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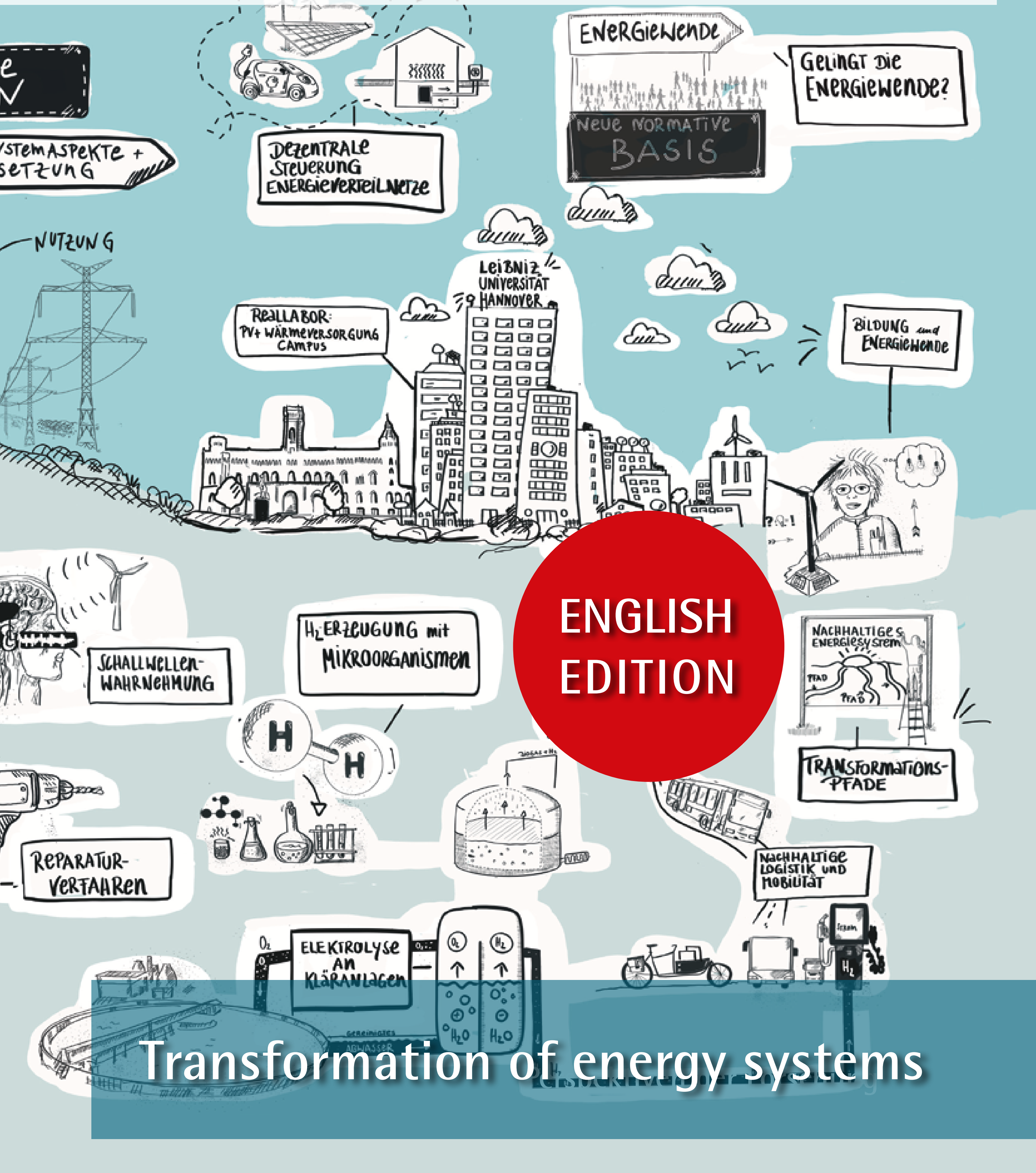


## ENGLISH EDITION

# Transformation of energy systems

# Editorial

Dear Reader,

for decades our energy systems have been based on fossil fuels such as coal, oil and gas. But climate change shows us clearly that the resulting $CO_2$ emissions are a danger for our biosphere and thus also for humanity.

The problem of far too high $CO_2$ emissions was reinforced in February 2022 as Russia started the war of aggression against Ukraine, which reveals how totalitarian states use our dependence on fossil fuels as a weapon, to put pressure on democratic systems.

Science has been warning for a long time and ever more urgently of the consequences of climate change, it has been calling not only for changes, but has also developed new technologies for years, which in many cases - such as photovoltaics, wind power or heat pumps – are already being used. Over 42 percent of electricity in Germany was generated with renewable energies in 2021. The heating sector lags behind with 16.5 percent, the transport sector with 6.8 percent. There is still a lot to be done and it is not enough to replace individual energy sources. What is needed is a complete transformation of the energy systems. The various parts of the system must be cleverly interlinked with each other in order to achieve the goals of climate neutrality and security of supply. At Leibniz University, energy research has a long tradition through the engineering disciplines.

Since 2010, the energy sciences have been programmatically bound together with the founding of a research initiative, and in 2014 transfered into the research centre LiFE 2050, which has the aim of supporting the transformation of energy systems with scientific expertise to support the transformation of energy systems.

More than 50 scientists from all nine faculties of Leibniz University have contributed to this issue and show a wide range of progress and possibilities.
It becomes clear that an interdisciplinary approach is often necessary. Last but not least, the researchers are trying to show how these topics and upcoming transformations can find social acceptance. Leibniz University has set itself the goal of becoming climate neutral by 2031.
In the LUH's „Real lab“, students will find an experimental space where they can gain insight into research and can bring this knowledge into society.

I wish you an interesting and informative reading!

Prof. Dr. Volker Epping
*President*
*Leibniz University Hannover*

# Transformation of energy systems

## Leibniz Research Centre Energy 2050

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# Transformation of energy systems

## A compact overview of energy research at Leibniz University Hannover


The use of energy in many forms permeates our lives. At the same time, access to fossil fuels has triggered unprecedented economic growth and an increase in the quality of life over the last 200 years. Energy consumption is closely linked to our standard of living, but also to crises that increasingly permeate our societies.

As early as 1972, the Club of Rome formulated the limits to growth through finite resources in our planetary boundary [The Limits to Growth, https://www.clubofrome.org/publication/the-limits-to-growth/]. This increased the awareness that lack of resources alone is a reason to change our energy supply to sustainable sources. The warming of the atmosphere through the emission of greenhouse gases leads to anthropogenic climate change via the greenhouse effect and is another argument for limiting the use of fossil fuels. Since 1979, world climate conferences under the auspices of the United Nations have had the goal of coordinating and agreeing on an international climate protection policy. In order to limit the effects of climate change, the 21st conference in Paris in 2016 agreed on the goal of staying below 2 degrees, preferably up to 1.5 degrees, of global warming compared to the temperature of the pre-industrial age [The Paris Agreement, http://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement]. This will lead to further intensification of climate change. And this leads to a further intensification of efforts to restructure the energy system. Different scenarios assume that the budgets for climate gas emissions in Germany will be exhausted by 2035.

The member states of the United Nations have also drawn up 17 Sustainable Development Goals (SDGs), which were adopted in 2016. SDG-7 and SDG-13 pursue the goals of ″affordable, clean energy“ and ″climate protection“, for which energy research at Leibniz University Hannover is developing solutions. In addition to the risks, however, there are also many opportunities to be had by switching to sustainable energy and material flows. If Germany is currently largely dependent on the import of fossil fuels, this could be changed with the use of renewable energy sources. Renewable energies are already produced locally in Germany today. It is also to be expected that a global market for renewable energies will not be concentrated on a few producers, as is currently the case with fossil fuels, due to the many possible locations. Competitive photovoltaics and wind power also offer opportunities for new industrial sectors in Germany for equipping production plants, manufacturing components, but also the competitive production of energy at the industrial site itself.

The so-called energy policy triangle describes the tension between three conflicting goals that must be reconciled and constantly re-evaluated when building and restructuring an energy system: Security of supply, environmental compatibility and affordability. Currently, a dramatic change in the assessment can be seen, as raw materials and energy sources are increasingly being used as a political instrument to exert influence in armed conflicts. Not only here, but in many conflicts fossil raw materials play an important role. These developments show the need for dramatic and rapid changes in the use of finite energy reserves in our society, which are in line with the energy policy triangle.

Energy research at Leibniz University Hannover pursues the mission of enabling the transformation of energy systems, mobility and material transformation chains towards the use of renewable energy sources and to support and promote this scientifically with basic research, application-oriented research, science communication and knowledge transfer. A network of scientists has been formed for this purpose and is bundled through the Leibniz Research Centre Energy 2050 (LiFE 2050). The most important goals are to identify and specify interdisciplinary research questions and to initiate collaborative projects. Furthermore, networking within the university and beyond will be further strengthened in order to research the next steps in the transformation of the energy system, to develop scenarios for paths of the energy transition and to make their significance visible.

To this end, interdisciplinary focus areas have developed in component research for wind energy, solar energy, electrical energy technology, thermal and electrochemical energy technology and sustainable drives. Other focus areas are in overall system and transformation research as well as the digitalisation of the energy system. In addition to the focus areas, many other research topics illuminate the path to a sustainable energy supply. The diversity of interdisciplinary research is also possible because Leibniz University Hannover has a broad range of disciplines with its nine faculties and over 300 professorships, all of which are influenced by the energy transition and climate change and which can in turn make contributions.

Energy research at the university works closely with the Institute for Solar Research Hameln (ISFH) in LiFE 2050. In addition, research infrastructures have been built up and improved, so that testing and validation of models and simulations are possible in extensive joint projects, also in order to research solutions on pilot scale.

The following articles are intended to provide insights into the complexity of energy research at Leibniz University.

It is intended to arouse curiosity about the next possible steps towards a sustainable energy system. We have set ourselves the following guiding questions for the individual articles:

- What social relevance is associated with a research question on the transformation to a sustainable energy system?
- How does a project contribute to solving a research question and what interdisciplinary expertise and research infrastructures were used to do so?
- How can technical solutions be transformed into socially accepted applications to take into account, for example, climate protection, low resource consumption, costs and security of supply?

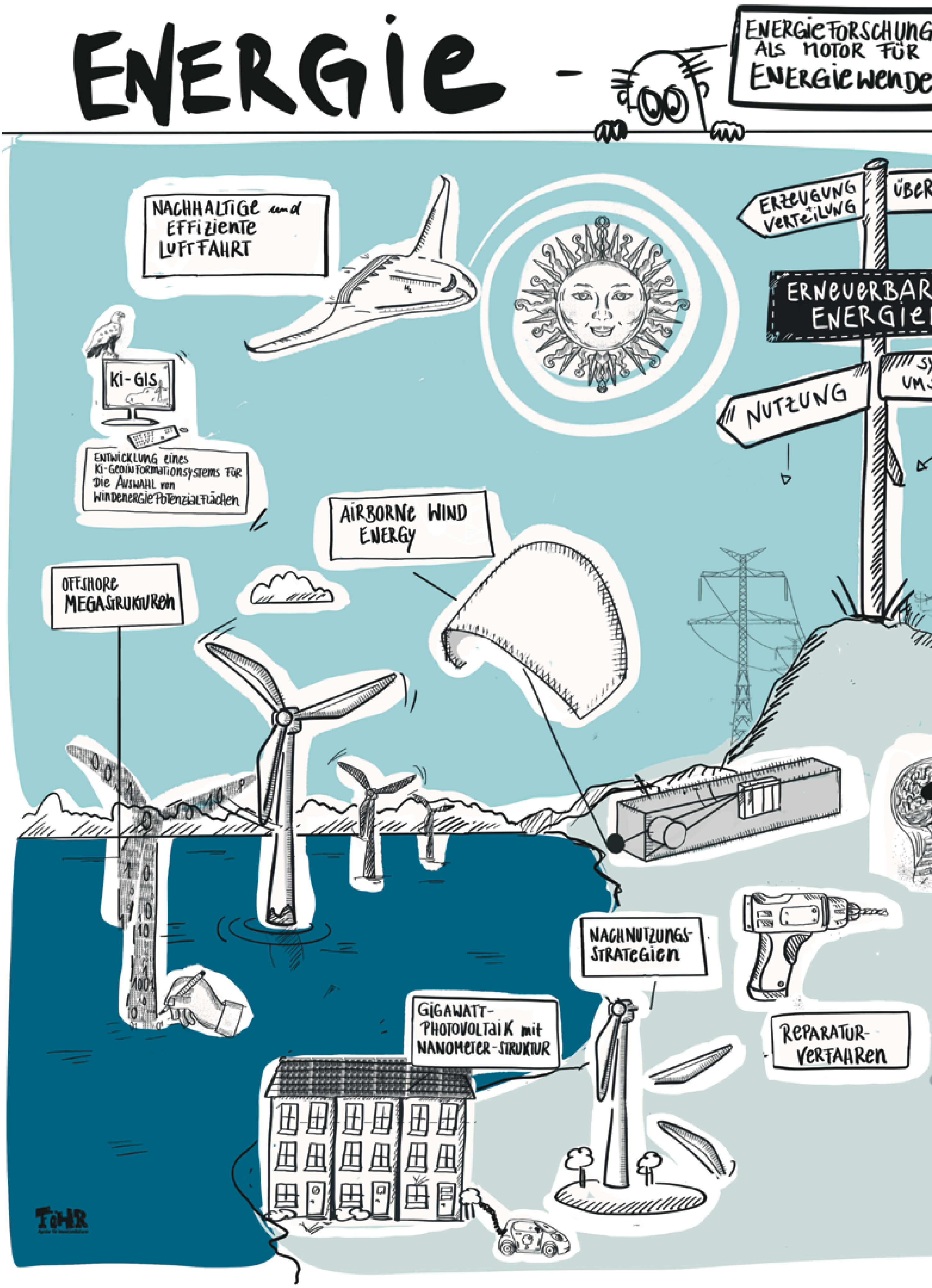
Stay confident and follow us on a short journey through current energy research at Leibniz University Hannover. With this magazine, we hope to provide ideas for possible answers and thus insights into current research.

