracts over 285,000 visitors annually. The exhibition area covers 366,000 square meters, distributed over ten halls. Visitors stream from the station on the first level and then spread out in all directions. The stands are assembled in blocks, surrounded by a grid of horizontal and vertical corridors, with cafés on the circumference. But visitors to the fair do not feel comfortable. It is difficult for them to move, they become lost, it is crowded, the air is of poor quality, there is nowhere to sit for people who need a break. So, it is a challenge – especially for those who are dependent on a wheelchair or a blindman's stick, for example.

Researchers initially focused on the needs of families with children and people with walking and visual impairment. This resulted in a concept that gradually included other groups. The procedure is a common 'Darmstadt principle': Every semester, students can focus on groups, for example seniors, wheelchair users, short people, children, refugees or people with depression. The guiding question: How do these people perceive spaces? 'Seniors, for example, need half an hour to cover a distance that young people can cover in a few minutes,' says Professor Sabine Hopp, Head of the project 'Smart and Inclusive City' within the research group. 'We understand this view only through a change of perspective – both through self-experiments and the involvement of those affected.'

Information

Research Group Urban Health Games
Jun.-Prof. Dr.-Ing. Martin Knöll
Phone: ++49(0)6151/16-22167
knoell@stadt.tu-darmstadt.de
www.stadtspiele.tu-darmstadt.de

Photo: Katrin Binner

Good accessibility and broad usability of public spaces at a glance: Sabine Hopp, Marianne Halblaub Miranda, Martin Knöll (from left to right)

The approach pays off: Four TU students, for example, designed a guidance system for visually impaired people for Darmstadt Luisenplatz. It consists of a tactile model and indentations embedded in the floor. Blind people can guide their canes along these indentations and navigate safely across the space traversed by railroad tracks. The students were awarded the 'Hessian State Prize for Universal Design 2018'. The book fair also benefited from the ideas of the TU researchers – roads were widened, hall numbers were printed on easy-to-see signs in large black letters on a white background. Each hall was given its own key colour and additional rest zones. A homogeneously illuminated walkway passed all the stands. In each hall there were information booths, information pillars and stations for people with restricted mobility skills. Haptic modules provided information for blind visitors.

'The fair is a city on a small scale,' says Knöll. 'Its problems are transferable to public space – there, too, accessibility, room to manoeuvre and health play a subordinate role'. There are standards that make public buildings accessible to wheelchair users, but few for urban spaces. This was demonstrated, for example, in the implementation of a law according to which stations in Germany must be barrier-free by 2022. Urban space, say critics, has simply been disregarded in legislation. 'It does not help much if the station is barrier-free, but people cannot get there easily', says Knöll. He calls for more participation and knowledge transfer. Amongst other things, he organized the conference 'Accessible Hubs' with researcher Marianne Halblaub Miranda, bringing together international experts in urban planning, product design, geography, economics and environmental psychology in Darmstadt. The conference title was the programme: A city needs central hubs that are accessible to all.

Knöll's research group includes scientists from urban planning, architecture, psychology, sociology and sports science as well as a computer scientist from the Multimedia Communications Lab (KOM) to collect and analyse data. 'As urban planners, we must study exactly how people use the space,' says Knöll. 'For that we need data to show us what interventions have which effects. Not lastly, we must communicate the results to people and make it easy for them to become involved in planning.' For example, the app 'MoMe' developed by Marianne Halblaub Miranda makes it possible to individually assess urban spaces, highlight areas and elements of public space that are perceived as stressful or relaxing, and record these personal perceptions and behavioural patterns.

The author is a technology journalist.

Further information:

The research group of Professor Martin Knöll also studied how urban design can contribute to more sustainable mobility systems – including participatory design. He coordinates research in 'Urban Design and Mobility' as part of the multidisciplinary LOEWE research cluster 'Infrastructure - Design - Society' supported by the state of Hesse with 3.5 million euros.

www.project-mo.de

Article on Inclusive Urban Design:
https://tuprints.ulb.tu-darmstadt.de/8333

Video documentation of conference Accessible Hubs:
www.stadtspiele.tu-darmstadt.de/hubs

Research cooperation with the Frankfurt Book Fair:
www.stadtspiele.tu-darmstadt.de/buchmesse

Article on the application MoMe@school:
www.urbandesignmentalhealth.com/journal-3---mome.html

The road to the car wi
a true environmental p

The research association 'Vehicle 5.0' focuses on vehicles that continuously learn from operating data and optimize themselves. The knowledge-based approach should also improve the life cycle assessment .

By Jutta Witte

'We combine the revolutionary approaches of big data and machine learning with the classical evolutionary methods of vehicle development': Professor Stephan Rinderknecht, coordinator of the 'Vehicle 5.0' research association at TU Darmstadt, formulates a challenging, visionary framework. He believes that new technologies with which gigantic data quantities can be collected, aggregated, and analysed, together with the growing interconnection of vehicles, open new potentials for a paradigm shift in the automotive industry. Digitization offers the opportunity to adapt vehicle properties to the constantly changing driving and environmental conditions during operation, instead of updating them based on fixed reference models and driving profiles as in the past.

'We want to evaluate the ecological footprint of a vehicle under real conditions.'

The interdisciplinary association anchored at the TU Darmstadt seeks to raise this potential and has already developed concrete application ideas and is currently researching the scientific principles essential for practicability. Experts are not only looking at the technical challenges, but also significant aspects of society as a whole - such as the protection of data and privacy, acceptance issues or consequential costs for the economy and the environment..

'We want to evaluate the ecological footprint of a vehicle under real conditions,' summarizes Professor Rinderknecht, head of the Institute for Mechatronic Systems in Mechanical Engineering (IMS), about one of the superordinate objectives. How this can look in practice is shown in the context of the project 'FahrKLang'. And for that they apply the thus-far unsatisfactory framework conditions: Today, to assess a car's fuel consumption or CO_2 emissions, it undergoes an EU-wide binding measurement process based on standardized driving profiles derived from average data. This involves two problems: Firstly, these driving profiles rarely correspond with actual usage behaviour. Secondly, an electric vehicle leaves such a test with the label 'zero CO_2 emissions'. Considering this to be misleading, the IMS team is working towards a constantly updated assessment of the environmental impact of a car. The idea is to depict the entire life cycle assessment, from the manufacture of drive components to the generation of electricity and provision of fuel all the way to disposal.

Information

Institute of Mechatronic Systems in mechanical engineering
Prof. Dr.-Ing. Stephan Rinderknecht
Phone: ++49(0)6151/16-23250
rinderknecht@ims.tu-darmstadt.de
www.ims.tu-darmstadt.de

'For this, we need key figures that are always up to date, and agile driving cycles that continuously adapt based on this real-time data,' explains Arved Eßer. The IMS scientist shows that a very differentiated picture emerges, particularly when it comes to electric drives. Using statistical data from the Institute for Transport Research at DLR, Eßer and the research team investigated a wide range of drive concepts, optimized the respective drivetrain designs in terms of environmental impact and compared their potentials. The focus was on the long-distance suitability of the vehicles. He arrived at a differentiated result: 'Although it is classified as a zero-emission vehicle, today, the pure electric car is counterproductive for actual high operating ranges of 350 kilometres in Germany in .' Because to make a Battery Electric Vehicle (BEV) suitable for long-distance travel, it requires a very large battery, which on today's market is not only very expensive but also gives poor life cycle assessment results. At the same time, however, such a pure electric drive architecture offers advantages for ranges of up to 100 kilometres and in city traffic, because there, low battery capacity is sufficient, and a BEV can drive locally without emissions.

'For long distances, therefore, it makes more sense to additionally install an internal combustion engine and a multi-speed transmission than to invest in very large battery capacities, which are statistically only rarely really used,' summarised Eßer. For example, the many parallel plug-in hybrids offer the greatest potential, that is to say vehicles that can also be charged at the socket and whose electric motor is supported by a combustion engine if required.

'We want to drive electrically, but we do not want to throw the attractive technology of the combustion engine overboard for the long haul,' stresses Rinderknecht. How the two can be combined in as efficient and environmentally-friendly way as possible, the experts have explored in the context of the project 'DE-REX'. The acronym stands for 'Two-Drive-Transmission with Range-Extender'. Range extenders are usually combustion engines that drive a generator, which in turn can supply power to the battery and the electric motor. The combustion engine is only used when the battery charge level is too low. The th

rofile

new architecture developed at TU Darmstadt is based on two relatively small electric motors and a combustion engine which, in contrast to conventional range extender concepts, all three can be connected via a simplified automated transmission with the drive shafts of the car.