**Dr.-Ing. Volker Schöber**
**Prof. Dr.-Ing. Richard Hanke-Rauschenbach**

→ Info and contact details see page 58

The Limits to Growth:
https://www.clubofrome.org/publication/the-limits-to-growth/

The Paris Agreement:
https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement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KI-GIS
ENTWICKLUNG eines KI-GEOINFORMATIONSSYSTEMS FÜR DIE AUSWAHL von WINDENERGIEPOTENZIALFLÄCHEN
AIRBORNE WIND ENERGY
OFFSHORE MEGASTRUKTUREN
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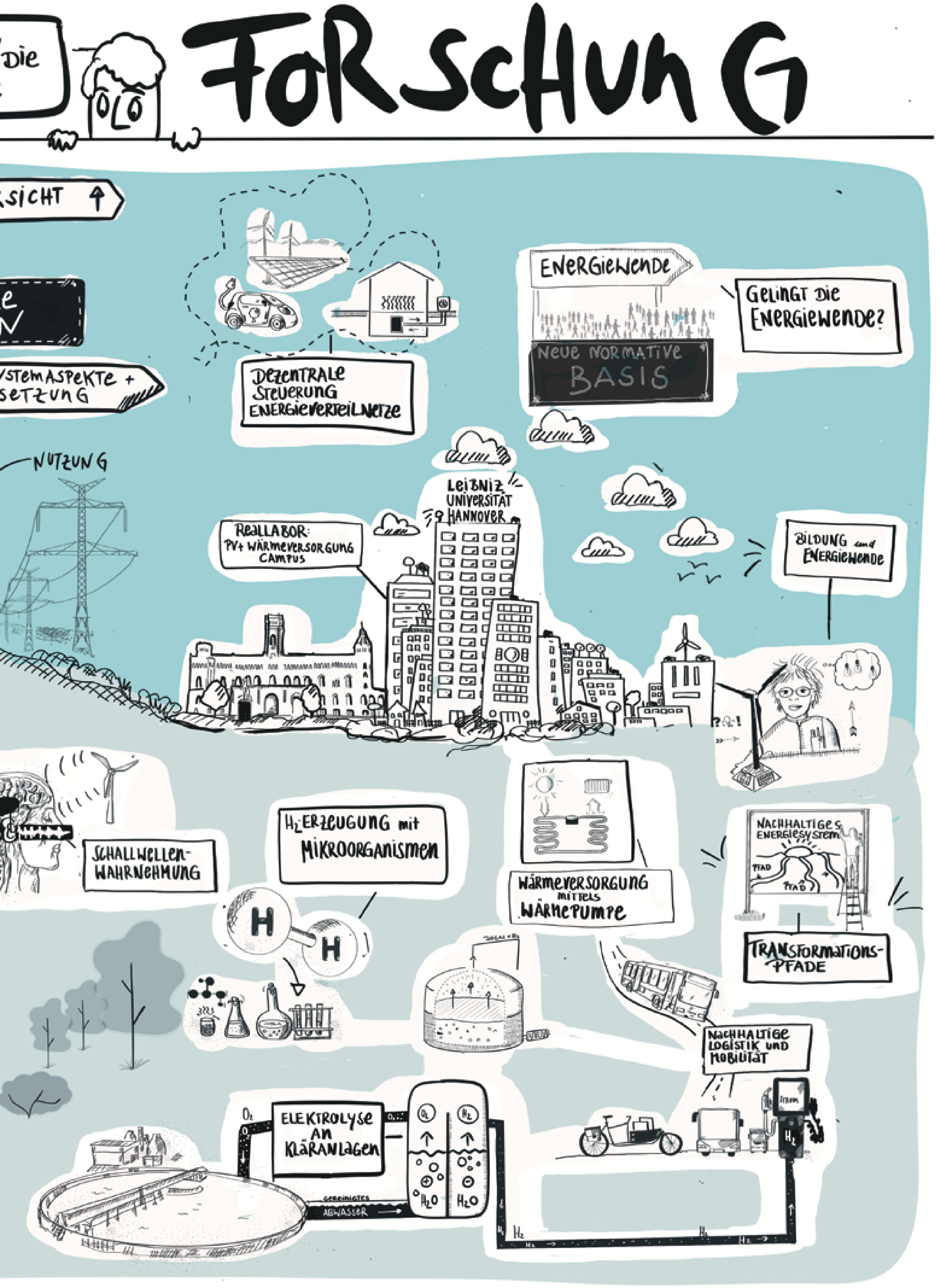

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# Towards the realisation of mega wind turbines at sea

Collaborative research centre develops digital twin


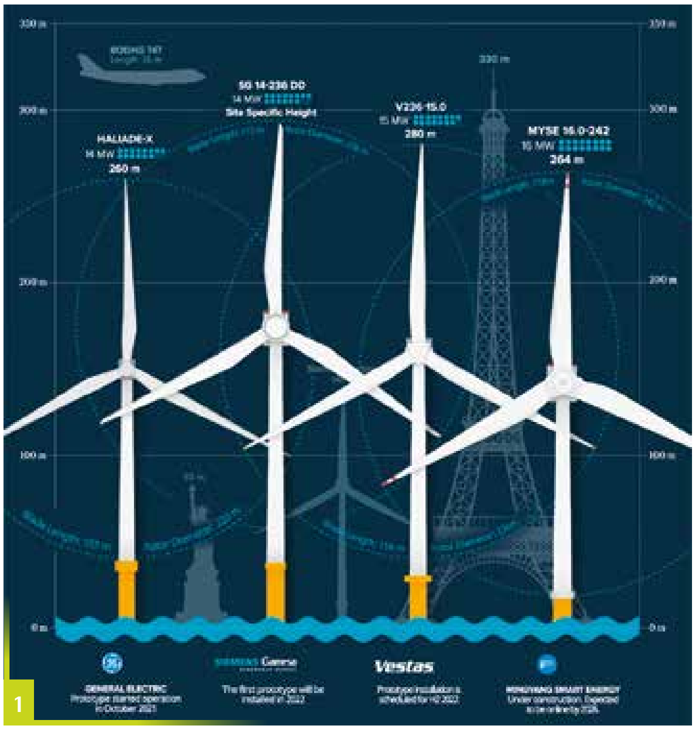


Figure 1
*The world's largest wind turbines, status 2022*
*Source: VS Elements*

In view of the challenges posed by man-made climate change and the geopolitically induced volatility of fossil energy availability, major efforts are being made at both national and international level to decarbonise energy production and European interconnection of supply security. As part of the German energy transition and the European Commission's Green Deal, a significant share of the future electricity supply is to be covered by wind energy, especially electricity generated offshore. In order to realise the required expansion of electricity generation capacities, larger and more powerful offshore wind turbines (WTGs) are needed than those currently installed. Such offshore megastructures are more efficient at generating electricity and thus more economical than today's smaller plants, so that the development has been moving towards larger plants for many years. Thirty years ago, typical turbine outputs of onshore wind turbines were 0.6 MW and a rotor diameter of 40 metres, but these numbers have increased to 14 MW and 220 metres for the prototype of an offshore turbine from General Electric installed in 2021 (Haliade-X). A single rotor blade reaches a length of 107 metres and the blade tip a height of 260 metres above sea level. In 2022, even larger offshore turbines from Siemens Gamesa (SG 14-236 DD) and Vestas (V236-15.0) were installed, and the Chinese manufacturer Mingyang Smart Energy has already announced the installation of a 16 MW turbine for 2026 (MYSE 16.0-242).

The future trend points towards even larger turbines with 20-30 MW capacity and beyond. However, today's design tools and construction principles are already approaching the limits of their capabilities, so that the technical and economic realisation of future, even significantly larger turbines currently faces unanswered questions regarding design boundary conditions, design principles, control and structural monitoring. The **Collaborative Research Centre (CRC)1463 Offshore Megastructures**, which has been funded by the German Research Foundation (DFG) since its project start in January 2021, addresses precisely these challenges to further growth in the size of offshore wind turbines. Under the project management of Prof. Raimund Rolfes (Institute of Structural Analysis), researchers are working together across institute locations and in a multidisciplinary manner, including several members of

ForWind – the joint centre for wind energy research of the universities of Oldenburg, Hannover and Bremen (see infobox). The physical, conceptual and methodological foundations for the integrated design and operation methodology are being investigated in sub-projects and brought together using the **"digital twin"** – a digital image of an offshore wind turbine that learns over all phases of the turbine's life. The approach in the project is modular and at the same time interconnected and takes a holistic view of the design, installation, operation and dismantling of the megastructure.

The vision of CRC 1463 is to develop an integrated design and operation methodology for offshore megastructures using the concept of the digital twin and to implement it on a demonstration example of an offshore wind turbine with a capacity of more than 20 MW with a focus on the support structure and rotor blades. In the **first funding period of the CRC** (2021 – 24), the focus is on concept and method development and the design of the large structural components and relevant coupling effects. The comprehensive verification and validation of these methods will take place in the **second funding period** (2025 – 28). In the final **third funding period** (2029 – 32), the focus will be on researching the interaction of the individual concepts and methods in the overall system. Therefore, in the first funding period, the focus will be on the design boundary conditions, while questions regarding manufacturing, materials and dismantling as well as an even more extensive consideration of control and structural monitoring will be addressed in the possible later funding periods.

In the project area **Design Boundary Conditions (A)**, the investigation focuses on design and installation boundary conditions that have not yet been researched or have been researched insufficiently. The significant increase in dimensions compared to comparable existing structures, complex aeroelastic, hydrodynamic and soil morphological interactions with each other as well as with the increasingly flexible support structure, require a deeper understanding of previously unexplored processes and their causes in the boundary conditions of offshore megastructures. Since the influences and interactions of the parameters involved in the processes are often unknown, comprehensive modelling is first carried out on the basis of measurement and simulation time series as well as experimental tests. To integrate these models into a real-time capable digital twin, a simplification of the realistic complex partial models is planned in a next step, whereby the most important previously identified effects are retained despite the simplification. The modelling of the interaction of design boundary conditions with each other, the interaction of design and installation boundary conditions as well as the coupling with reactive and dynamic WTGs is essential for a holistic design and operation methodology.

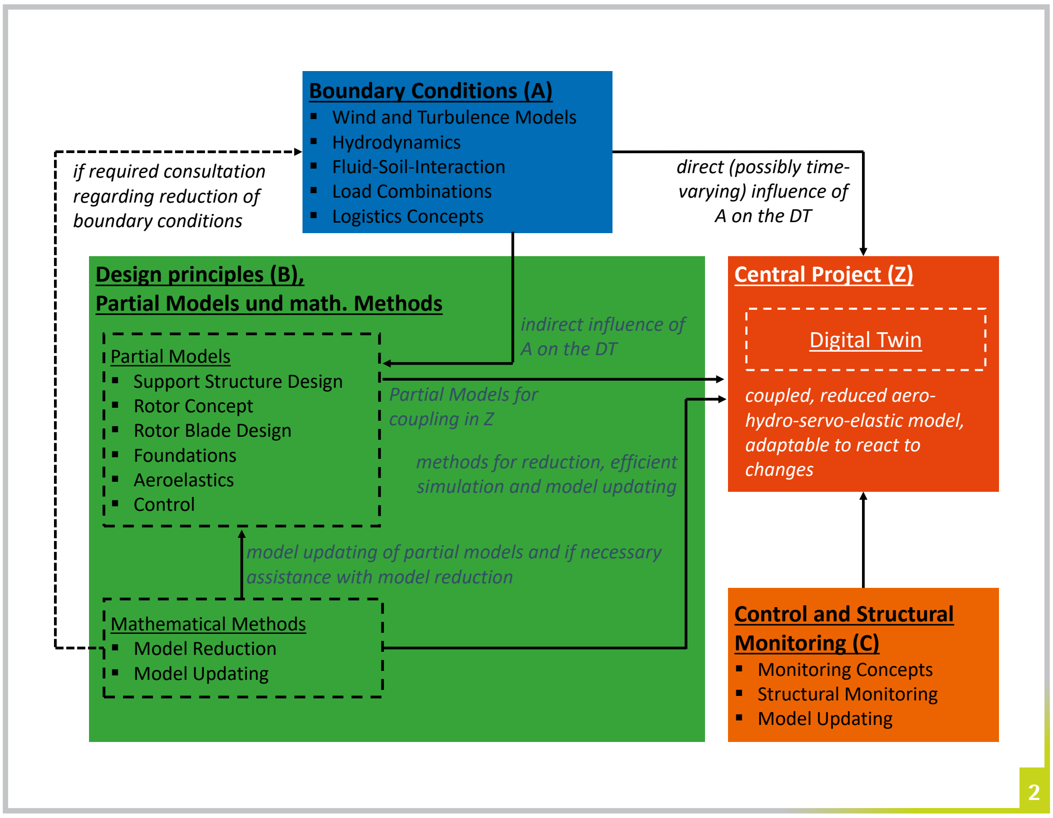


Figure 2
*Connection of project areas A – C to the Digital Twin (Z01)*
*Source: SFB 1463*

In the project area **Design Principles (B)**, the focus is on integrated design principles for future offshore megastructures and their components as well as the interaction of components of the megastructure and their environment. The integration of the investigated design boundary conditions and the model reduction are of particular methodological importance here. Model reduction is crucial for holistic designs in the early design process where detailed structural mechanical models are not available. The aerodynamic interactions occurring within offshore wind farms are initially considered in a simplified way in the load assumptions of the offshore megastructures.

The link between real structure and digital twin is essential for the subject of the CRC. This requires precise and robust monitoring concepts and suitable model updating procedures. These concepts and procedures will be implemented with the help of conventional and already proven measurement and sensor technology. The focus of the project area **Control and Structural Monitoring (C)** is the investigation of the link between the “real twin” with the digital twin, although a real twin will only exist in future industrial applications. Failure and temporal change of sensor signals over the lifetime with increasing knowledge of the structural behaviour, damage detection and localisation, and the smart and adaptive control of offshore megastructures will be considered.

The partial models from project areas A to C are combined in a reduced holistic model in the sub-project Digital Twin of a Wind Turbine (Z01). The main focus is the research and further development of coupling methods that are able to deal with different temporal and spatial discretisation. Within two years, a real-time capable initial digital twin for an WTG with more than 20 MW has been developed, which, however, does not yet comprise the contributions from all subprojects. At the end of the first funding period after four years, the digital twin should be available as an holistic model of an offshore megastructure for forecasts and load calculations as well as for control processes and optimisation procedures. This model is to be real-time capable in the sense that all incoming measurement and simulation data generated by the real twin can be captured in time and space.

The participating institutions have a globally unique research infrastructure at their disposal, which the CRC can utilise in various sub-projects. These include the Test Centre for Support Structures Hannover (TTH) and the Large Wave Flume (GWK+) at the Hannover-Marienwerder research campus, as well as the Research Laboratory for Turbulence and Wind Energy Systems (WindLab) in Oldenburg.

**Prof. Dr.-Ing. habil. Raimund Rolfes**
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ForWind – the Centre for Wind Energy Research unites the research projects in the field of wind energy at the universities of Oldenburg, Hannover and Bremen. Currently, 30 groups are working together in fundamental and applied research.

ForWind is integrated into the Energy Research Centre of Lower Saxony (EFZN) and works closely with the Fraunhofer Institute for Wind Energy Systems (IWES) and the German Aerospace Center (DLR) in the Research Alliance Wind Energy (FVWE). The Test Centre for Support Structures Hannover (TTH) has been available at LUH since 2014 for large-scale static and dynamic laboratory tests, hydrodynamic experiments can be carried out in the Large Wave Flume and the Wave-Current Basin in Hannover, and aerodynamic experiments in a large-scale Research Laboratory for Turbulence and Wind Energy Systems (WindLab) at Carl von Ossietzky University of Oldenburg. Successful examples of cross-location cooperation in recent years are the GIGAWIND, GIGAWIND alpha ventus, LENAH, HANNAH, Ventus Efficiens and SONYA projects, as well as the CRC 1463 Offshore Megastructures funded by the German Research Foundation (DFG).

The research focus of ForWind Hannover (15 research groups at 5 faculties) is in the areas of:

- Structural components – support structure and rotor blade
- Multiphysical simulation, structure-fluid interaction and structural health monitoring
- Drive train and grid connection
- Interaction with the environment, socio- and techno-economic aspects

# Airborne Wind Energy

## Airborne wind energy systems for the use of high-altitude wind


The Russian war of aggression on Ukraine has given new urgency to the need for rapid decarbonisation of the energy supply, not only in Germany but throughout Europe.
In Germany, therefore, the expansion of the generation of electrical energy from the sun and wind will have to be significantly accelerated.

Since good locations for onshore wind turbines are only available to a limited extent, wind turbines have already been increasingly built offshore in recent years. However, with increasing water depth, the foundation on the seabed becomes more and more complex and expensive. Another challenge is the volatility of energy generation from wind and sun, as wind speed can fluctuate greatly, especially near the ground.

One possible solution is to use wind at higher altitudes between 300 metres and 1000 metres to generate electrical energy, as the wind speed there is higher and more consistent than near the ground. However, it is almost impossible, and at the very least uneconomical, to erect wind turbines of conventional design, i.e. with a tower at the top of which the wind turbine and generator are installed, at such heights.

In the SkyPower100 project, a consortium consisting of the Hamburg-based company SkySails, the energy supply companies EnBW and EWE, and the Institute for Drive Systems and Power Electronics (IAL) at Leibniz University is pursuing a completely different concept, which is shown schematically in the picture at the top left.

It is based on a flexible flying kite as known from kite surfing, for example. The kite is driven by the wind and connected to an electric machine in a ground station via a rope and a winch. In the winch-out mode, the kite is controlled in the wind by a small, flying actuator system so that it flies dynamically. The flight path resembles a horizontal figure eight. In the process, the kite unwinds the rope from the rope drum and drives the electric machine, which now works as a generator and produces electrical energy.
When the maximum rope length – this can be up to 1000 metres – is reached, the kite is steered into the so-called neutral position, where it stands still in the wind, and is pulled back towards the rope drum by the electric machine, which now works as a motor, until it has reached a lower flight altitude of about 200 metres. Then the cycle starts again. In the winch-out mode, considerably more electrical energy is generated than is consumed in the winch-in phase, since the kite exerts about five times as much force on the rope during dynamic flight than in the neutral position in the winch-in phase.

The SkyPower 100 project is intended to demonstrate that fully automatic operation and power generation using such

Figure 1
*System test of the SkyPower 100 energy conversion system at the IAL's GeCoLab.*
*Photo: Volker Schöber*

flying wind energy systems, including automated take-offs and landings of the kite, are possible and reliable. The IAL is responsible for the systematic conception, dimensioning, simulation and comparative evaluation of different possible variants for the electromechanical energy conversion between the rope drum and the grid connection, whereby the environmental friendliness of the components themselves, for example the avoidance of critical materials such as rare earth metals, also was an important evaluation criterion.

In this context, the energy conversion system must be designed to have high efficiencies over a wide operating range and offer overload capacity, stability, redundancy and a long service life, especially for offshore applications. The project finally realised a pilot synchronous generator with an exterior ferrite magnet rotor and a peak power of more than 300 kW.

A particular challenge in the case of flying wind energy systems lies in the materials for the rope and the flying kite itself, which must be equally particularly lightweight, particularly windproof and particularly tear-resistant. But the non-uniform torque and speed characteristics and the fluctuating power also have a direct impact on the thermal dimensioning of the motor-generator and especially of the power electronic components that connect the motor-generator to the grid and, combined with a buffer battery, ensure uniform energy delivery to the grid and compliance with the usual grid connection conditions. The synchronisation of several turbines in a wind farm scenario also requires special precautions in the control and regulation of the energy conversion system.

A key objective of the SkyPower 100 project is to investigate and demonstrate the functionality and benefits of airborne wind turbines in practice as well. In the summer of 2020, the energy conversion system itself, i.e. the motor-generator and the power electronic components, was set up at the IAL's large-scale test stand, the so-called GeCoLab (Generator Converter Laboratory), and was subjected to extensive system tests (*see Figure 1*).

After the installation of the drive in the rope drum, the entire fully automatic airborne wind energy system with an average grid feed-in power of 100 kW was successfully commissioned near Klixbüll (North Frisia) in June 2022 and also tested in continuous operation under real conditions (*see Figure 2*).
As accompanying research, environmental compatibility aspects such as noise emissions and possible effects on bird life were also investigated, both with encouraging results: The sound emissions are low, and birds are apparently not disturbed by the kites.

The experience gained in the project shows that airborne wind energy systems are particularly suitable for generating electricity in remote locations (on islands, for example) or offshore, because offshore, there is no need for costly foundations for heavy and high structures on the seabed. Instead, the entire energy conversion unit including rope drum fits into a standard overseas container and can be installed on a floating pontoon, for example. Currently, with the support of the IAL, plants are being designed and dimensioned in the power range between 1 MW and 5 MW, which is of interest for commercial energy production.


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**Daniel Heide, M.Sc.**
**Bakr Bagaber, M.Sc.**
**Dr.-Ing. Jörn Steinbrink**
**Prof. Dr.-Ing. Axel Mertens**

→ Info and contact details see page 58

Figure 2
*Testing the demonstrator plant of the SkyPower 100 project near Klixbüll.*
*Photo: Skysails*

# What should we do with old wind turbines?

Sustainable end-of-life strategies for onshore and offshore wind turbines


Wind energy is an important pillar for achieving the energy transition in Germany and also – most recently – makes a significant contribution to the security of electricity supply. Most discussions are about expanding wind energy in the coming years, i.e., about the next generation of modern, more powerful, quieter and more economical turbines. Without a massive expansion of onshore and offshore wind energy, Germany will not be able to achieve its climate protection goals and will not guarantee a secure electricity supply. Although the wind energy sector is still a relatively young industry, many existing wind turbines (WTs) are already reaching their planned end of life. In Germany, between 2021 and 2025, more than 13,000 onshore WTs with a total capacity of more than 16 GW will fall out of subsidy for renewable energy. The topic of decommissioning will also become relevant for offshore wind turbines in the coming years, as *Figure 1* shows. Premature decommissioning of old WTs leads to major challenges. Inter alia, the resulting power gap must be mentioned here. The more than 16 GW of electricity generation capacity onshore must first be replaced by new turbines before there is any expansion of onshore wind energy. There is also the question of the sustainability of such a decommissioning. Hence, one might ask the question whether there is the possibility for profitable lifetime extensions from an economical point of view, but above all from a social point of view for some of these turbines? Finally, lifetime extensions are also being discussed for other "power plant types". In connection with the end-of-life issue of onshore wind turbines, the following questions arise: What should we do with old turbines? Can they continue to be operated through modifications – so-called repowering or retrofit – or is it technically necessary or economically sensible to decommission the turbines?

LUH researchers are working intensively on these questions in close cooperation with industry. One of the greatest challenges is the interdisciplinary nature of engineering, economics and mathematics. Purely technical solutions are just as ineffective as a purely economic approach. The collaborative research project TransWind, which deals with the design of optimal end-of-life strategies for aging onshore wind turbines, has been funded by the Federal Ministry of Economics and Climate Protection (BMWK) since the end of 2020. Further collaborative projects investigating the end-of-life issue for offshore wind turbines are planned from 2023. The relevance of these topics for the industry is demonstrated by the current and planned participation of key players in the wind energy sector, such as EnBW, TenneT or Deutsche Windguard, as well as future-oriented start-ups in the field of digitalisation of wind energy consulting, such as Nefino.

But what are – apart from interdisciplinarity – the concrete discipline-specific challenges in developing optimal strategies to further operate onshore and offshore wind turbines in an ecologically, economically and socially sustainable way? The challenges can be divided into three major problem areas. Technically, a fast and reliable probability-based remaining lifetime estimation is required. Only if it can be ensured that an aging turbine can continue to be operated safely is this an efficient option. In this field of research, researchers can benefit extensively from the ForWind research network, see info box, by using synergies with other research projects that are investigating probabilistic lifetime models for individual components, for example for rotor blades made of fibre composites. From an economical point of view, the main issue is the development of probabilistic investment and cash-flow models for the selection and design of optimal end-of-life strategies. Here, it must be constantly reassessed whether lifetime extensions, which may be associated with high costs for retrofits, still make sense. The current high electricity prices ensure that an increasing number of ageing wind turbines remain profitable for longer. Regulatory, spatial planning and environmental aspects are also gaining in importance. For onshore wind turbines, in particular, various distance rules to inhabited areas must be observed, which prevent repowering with larger wind turbines. These distance rules are based on various influencing factors, such as noise caused by the wind turbines, which is being researched in the BMWK-funded WindG-ISKI project (see page XX). Distance regulations are less relevant for offshore wind turbines. Here, more comprehensive regulatory framework conditions must be taken into account, which currently only allow, for example, lifetime extensions of five years beyond the estimated service life according to the permit. By taking these various aspects into account, optimal strategies for the end-of-life issue of onshore and offshore wind turbines are to be found within the framework of current and planned, mostly interdisciplinary research projects.