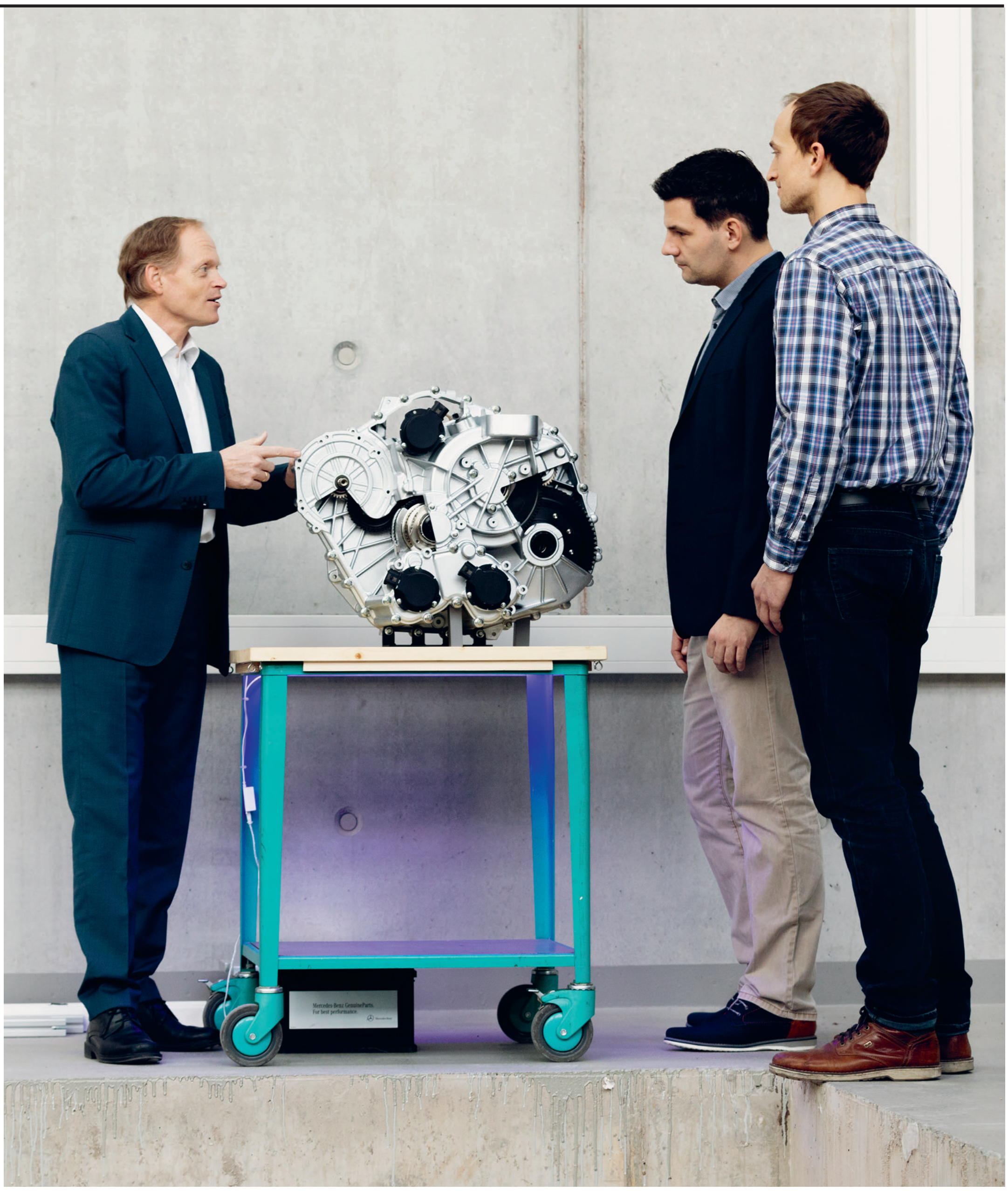

Photo: Katrin Binner

Discussion at the cutaway model of a gear unit: Professor Stephan Rinderknecht, Andreas Viehmann and Arved Eßer (v.l.n.r.)

DE-REX offers many operating modes, which are automatically selected by the operating strategy. For example, at partial load, one electric motor is usually enough; when it comes to full power requirements, both electric motors can be used. When the combustion engine is switched on, the control units choose. While the subtransmission switches the gear of one electric motor, the second drives the car, so that no interruption of traction force occurs. 'This increases the overall efficiency and drive comfort at the same time,' explains Andreas Viehmann, responsible for the development of the 'DE-REX' at the IMS. In comparison, the prototype, which will remain available for research purposes until 2020, shows promising values: The Darmstadt model was able to reduce the electric power by more than 40 percent versus a comparable serial hybrid drive concept, while increasing the vehicle's electric range by ten percent.

Both projects show that we are on the right track with our real-driving and knowledge-based methods,' says Stephan Rinderknecht. For targeted optimization and further development of vehicles, the agile model in which all relevant parameters including the actual ecological assessment are to be incorporated should now be further refined. On the research agenda is also the development of a drive concept for a smart eco-effective universal vehicle that drives locally emission-free in the city, is suitable for long-distances, does not require a new infrastructure and could be integrated in the context of sector-coupling in a smart grid or smart home architecture.