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**Prof. Dr. habil. Michael H. Breitner**

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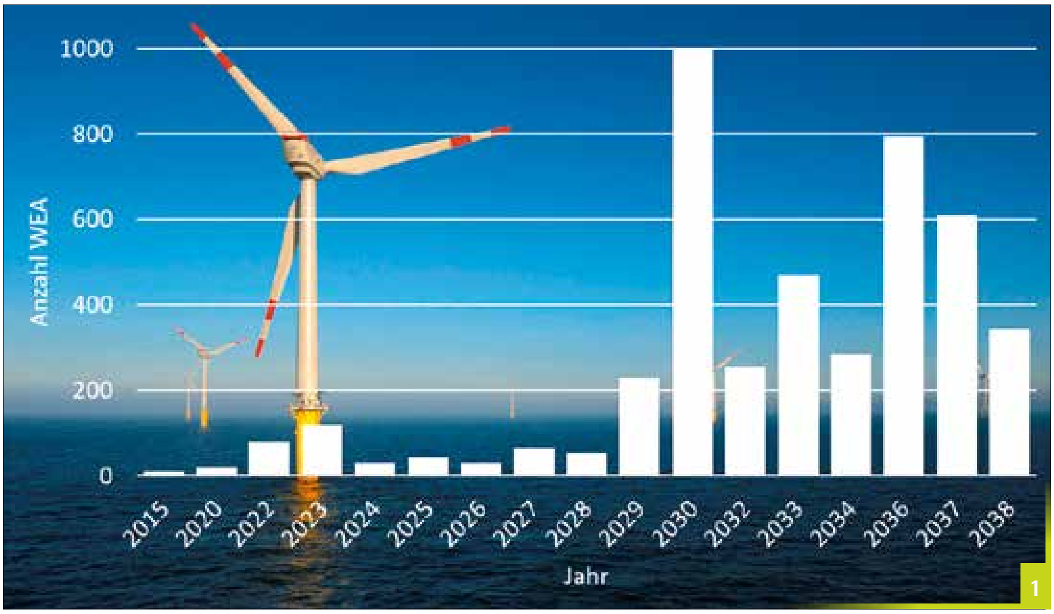


Figure 1
*Forecast of the number of offshore wind turbines to be decommissioned in the North Sea according to data.*
*Source: Kruse, M. (2019), Market Analysis Decom Tools 2019*


Figure 2
*The collaborative research project TransWind deals with the end-of-life issue of onshore wind turbines in the area of digitalisation of the energy transition, focusing on the topics of decommissioning, repowering and lifetime extension.*
*Source: LUH*

# How does noise arise from wind turbines?

Studies on sound propagation and sound perception


Onshore wind energy is a central pillar of the German energy transition. In order to achieve the associated expansion targets, new wind turbines are continuously being built and old turbines are being replaced by more powerful ones. With the increasing expansion, the locations of the wind turbines inevitably move closer to inhabited areas. The factors that play a role in site selection and how this process can be improved using modern artificial intelligence methods are being investigated in more detail in the AI lighthouse project WindGISKI. Despite high general approval ratings among the population with regard to the energy transition, the approach of turbines to inhabited areas is not infrequently met with rejection among the affected residents. Depending on the local conditions, this ranges from general uncertainty to loud protests by citizens' initiatives. A frequently cited reason for the rejection of the expansion of the onshore wind energy are the sound emissions of the turbines, which are perceived as noise.

Sound is produced by a wind turbine on the one hand as a result of the turbulent air flow around the rotor blade and on the other hand by mechanical vibrations in the generator. Especially the latter lead to a rather tonal character of the sound signal. The joint project DampedWEA is investigating how the vibrations in a wind turbine generator can be reduced and thus how the generation of the sound can be avoided. The emitted sound propagates in the environment. This does not happen spherically, as would be the case in a stationary homogeneous medium, but on curved paths, the courses of which are determined by the topography and local atmospheric conditions such as the wind speed and temperature distribution. Once in a person's ear, the physical particle movement is translated into nerve impulses that the brain can understand. These are then interpreted and trigger a sensation in the person.

Viewed as a whole, a chain of effects from the origin of the sound to its propagation and subjective perception is re-

Figure 1
*Photo of a WEA scene in the Immersive Media Lab.*
*Source: Final report of the WEA Acceptance project*

sponsible for the sound of a wind turbine reaching the resident and being perceived as noise. Under the motto "From the sound source to psychoacoustic evaluation", the joint project WEA-Akzeptanz, funded by the Federal Ministry of Economic Affairs and Climate Action (BMWK), has set itself the goal of making the noise effect of wind turbines on residents predictable and objectifiable by developing a process chain (sound generation, sound propagation, sound perception at the place of immission).

The aim of this audio-visual simulation of a planned wind turbine is to significantly improve the acceptance of wind energy by the affected population already in the planning stage of a wind turbine. Under the coordination of the Institute of Structural Analysis (ISD), LUH research partners from the fields of sound propagation (ISD), meteorology (Institute for Meteorology and Climatology, IMUK) and psychoacoustics (Institute for Communication Technology, IKT) worked together with the wind turbine manufacturer Senvion, whose focus is on the sound source, on this highly interdisciplinary task.

In the area of sound propagation, an efficient model was developed in the project that allows the propagation of sound to be simulated under complex atmospheric conditions with specific ground properties. For the consideration of local and time-dependent wind and temperature fields, the simulation data of a model of the near-ground atmosphere were integrated. In the field of sound perception, an immersive audiovisual simulation environment was developed in the Immersive Media Lab (IML) of the IKT (*Figure 1*), which allows a realistic visualisation and audibility of scenarios in the vicinity of wind turbines for the performance of subject tests. In order to test the developed process chain and the associated sub-areas under realistic conditions, five extensive measurement campaigns were carried out at different wind turbines at different times of the year. An exemplary measurement setup is shown in *Figure 2*. A data set was recorded that contains acoustic, psychoacoustic, meteorological and turbine-specific data and is unique in its scope. In the follow-up project WEA-Akzeptanz-Data, funded by Federal Ministry of Economic Affairs and Climate Action (BMWK), a platform is currently being created that will enable the data set to be made available to international research partners. To this end, LUH is in contact with various international partners via the International Energy Agency (IEA, Wind Task 39).

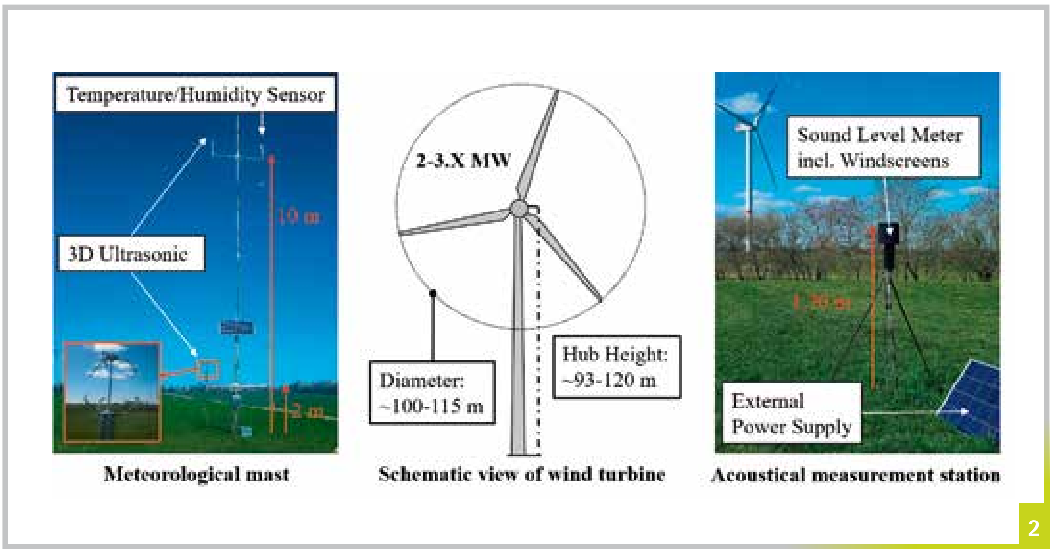


Figure 2
*Measurement setup for acoustic & meteorological measurements.*
*Source: Final report of the WEA acceptance project*

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# Gigawatt photovoltaics with nanometre structures

Research for mankind's most important energy source


## Photovoltaic against climate change

At the Paris Climate Conference in 2015, the international community agreed in binding international law to limit global warming to well below 2 degrees and, if possible, even below 1.5 degrees compared to pre-industrial levels. This requires a far-reaching decarbonisation of the entire energy system within the next two decades. Photovoltaics (PV) is the most important technology globally for replacing fossil fuels and will probably have to provide more than half of the world's primary energy (69 percent) [A1].

After the transformation of the fossil energy system, Germany will need about 2000 TWh of energy per year [A1], which means a quadrupling of the current electricity demand. If we assume a 25 to 50 percent supply through PV, we can estimate that we will have to build 500 to 1000 GW of PV plants in Germany. For Lower Saxony, 65 to 130 GW would have to be built, depending on how much import of green energy is assumed to be feasible. At the current PV expansion rate of 0.5 GW per year, this would take 120 to 240 years. We do not have this time. We therefore need a PV expansion rate accelerated by a factor of 6 to 12 in the form of rooftop, ground-mounted or agricultural PV. The two blue squares in *Figure 1* show the size of the total module area for 500 and 1000 GW of PV at 20 percent module efficiency.

Climate change will result in changes in temperature [A2] and speed [A2], but this will only lead to slightly lower yields. However, there are also long-term trends in cloud cover and dust particles that have led to changes of more than 10 percent in irradiance [A3]. Understanding the complex interplay between clouds and radiation better [A4] and being able to better forecast the influence of climate change on clouds [A5] and thus solar energy [A6] is one of the research priorities of the meteorological institute in Hannover.

## Nanostructures for the mass production of better solar cells

Solar cells convert solar radiation into electrical power. They consist of 160 µm thick crystalline silicon (c-Si) and have an efficiency of about 22 percent. Silicon is made from quartz and is therefore available "like sand on the beach". The light absorbed in c-Si produces electrons and holes. The solar cell is supposed to convert most of the energy of these electrons and holes into electrical energy. To do this, the solar cell is constructed in

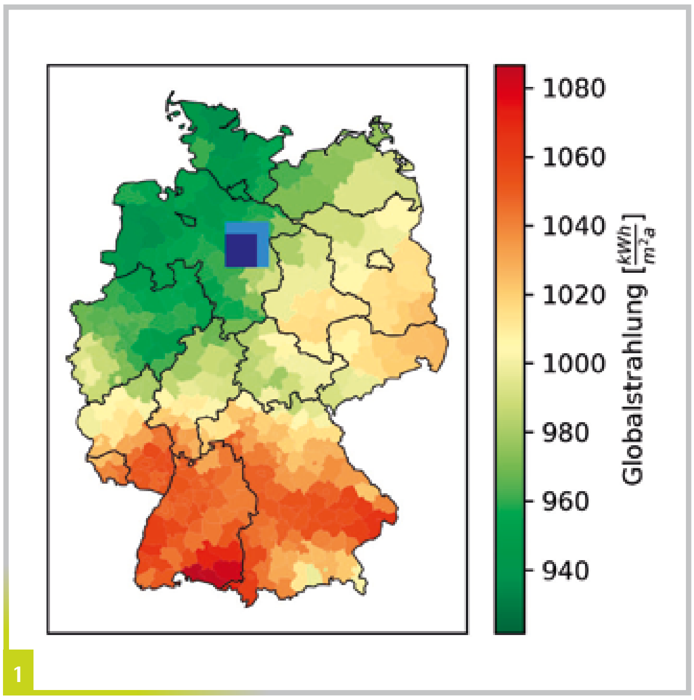


Figure 1
*Roughly estimated area required for solar modules in Germany for 500 and 1000 TWh of annual electricity generation. Irradiation map: World Bank 2019.*
*Source: ISFH*

such a way that the electrons only have to overcome a small electrical resistance on their way to the negative pole, while the same path for the holes is blocked by a high electrical resistance. Today's solar cells achieve this selective effect by incorporating phosphorus (P) atoms into the front of the c-Si disc. A higher concentration of P atoms causes a more selective contact, which allows the electrons to pass through better and the holes to pass through worse. We asked ourselves and answered the question of how the selectivity of the contacts of both polarities can be described theoretically [B1] and how the selectivity can be in experiments.

The electron micrograph in *Figure B-1* shows the solution [B2, B3]: The image shows an approximately 2 nm thin silicon oxide layer that is sandwiched between the Si wafer surface and an extremely highly phosphorus-doped 0.1 µm thick poly-silicon layer. Heating this layer system, called POLO (for poly-silicon on oxide), to about 1000 °C leads to the formation of 2 to 10 nm small holes in the oxide. The P atoms can diffuse from the poly-silicon layer into the Si wafer through these small holes and the solar current then flows through them [B4]. The holes in the oxide only account for about one millionth of the solar cell area. The P concentration in the poly-silicon is much higher than that in the surface of today's solar cells and thus improves the selectivity of the contacts. Unavoidable negative side effects of the high concentration are limited by the small area of the holes.

With the new POLO contacts, we have already achieved an efficiency of 26.1 percent in the laboratory [B5]. This is a great step forward because the PV footprint and material consumption are reduced by 18 percent compared to today's standard efficiency. However, in order to transfer the laboratory results to worldwide mass production, difficult development questions still need to be solved, which we are currently working on: In which solar cell structure should the new POLO contacts be integrated? Which processes and machines can we use to produce the poly-silicon in the best and most cost-effective way? What will change for the photovoltaic modules when they are made of new, more efficient POLO cells? At present, the first production lines for POLO cells with several GW of annual capacity are being built in Asia. We are working to ensure that large factories for the production of new solar cells will soon also be built in Germany, so that we do not replace our dependence on Russian gas with new dependencies on other autocratic states.

Research on the POLO solar cells is being carried out at the Institute for Solar Energy Research, the Institute for Materials and Components in Electronics, the Laboratory for Nano and Quantum Engineering and the Institute for Solid State Physics in cooperation with numerous mechanical engineering companies and is funded by the Federal Ministry of Economics and Climate Protection in joint projects [B6].

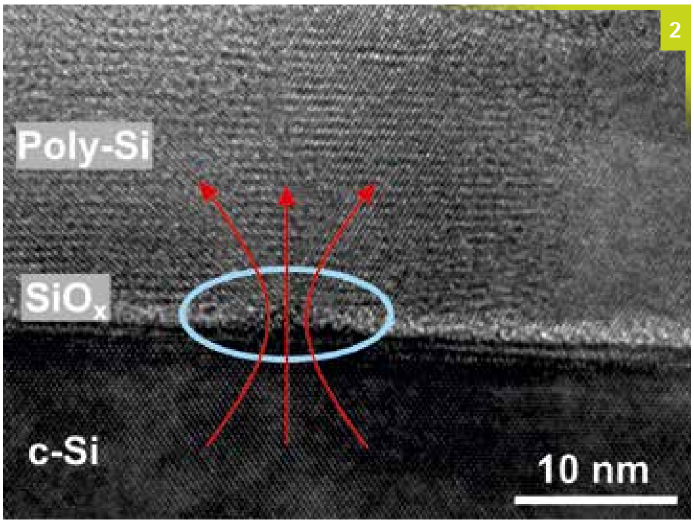


Figure 2
*Electron microscope image of a POLO contact: at the point circled in blue, there is a hole in the thin oxide that separates the poly-Si from the silicon wafer. The solar current flows through the small holes.*
Source: ISFH

### Fully integrated and system-optimised electronics solutions in the solar module

For decades, science and industry have been pursuing the goal of electronics integrated directly into the solar module in order to increase installation, planning, system safety and yield. Despite marketable product solutions, it has not yet been possible to achieve competitiveness with conventional system concepts.
LUH is researching new solar modules with integrated electronics for applications such as single-family homes and small balcony systems to make them competitive. For this, the PV modules must become "intelligent" compared to today's status, so that they can provide system services in the power grid and can be integrated into the controls of "smart home" systems in a user-friendly way. Ideally, this should be done in compliance with global standards.

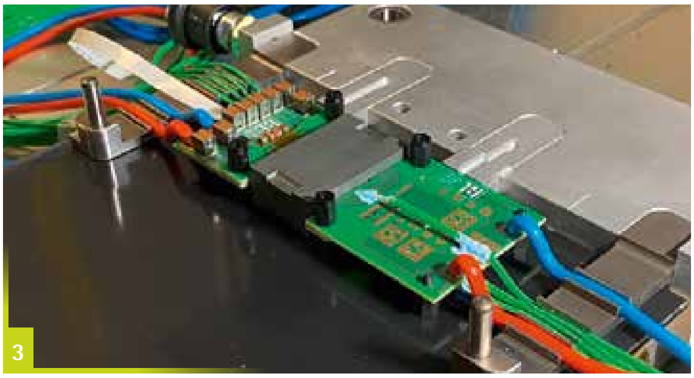

Figure 3
*Electronics on the test module before the potting process.*
*Photo: IAL*

Figure 4
*Electronics on the test module after the potting process.*
*Photo: IAL*

All this is to be achieved with electronics that are encapsulated by means of a novel encapsulation process and attached directly to the PV module. This eliminates some of the electrical wiring and increases reliability. In addition, a fault-tolerant wireless communication with a so-called IoT mesh (IoT = Internet of Things, mesh = dynamic communication network) is implemented by means of an adapted antenna and tested and evaluated in a network of several PV modules on a test roof of the ISFH over several months. Electronic circuit concepts are being investigated that require fewer components, materials and therefore ressources, but also allow the use of supply chains other than those commonly used today. This should help to reduce the impact of dynamic crisis areas on our energy transition. The "intelligent" solar modules outlined here are not only suitable for roof tops, but also for other urban surfaces such as facades.
A test setup consisting of electronics and PV module is shown in *Figure 3* before and in *Figure 4* after the potting process.

The Institute for Drive Systems and Power Electronics, the Institute for Microelectronic Systems, the Institute for High Frequency Technology and Radio Systems and the ISFH cooperate closely with several industrial partners in this topic area. In addition to project funding from the BMWK, the research work is also supported by funds from the DBU and supplemented by international student activities in professional associations with high visibility (IEEE).

## Fast calculation methods for accurate yield predictions in cities

Unlike wind energy, photovoltaics can also be used in urban areas for decentralised energy supply. Urban densification and high urban electricity demand will make suitable areas for PV systems a scarce commodity. Accurate yield forecasts should take into account the real urban environment and also include the building facades. For the design of decentralised energy systems, the solar irradiation in the plane of the building surfaces must be taken into account, taking into account complex and time-dependent shading as well as light reflections in the surroundings [D1].

To make this possible, we combine geoinformation from several sources and process it into a 3D city model. This city model forms the basis for optical ray tracing simulations, which are greatly accelerated by a highly parallelised approach. The result is a temporally resolved solar cadastre for both roof and façade surfaces of the entire urban area.

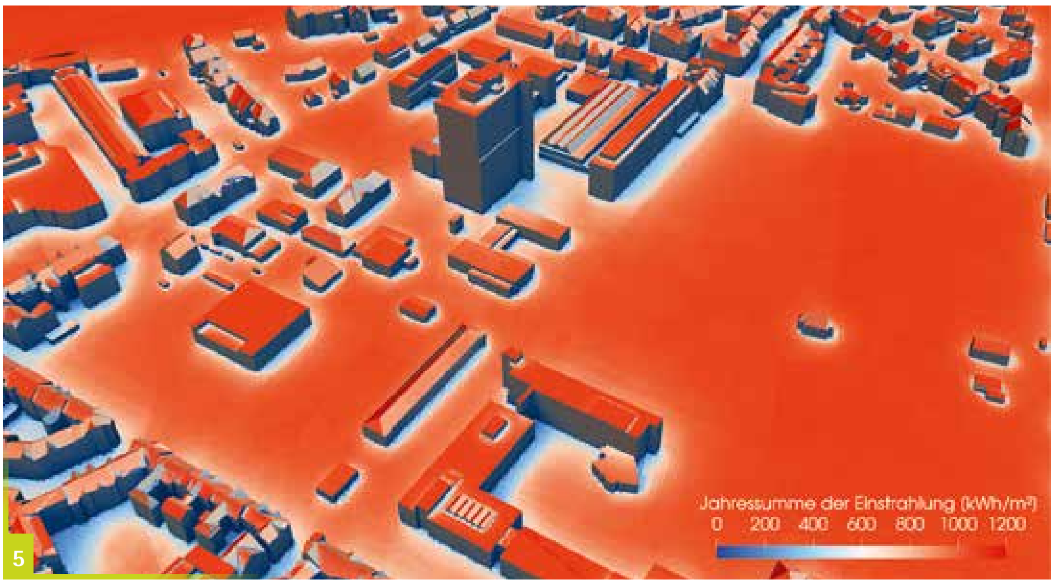


Figure 5
*Annual sum of solar irradiation shown for an area of the LUH campus.*
*Source: CC-BY-4.0, City of Hannover, Geoinformation Department*

Figure 6
*Assembled demonstrator vehicle with lightweight solar module generation.*
*Photo: ISFH*

Due to the temporal resolution, savings can already be calculated in the planning phase of a PV system by balancing PV yield and electricity consumption on an hourly basis. The simulation work is being carried out by the Institute of Solid State Physics and will use radiation distributions currently obtained with new measurement techniques from the Institute of Meteorology and Climatology [A4].

## Vehicle-integrated photovoltaics for greater ranges

Emissions from the transport sector are now the third largest contributor to greenhouse gas emissions in Germany, although emissions from this sector have been stagnating for some time. Electromobility can make a major contribution to reducing emissions if the electrical energy is provided in a renewable way. Vehicle-integrated photovoltaics is an attractive approach with high user comfort. The research partners have built a PV supported delivery vehicle that feeds the solar power into the high-voltage battery via a DCDC converter. More than 8000 km of test drives in the Weserbergland region have been completed, demonstrating range extensions of up to 36 km on sunny summer days [E1]. A further increase to over 50 km per day would be possible with measures that can already be implemented, including, for example, a further increase in the chain efficiency of the power electronics and the buffer storage of currently 69 % [E1]. In parallel, the necessary readjustment frequency of the optimal operating point under transient partial shading at 50 Hz was determined using systematic irradiation measurements with high time resolution, in conjunction with dynamic modelling of the solar modules [E2]. This work was carried out by the Institute for Electronic Materials and Devices , the Institute for Solar Energy Research Hamelin and other partners from industry and research within the framework of a BMWK-funded project and was included in the work of the International Energy Agency Photovoltaic Power System Programme called "Task 17 - PV for Transport".

## Summary

Photovoltaics is a very central component of the increasingly networked energy systems of the future, both here in Germany and worldwide. Photovoltaic research at LUH covers the fields of meteorology, physics, electrical engineering and computer science, mechanical engineering, building physics, and landscape and environmental planning. Our research contributes to making photovoltaics even more cost-effective and resource-efficient than it already is today. Such research facilitates the global "PV roll-out" that we urgently need for a future worth living for mankind. "PV made in Europe" is also a great opportunity for our economy, for exciting new jobs [A1] and for reducing political dependence on autocracies.

Unfortunately, references had to be omitted. The authors provide a version of this text with references here: https://www.energie.uni-hannover.de/de/information/downloads

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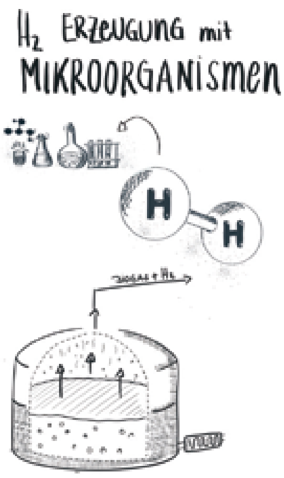
# Life always finds a smart way

## Production of hydrogen by microorganisms




Hydrogen is anticipated to become an important component of the energy transition. Hydrogen, as a central intermediate in the anerobic feeding chain, is easily produced via microbial fermentation of organic material upstream of biogas production in two-stage plants, thus locally providing a high quality energy source. But what are the microbiological principles of hydrogen ($H_2$) production and how can this potential be harnessed?

$H_2$ is produced in the absence of oxygen ($O_2$) during the decomposition of organic material by certain microbial fermentations, which are usually part of the anaerobic feeding chain (*Fig. 1*). In this process, highly diverse microbial communities metabolize complex organic compounds into simpler intermediates, which in turn are used as substrates by other groups of bacteria.
As an end product, biogas, which is a mixture of $CH_4$ (methane), $CO_2$ and water vapor ($H_2O$) is produced via a tight interaction of different microorganisms.

The microbial formation of $H_2$ from protons and electrons is enzymatically catalysed by hydrogenases. Two prominent classes of hydrogenases are recognized among bacteria: [NiFe] hydrogenases and [FeFe] hydrogenases.
[NiFe]-hydrogenases are very diverse and catalyse the reduction, oxidation or reversible reaction of $H_2$, whereas [FeFe]-hydrogenases are mainly involved in the production of $H_2$. $H_2$ formed can be used directly by methanogenic archaea for the synthesis of $CH_4$ from $CO_2$.

Biogas production processes are well established, although the exact composition and interaction of the organisms involved has not been fully elucidated. Detailed knowledge is crucial here, however, in order to be able to detect and avoid process instabilities early on during operation. Temperature, pH, and ammonium must be controlled in biogas plants to ensure optimal growth and activity of the microorganisms.
In case of heavy process disturbance like a drop in pH below 6 or ammonium accumulation to a certain extent, secondary fermenters and methanogens are heavily impacted and the biogas formation breaks down. However, early countermeasures after a process disturbance has been detected might induce counter-actions to prevent process failure.

In the joint project MODISTO (derived from "Model of the

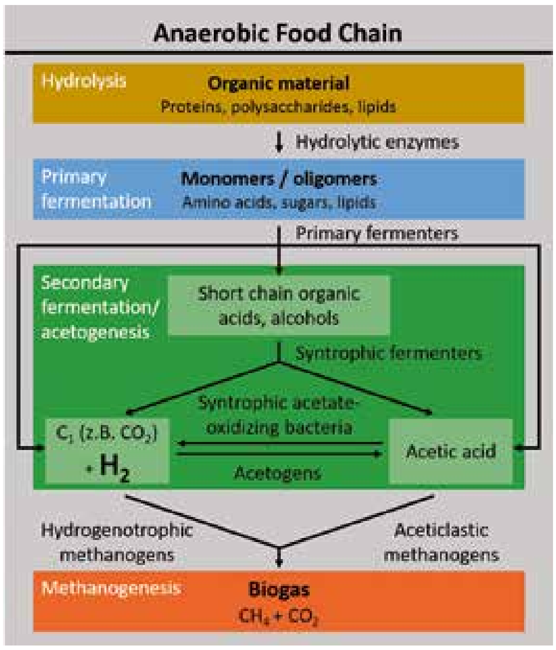



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Figure 1
*Large polymer molecules from organic material, such as maize straw and manure, are first broken down into smaller building blocks by hydrolytic enzymes. These can serve as substrates for primary fermentations. Organic acids such as acetic acid, propionic acid, lactic acid and butyric acid, alcohols, $H_2$ and $CO_2$ are produced. The short chain organic acids are mainly degraded by syntrophic fermenters to $H_2$, $CO_2$, and acetate. Such reactions are thermodynamically dependent on the activity of methanogens constantly removing such compounds from the reaction to produce $CH_4$. Thus, methanogens act as the terminal electron sink.*
*Source: own representation*

Intermediary-Metabolism of Biogas Processes), processes in the fermenter were investigated after experimental disturbance under mesophilic (37°C) and thermophilic (50°C) conditions. If the amount of substrate is increased (overfeeding), process instability occurs due to an increase in acidic intermediates (pH drop), lowering $CH_4$ production. In the mesophilic state, lactic acid was formed as an intermediate due to the induced instability. There was an accumulation of acetic acid and propionic acid, but only a small increase in $H_2$. The absolute abundance of the marker gene *hypD* indicative of [NiFe]-hydrogenases and the genes encoding [FeFe]-hydrogenases as well as their expression was not increased (*Fig. 2*). The occurrence and expression of [FeFe]-hydrogenases associated with secondary fermenters of the phylum Cloacimonetes were reduced compared to stable conditions (*Fig. 3*). Under thermophilic, unstable conditions, mainly acetic acid and butyric acid accumulated in response to the perturbation. The proportion of $H_2$ increased to 10 – 44 per cent in the gas phase, without significant $CH_4$ production. Expression of [FeFe]-hydrogenase genes was not detectable (*Fig. 3*). The abundance of the marker gene *hypD* for [NiFe]-hydrogenases was almost 18-fold increased compared to stable operation, indicating an important role of these hydrogenases in the formation of $H_2$. In summary, different fermentation reactions were involved in substrate degradation under mesophilic than under thermophilic conditions, with $H_2$ being produced mainly at elevated temperature and low pH. Specific hydrogenase genes and microorganisms were enriched under disturbed compared to undisturbed conditions. These findings provide the basis for the development of diagnostic molecular biological methods for the early detection of process instabilities, and will thus enable plant operators to react at an early stage to beginning process instabilities.