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

'Vehicle 5.0' interdisciplinary

The research association 'Vehicle 5.0: The knowledge-based automobile of the future', with its software-based lightweight construction, actual travel optimised drive and accepted autonomous function, comprises three profiling areas of application. Cross-cutting issues are Big Data, Human Factors, Economy and Ecology, and Technical Methods. Vehicle 5.0 projects are currently underway at the Institute of Mechatronic Systems in Mechanical Engineering (IMS), the Institute of Internal Combustion Engines and Powertrain Systems (VKM), the Institute of Automotive Engineering (FZD), the Institute of Electrical Energy Conversion (EW) and the Department of Material Flow Management and Resource Economics (SuR) (all TU Darmstadt). Amongst other organisations, the association cooperates with the National Research Center for Applied Cyber Security (CRISP) and the spin-off Compredict. The projects 'FahrKLang' and 'DE-REX' were publicly funded by the Federal Ministry for Economic Affairs and Energy.
www.fahrzeug5.de and **www.de-rex.de**

Upgrade for climate protection

A research team at TU Darmstadt has developed a process for the separation of carbon dioxide that uses surplus electricity from waste incineration.

By Boris Hänßler

It is not all that easy to make money from electricity production by waste incineration . If they feed electricity generated from such plants into the grid, often the operators of waste incineration plants (WIPs) must pay for the privilege: This happens whenever the sun and wind supply a great deal of energy and the stock exchange electricity prices in negative figures. 'This will happen even more often in the future', says Bernd Epple of the Institute of Energy Systems and Energy Technology at the Technische Universität Darmstadt.

But the mechanical engineering professor immediately offers a way out: Use the electricity itself to convert the carbon dioxide produced at waste incineration into methanol. The chemical product can be further processed to the diesel substitute OME (oxymethylenether) or used as raw material for the chemical industry, says Epple. This way, the process benefits the environment. This method is driving the energy transition forward, says Epple, by strengthening so-called sector coupling and networking the pillars of energy, transport and industry. Secondly, the process removes the CO_2 from the environment, because WIPs also burn wood. Because the resultant methanol partially ends up in plastics, it binds the CO_2 collected for an extended period. 'This is plastic without crude oil,' points out Epple.


Photo: Katrin Binner

Prof. Epple at the institute's own megawatt pilot plant.

At a pilot plant on the TU Lichtwiese campus, scientists have tested their methods in an industrial scale. Two reactors climb several floors into the sky. In one of them, carbon dioxide reacts with calcium oxide to form calcium carbonate, also known as limestone. 'The limestone is solid and can be easily removed from the off-gas stream," explains Epple. In the second reactor, the CO_2 is released again in that calcium is heated. The heat for this – and this is what is new about the process – comes from the combustion of waste materials. 'We can handle many types of waste,' says Epple. He is confident that there will always be fuel for the new process in WIPs.

Once pure CO_2 is present, the surplus electricity comes into play. It helps convert the climate killer into methanol. Electrolysis splits the stream of water. This produces oxygen, which fuels the combustion of waste, and hydrogen. This binds with the CO_2 to form methanol. The research group has optimized operation of the waste-fuelled plant so that, for example, no lumps arise. 'The system is very stable,' says Epple. 'We can remove over 90 percent of the CO_2 from the tested waste flue gases.'

Information

Institute of Energy Systems and Power Engineering
Prof. Dr.-Ing. Bernd Epple
Phone: ++49(0)6151/16-23001
bernd.epple@est.tu-darmstadt.de
https://www.est.tu-darmstadt.de

Now the method is to be tested in a demonstration plant. A project partner, the Cologne waste management company 'Suez Deutschland GmbH', is investigating the integration of this process into its waste incineration plant. Epple hopes to kick off working there in early 2021. The researcher sees a bright future for the process. The plant is designed such that it can easily be retrofitted. 'The great thing is that the existing plant remains unchanged.' Not only with WIPss, but with all types of incineration plants. Economically, carbon capture and storage with the new method is superior, says Epple. 'Compared to all other CO_2 capture processes, we are more than 50 percent cheaper.' Only the electrolysis is still expensive. But more favourable processes are being developed worldwide, emphasizes Epple.

The author is a technology journalist.

Project funding

The development described is part of the project MONIKA ('Methanol from electricity and CO_2 of a waste incineration plant – Studies of CO_2 capture with limestone'), which is funded by the Federal Ministry of Economics and Technology with around 370,000 euros. Contact person is the scientific assistant Martin Haaf: martin.haaf@est.tu-darmstadt.de