During biogas formation in the single-stage process (all reactions take place in one fermenter), $H_2$ is rapidly further converted to $CH_4$. Thus, biogas contains only traces of $H_2$. The key is to increase the $H_2$ content in the gas phase by decoupling the closely interlocked anaerobic feeding chain, i.e. separating $H_2$ production from $H_2$ consumption. This is facilitated by implementing two-stage processes. In this process, hydrolysis and primary fermentations are spatially separated from secondary fermentations and methanogenesis. In the first stage, hydrolysis runs optimally under acidic conditions. Primary fermentations are acid-tolerant and ferment released monomers such as sugars to $H_2$, $CO_2$, organic acids as well as alcohols. Since secondary fermenters and methanogenic $H_2$ consumers are essentially absent due to the low pH, $H_2$ concentrations around 40 percent can be achieved in the gas phase. $H_2$ from the gas phase can easily be separated and used directly. In the second stage, the remaining dissolved organic acids, alcohols and other intermediates are then converted to $CH_4$ under neutral to slightly alkaline pH values.

Given a good quality control of substrates (e.g., substrate needs to be free of heavy metals), the residues of the fermentation can be used as fertiliser in agriculture.

For the refinement of waste materials from agriculture, such as maize straw, liquid manure, or biowaste from households, hydrogen and biogas production is of far-reaching importance for the optimal use of these energy-rich resources. The production of $H_2$ during biogas production offers an additional possibility for sustainable energy generation and thus represents an important component of a sustainable circular economy.

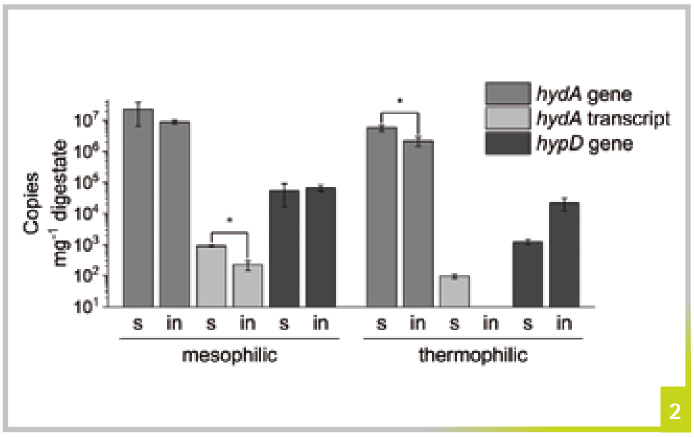


Figure 2
*Transcript abundance (indication for gene expression and activity) and gene abundance of the H-cluster hydA of the [FeFe]-hydrogenases and the gene abundance of hypD as marker for [NiFe]-hydrogenases of the stable (s) and unstable (in) process of the mesophilic and thermophilic fermenter operation. Transcript abundances of the thermophilic unstable state were below the detection limit. Error bars show the standard deviation. Statistical analysis was performed using paired T-test.*
** p ≤ 0.01*
*Source: own representation*

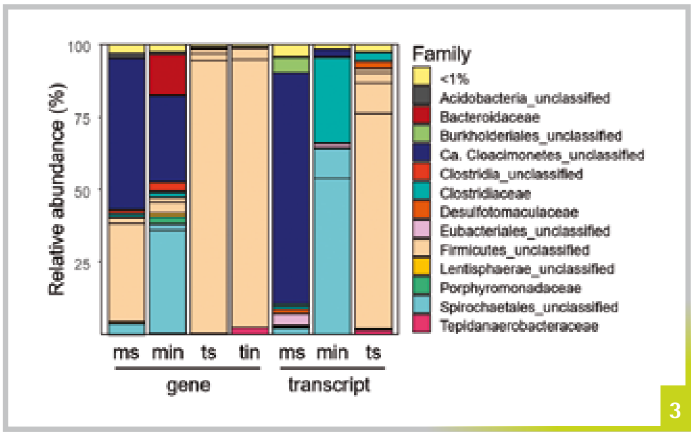


Figure 3
*Relative abundance in (%) of genes and transcripts of [FeFe]-hydrogenases of the operation states (ms: mesophilic stable; min: mesophilic unstable; ts: thermophilic stable; tin: thermophilic unstable). [FeFe]-hydrogenases were determined by sequencing the gene for the H-cluster hydA.*
*Source: own representation*

**Prof. Dr. Marcus A. Horn**
**M.Sc. Nadine Rüppel**

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# No fear of the blackout

## A decentral black start is feasible!


Modern society relies almost entirely on the permanent availability of electrical energy. With the current trend of ever-increasing dependence of the power supply on information and communication systems, the vulnerability of the energy supply system is unfortunately also steadily increasing. The current situation of increasing confrontation between the various political systems puts even more attention to the possibility of a provoked large-scale failure of the power supply.

Currently, in the event of a prolonged and widespread power blackout, only individual important institutions such as hospitals, fire brigades, police, city halls, etc. are supplied via their emergency generators. Gradually, additional diesel generators will be set up to operate smaller sub-grids as part of disaster control. Even a nationwide expansion of stationary and mobile emergency power generation capacities would, however, in view of the immense demand as well as increasing competition for fuel, only improve the availability of critical infrastructures selectively and for a limited period of time. The report of the Bundestag Committee for Education, Research and Technology Assessment therefore proposes the formation of island grids for a sustainable increase in the robustness of the (emergency) power supply [DBT_2011]. Here, local power generation plants (for example renewable energies) are to be used which are interconnected only in decentral groups. This places special demands on procedures for frequency- and voltage-stability management in islanding grids for different feed-in and load scenarios. In the currently available grid restoration concepts, such local islanding is not provided for, but it will become relevant in the future with increasing penetration of renewable energies and decentral generation plants.

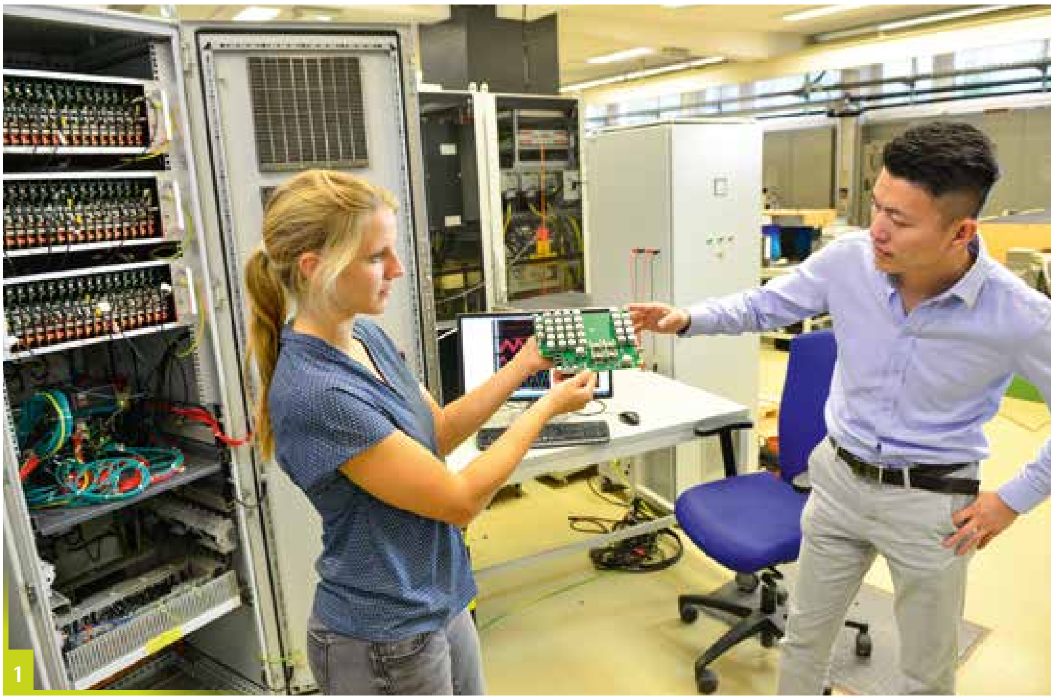

Figure 1
*The Institute for Drive Technology and Power Electronics is conducting intensive research on power electronic systems. They are an indispensable building block for a decentralized and sustainable energy supply and form a key component in the RuBICon project.*
Source: IAL

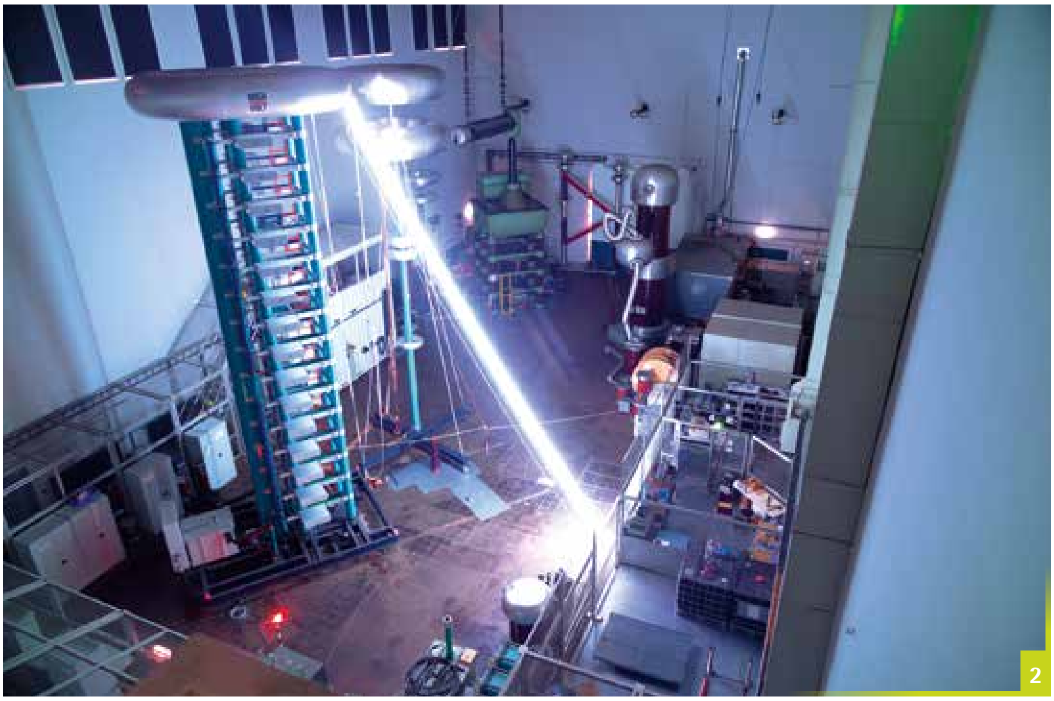

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Figure 2
*In the laboratories of the Schering Institute for High Voltage Technology, various prerequisites were confirmed in extensive test series. For the project, for example, it had to be tested whether classic protective devices, such as automatic circuit breakers and residual current circuit breakers, could cope with the larger variances in voltage and frequency*
*Source: Schering-Institut*

The project "Rule Based Initialization of Converter Dominated Grids" (RuBICon) addresses this gap by investigating the black start capability and islanding capability of distribution grids with a high share of renewable energies. The aim of the project is to develop and validate robust procedures for the grid restoration of small island grids on the low and medium voltage level, not requiring a central higher-level control or communication infrastructure. It is assumed that in the event of a blackout, the central control of the grid and all communication systems (internet, mobile radio, etc.) are down or no longer accessible. This requires rule-based, decentralized processes for the converters of the decentralized power generation plants and battery storage systems as well as for smart consumers. The local distribution grids should operate as self-sufficient island grids until the higher-level power grid becomes active and wants to reconnect to the distribution grids. The necessary processes for interconnecting several sub-grids to one overarching medium-voltage grid are also the subject of this project.

A possible scenario is as follows: In the event of a crisis (grid failure), a distribution grid is first isolated, larger (switchable) consumers as well as local transformer stations are switched off and then the grid is gradually restarted with the existing energy storage systems and generation facilities based on renewable energy sources (for example PV plants, CHP and biomass power plants, wind energy plants), initially as an island grid. In this case, the properties of the converters are used to automatically distribute the loads based on the voltages and frequencies present in the grid, as known from research on autonomous microgrids. At least one or preferably several power electronic generation plants must have a grid-forming control. This can be both converter systems at the low-voltage level that have an energy storage system (battery) included or, for example, a PV park at the medium-voltage level.

The processes take advantage of the fact that the converters can also operate at voltages and frequencies that deviate more than in normal operation from the nominal values. This feature serves as a starting point for a decentralized (self-)organization of the available distributed generation plants. In the first step, several grid-forming inverters in the distribution grid synchronize with each other at still reduced voltage, if necessary at also deviating frequency. In this process, sufficient power must be transmitted to supply the smart metering systems that will be widespread in the grid in the future and include local load switching devices, plus any loads that cannot be switched off. In addition, the necessary amount of reactive power also needs to be supplied. The smart metering systems, with the switching and control capabilities linked to them, can use the information about the status of the power supply which is transmitted via voltage and frequency to operate (grid-serving, prioritized) load management within their local connection

Bundesministerium für Wirtschaft und Klimaschutz

*This project was supported by the Federal Ministry for Economy and Climate Protection based of a decision of the German Bundestag.*

***Project:*** *RuBICon*
***Funding number:*** *03EI4003A31*

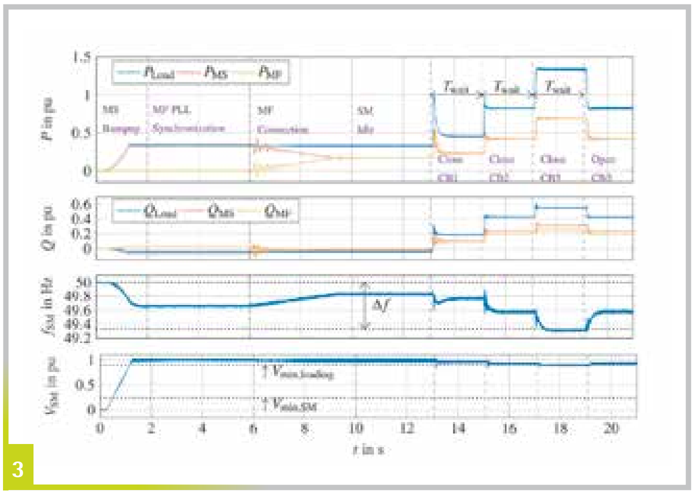


Figure 3
*The black start of a distribution grid was demonstrated in a laboratory test. Two decentralized, grid-forming converters share the demand for active power (P) and reactive power (Q) equally. The measured grid frequency ($f_{SM}$) and voltage ($V_{SM}$) are metrics for smart load management*
*Source: IAL*

area, for example to keep the load as low as possible during restart. Further electricity consumers are then connected step by step and automatically on the basis of a set of control laws and rules – known in advance to each grid participant – whereby voltage and frequency are successively brought up to the nominal values. In the last step, the isolated distribution network is synchronized with the electricity network and reconnected to it. Here, the (controllable) local transformer stations and their equipment with switchgear and measuring devices play an essential role.

The project takes into account that in the future almost all consumer connections will have smart metering and measuring devices, which will be rolled out with the digitalization of the energy infrastructure. In the event of a crisis, these devices could also take over control tasks, for example an automatic rule-based disconnection of larger consumers from the distribution grid by means of switch boxes. In the project, among other things, the possible uses of the measuring devices for the evaluation of voltage, frequency, power and energy direction are being investigated in order to derive criteria for control and prioritization as well as to realize decentralized connection during grid restoration. Recommendations for supporting black start capability in distribution grids of the future are derived from the investigations, especially if central control instances, for example the smart meter gateway administrator or CLS manager, are not available due to a failure of the communication networks.

Since the network structure is supposed to function without communication in principle, competing decisions can occur in the given decentralized arrangement, which can lead to an overload or even to a renewed collapse of the island network. For this purpose, simple rules are proposed that effectively prevent a simultaneous start-up attempt of several inverters.

So far, the concept has been implemented and examined in simulations and in the laboratory (picture: microgrid laboratory of the IAL).
The approaches could be confirmed. In a large-scale test at the SysTec Technical Centre of the Fraunhofer Institute for Energy Economics and Energy System Technology, the synchronization of several low-voltage grids via the medium-voltage line is also being tested experimentally.

The acronym RuBICon was deliberately chosen because the underlying approach crosses a border – in ancient Rome, the river Rubicon. Today, the grid restoration of future energy grids is almost always defined under the premise that a digital information and communication infrastructure is available and enables a more or less central governance of the grid restoration process by the grid operators. However, in past projects, communication and its availability has proven to be a bottleneck. It is precisely here that opposite assumptions are made in RuBICon. Based on the promising results, the network operators should also slowly give up their previous reluctance in the future.

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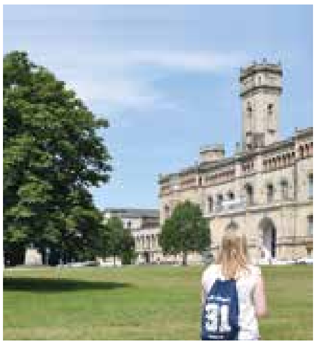

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# Aviation of tomorrow

## Energy-efficient and sustainable flying


Civil aviation is responsible for about 3.5 percent of climate-damaging emissions, and the resulting climate change is a global problem. The question is, how sustainable aviation will look like in future? In aviation research, the following picture is currently emerging: while fully electrically powered aircraft could be used on short-haul flights in the near future, according to the current state of research, they are not suitable for longer ranges. One reason for this is that batteries are so heavy to contain the necessary energy and they do not become lighter during discharging, while liquid fuel disappears during the flight which reduces the weight. Alternatives are needed here.

Scientists at Leibniz Universität Hannover are researching on alternatives within the Cluster of Excellence 2163 "Sustainable and energy-efficient aviation" (SE$^2$A), together with the partners at the Technische Universität Braunschweig.

### Sustainable and energy-efficient aviation

In the German research landscape, Clusters of Excellence are a big deal: hardly any other funding programm enables such broad and transdisciplinary research for the wide question about sustainable aviation systems of tomorrow. This is necessary here, since the extent of application scenarios – and of possible solutions – requires research in diverse fields of engineering and even social sciences. The necessary solutions are not limited to aircraft propulsion, but also include aircraft design and infrastructural considerations.

Electric propulsion components, propulsion systems for flying with hydrogen or eFuels, the on-board network and the question of how all this can be integrated into a possible lightweight aircraft plays just as central a role as economic issues.

### Flying with hydrogen

Long range aviation requires energy carriers with a high energy content, such as sustainably produced hydrogen. Two approaches are currently followed: usage in fuel cells or direct combustion of the hydrogen. Hydrogen could be converted into electricity via fuel cells to supply an electric drive technology. Fuel cells in the high power classes required for this pose a technological challenge, because higher power densities are indispensable for use in aircraft. Questions regarding cooling or integration with the compressor have to be answered. This is one of the emerging research fields in SE$^2$A. Another approach is the direct combustion of hydrogen. Here, modified engines could be used in a similar system arrangement as before. Current research topics in the field of hydrogen combustion include flame stabilisation and the reduction of excessively high flame temperatures. These is investigated by 23 partners in the EU-HESTIA consortium, including the Institute for Technical Combustion (ITV).

Hydrogen storage technology also remains challenging, with cryogenic storage under very low temperatures in liquid form being favoured. However, this would mean losing about a third of the passenger seats for the hydrogen tanks, which is economically problematic. An alternative would be aircraft designs with more capacity.

Liquid energy carriers have advantages over hydrogen here due to their higher energy storage density. Close to readiness for application is sustainably produced kerosene (Sustainable Aviation Fuel, SAF; also known as eFuel). Its advantages are obvious: existing aircrafts can continue to be used without need of new design and SAF is $CO_2$-neutral. However, the combustion of SAF still produces pollutant emissions, such as soot particles and nitrogen oxides, which are about twice as harmful as $C0_2$. Therefore, research is also being conducted in SE$^2$A on how to find better synthetic energy sources that allow an ultra-clean combustion process. A promising option is the lean premixed prevaporized combustion approach, which, however, needs other synthetic eFuels than kerosene. Initial research results from the ITV and the Physikalisch-Technische Bundesanstalt Braunschweig are promising and support this vision of $CO_2$ neutral and zero pollutant long distance aviation.

Availability of hydrogen propulsion for short- and medium-haul flights is predicted for 2030 at the earliest.
For long-haul aircraft, the use of sustainably produced synthetic liquid fuels (eFuels) is considered likely (*Figure 1*).

In addition to technological challenges, the usage of hydrogen as an energy carrier is accompanied by extensive economic implications, because hydrogen must be produced, stored, liquefied and transported, which in turn is related to costs, but also to aspects such as employment effects. These effects are being studied at the Institute for Environmental Economics and World Trade (IUW). There may also be macroeconomic adjustments on the consumer side: The aviation sector is linked to a wide range of industries and sectors that a switch to hydrogen-powered aviation also strongly affects.

### Electric flying and avionics

The Institute of Propulsion Systems and Power Electronics (IAL) is focusing on the investigation of the electric drive train as well as the on-board network for use in future electrically powered aircraft. System aspects, such as various circuit concepts, heat dissipation, redundancy and reliability, as well as basic research in the field of so-called power semiconductors and methods for dimensioning electrical machines according to requirements are developed. In particular, high power density combined with high efficiency and the optimal integration of the various components play a decisive role.

### On-board power supply and drives

The main consumers in electrically powered aircraft are the propulsors. Propulsors replace or supplement conventional drives, the electrical energy is stored in batteries or fuel cells, an electric motor drives a propeller or a fan.
For their supply, both a centralised and a decentralised energy supply system are being investigated in close cooperation with the Institute for Electrical Machines, Propulsion and Trains (IMAB) at the Technical University of Braunschweig. Both approaches must be tested for their suitability. In addition to weight and installation space, reliability also plays a decisive role.

A DC network is particularly suitable for the on-board network in a central system, as this avoids reactive power losses and additional weight can be saved by omitting the rectifiers that would otherwise be necessary.

### Lightweight construction, aerodynamics and compressors

In addition to the question of whether electrically stored energy, hydrogen or SAF are used for flying, the energy efficiency of the overall aircraft system is always of central importance. With regard to energy efficiency and power density, progress must also be made in the areas of lightweight construction, aerodynamics and drive components in order to meet the requirements for sustainable aviation.
Within the framework of SE²A, the two “adjusting screws” of lightweight construction and aerodynamics are being turned by the design and integration of a “Suction Panel” in the wing. By means of an active boundary layer suction, the laminar running distance is extended and thus the aerodynamic resistance is greatly reduced. For this purpose, an additively manufactured polymer structure with a micro-perforated surface is embedded in the wing at the critical point, through which the boundary layer can then be extracted. However, this increases the construction weight, which in turn must be compensated for by a more efficient supporting structure of the wing. In this context, the Institute for Statics and Dynamics (ISD) is researching the static and dynamic behaviour of so-called “thin-ply” laminates. These are carbon fibre composite laminates with particularly thin individual layers. Compared to conventional laminates, they have superior mechanical properties in terms of strength and fatigue (*Figure 2*). For this purpose, new structural analysis methods are being developed by the ISD to help in the design of ultralight load-bearing structures.

Turbo compressors, which use rotating blades to compress air, play a central role in efforts to make aviation more sustainable, because both fuel cells and hydrogen combustion require an efficient and flexible compressor to provide compressed air as a working medium. Therefore, the Institute of Turbomachinery and Fluid Dynamics (TFD) is researching new, innovative compressor concepts as part of SE2A.

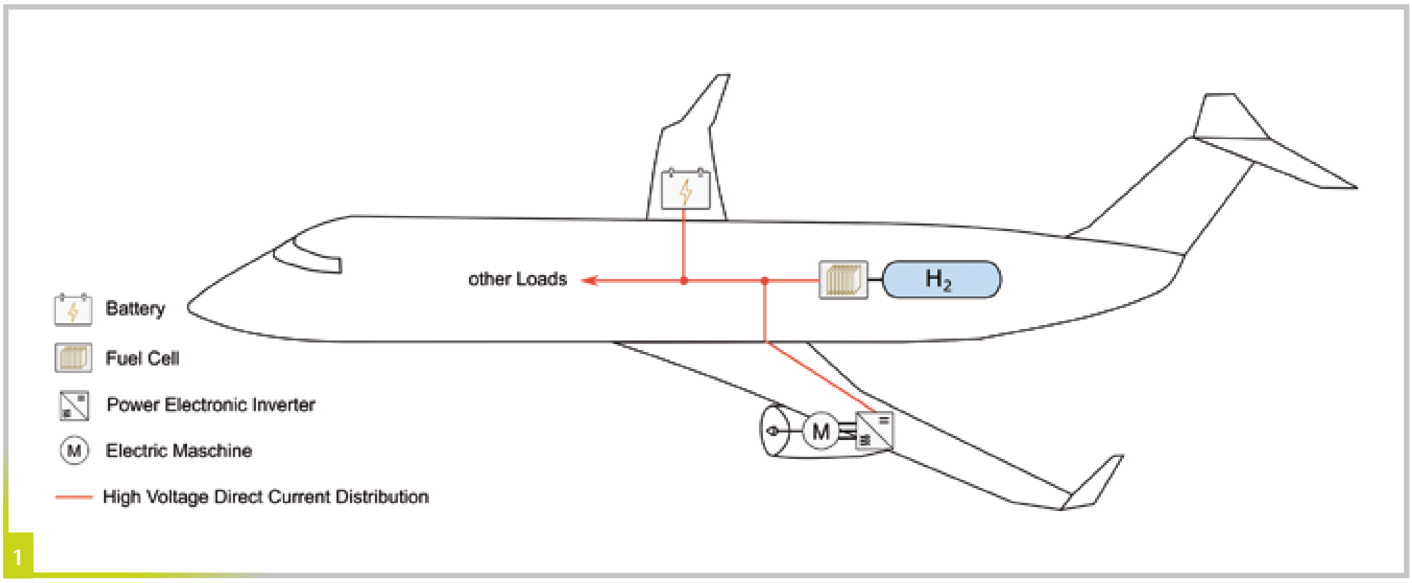


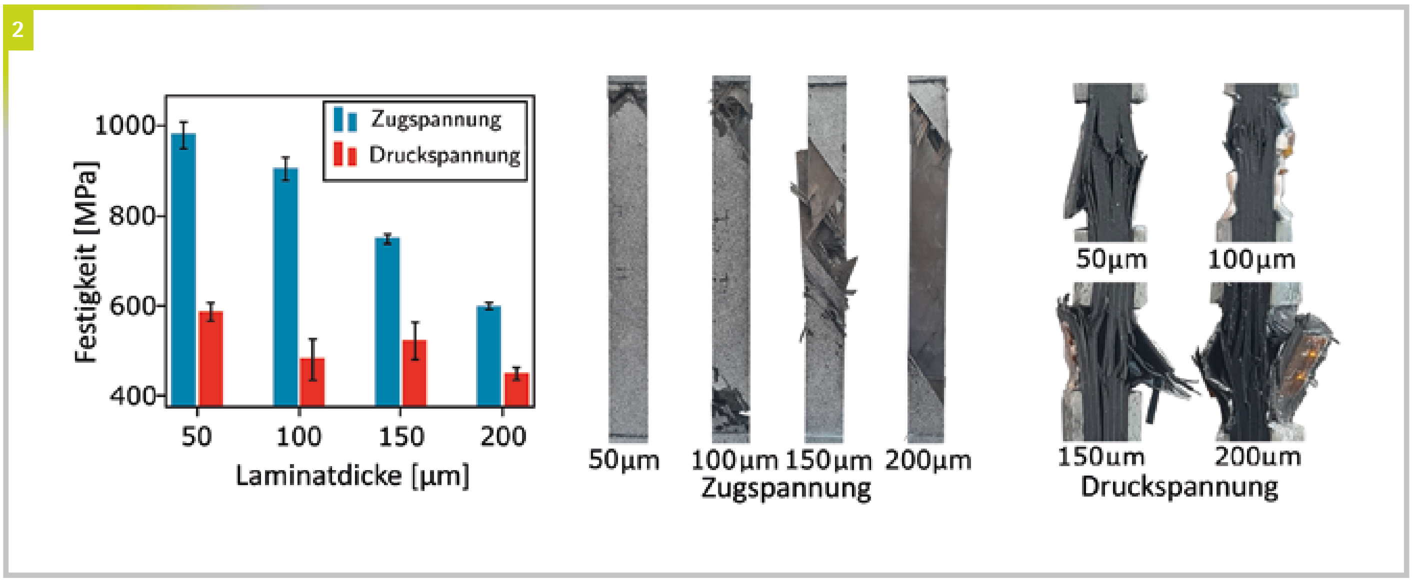

Figure 1
*Feasibility of hydrogen-powered and synfuel-fuelled aircraft*
*Source: own illustration*

Figure 2
*Schematic structure of an on-board network with battery storage and fuel cell*
*Source: own illustration*

For example, the use of active flow control is intended to increase its efficiency and power density over a wide operating range. This involves extracting energy-rich air from the rear part of the compressor and blowing it back into the front stages to give the flow there additional impetus. As a result, the flow no longer detaches from the blades and their lossy wake is reduced. If the air is extracted from areas in which greater pressure losses occur anyway, for example in the gap between the blade and the casing or in the area of efficiency-damaging flow separations, the benefits are twofold (*Figure 3*).

With the help of shape-variable blades, which are being researched together with scientists from the DLR and the Technical University in Braunschweig, the flexibility of the compressor is also to be improved. Using small electrical actuators, these compressor blades can be deformed in such a way that they are ideally flowed against in the important operating areas. This means that the compressor also works optimally outside the actual design point, for example during take-off.

Many questions still need to be clarified before they can be implemented in the application. Therefore, numerous flow simulations and experiments are carried out at TFD to achieve a better understanding of compressor aerodynamics and to explore the limits of what is technically feasible. Machine learning methods are also being investigated to see if they can be used to improve the design process of such ad-



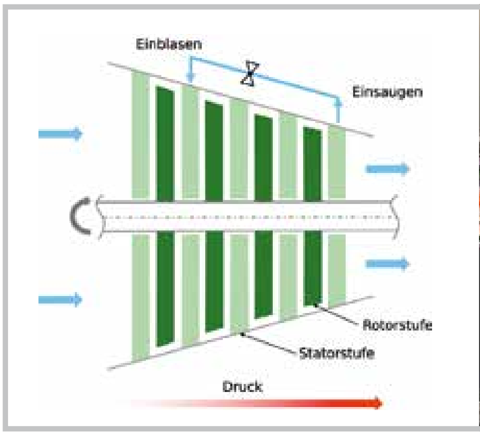




Figure 4
*Left: Schematic representation of active flow control in the compressor by controlled blowing in and out of air. Right: Four-stage axial compressor in the Dynamics of Energy Conversion research building*
*Source: own illustration*

vanced compressors in the future.

### Conclusion

Sustainability efforts are a high priority in aviation. Precisely because it is still open which technologies will ultimately prevail, the research work in the SE²A Cluster of Excellence paves the way for sustainable and energy-efficient aviation.

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# The heat pump

## The linchpin of the heat transition


In order to be able to implement the decarbonisation of our energy economy, the demand for heating and cooling must be completely covered without the emission of greenhouse gases. According to the current state of knowledge and technology, this can only be achieved with the help of heat pumps. These can provide heat for heating and hot water with little additional electrical energy, especially in the low-temperature range. The heat pumps can be operated with the help of renewable electricity, which enables a very important coupling between the electricity and heating sectors. The heat pumps can be used locally or in district heating networks. The contributions to both areas of application made by LUH are described below. However, since heating and cooling are still largely provided by fossil fuels, which cause over 30 percent of current greenhouse gas emissions, and since heat pumps and their possibilities are still little known in industry, trade and private households, LUH is also dedicated to broadening the knowledge base around heat pumps.

### The project

District heating networks are an efficient way of providing heat for heating and hot water supply in buildings in many conurbations. The heat required for this purpose currently comes from a few heat sources, typically fossil-fuelled combined heat and power plants, see *Figure 1*. In order to be able to feed the district heating networks with as many climate-neutral heat sources as possible in the future, such as solar thermal energy, geothermal energy or industrial waste heat, the operating temperature of the district heating networks must be lowered from the current approx. 100 °C to 70 °C, for example. As an additional benefit, this can reduce the heat losses of the network's kilometre-long pipelines. For building heating and for water heating, i.e. for most users of the district heating network, the lower temperatures are sufficient; only some commercial users continue to require a higher temperature level. To close this temperature gap, special high-temperature heat pumps must be used, which raise the temperature provided by the network from, for example, 70 °C to 120 °C. For these purposes, the Institute of Thermodynamics (IfT) is working on the practical application of an environmentally

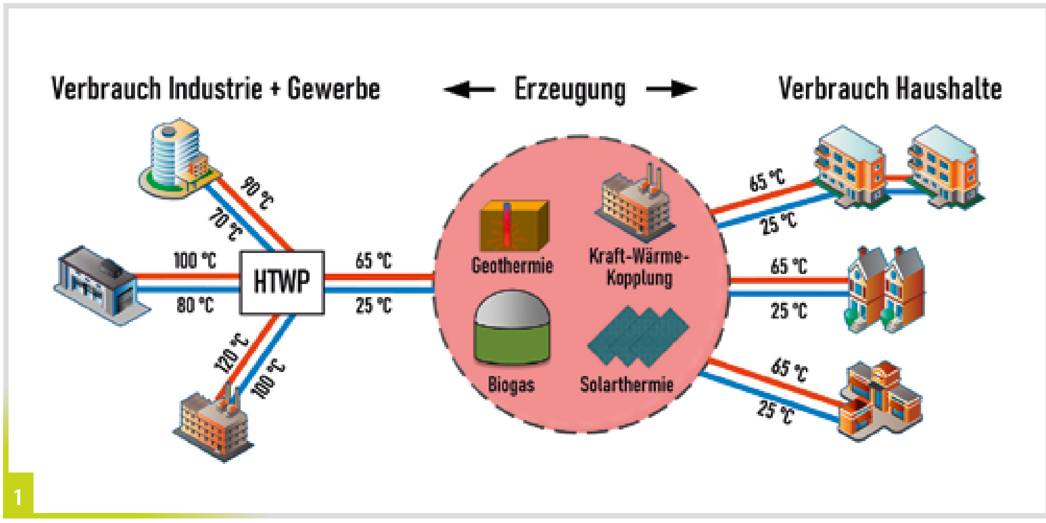


Figure 1
*District heating network schematic*
*Source: own representation*

friendly ammonia-water high-temperature heat pump (HTWP) in the project „Investigation of two energy converters with low power requirements for supplying high-temperature consumers from low-temperature district heating networks“, whereby efficiency, partial load behaviour and the optimisation of the underlying cycle process are the focus within the ongoing investigations. For this purpose, extensive cycle simulations are being carried out on the one hand, and on the other hand experimental investigations are being carried out on a pilot plant scale, see *Figure 2*. The District Heating Research Institute in Hanover and the University of Stuttgart are partners in this joint project.

Figure 2
*The ammonia/water high-temperature pilot plant at the IfT*
*Photo: IfT*

### The principle

The high-temperature heat pump at the IfT is based on the same functional principle as a commercially available refrigerator with a mechanical compressor, which is used millions of times. From a technical point of view, refrigerators and heat pumps are very similar, the different designation is only used to distinguish the heat flow and temperature level used. Refrigerators transport heat from their cold interior into the warmer environment, while heat pumps bring heat from the environment to a higher temperature level and use it to heat a building, for example. Their operating principle can be seen in *Figure 3*. A working fluid (refrigerant) circulates inside a heat pump, which is responsible for transporting energy between the individual apparatuses of the heat pump cycle shown in the picture. The fact that pressure and temperature of a gas are coupled via its density is already noticeable in the air pump, which heats up considerably when the bicycle tyre is inflated. The widespread cold vapour compression cycle process of a heat pump shown in *Fig. 3* makes this a little more sophisticated: First, the refrigerant absorbs heat at low pressure (and thus also lower temperature) and evaporates. Then the pressure (and thus also the temperature) is increased in the compressor. Now liquefaction at a higher temperature is possible, with heat being released on the heating side. Through the subsequent pressure reduction (expansion) to the lower pressure, the refrigerant is again in its initial state and can again absorb heat. In order to transport („pump“) heat from a lower to a higher temperature level, contrary to the natural temperature gradient, energy must therefore be expended for the compressor. If the usable heat flow is put in relation to the electrical power used at the compressor, the so-called coefficient of performance (COP) of the heat pump is obtained. The coefficient of performance can reach values significantly greater than 1, which means that the heat pump can provide considerably more heating heat flow than the electrical power used for it. An electric fan heater can only achieve a coefficient of performance of maximum 1. Accordingly, heat pumps offer a strong lever to make renewable electrical

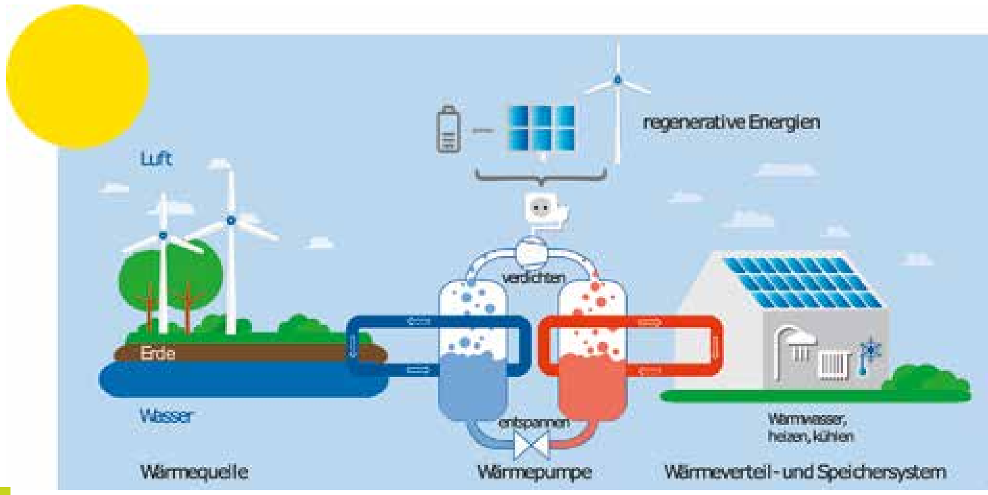

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Figure 3
*Functional diagram of a climate-neutral heat pump.*
*Source: own representation (idea from BWP e. V.)*

energy usable for heating applications. For this reason, heat pumps are a key technology for decarbonising the heat supply in Germany. In addition to the low-temperature HP for heating buildings, which is required in large numbers, many other variants are being developed, such as the high-temperature HP described at the beginning or the HP for efficient heating of electric vehicles. Due to the already mentioned proximity to the refrigerator, a heat pump can also be used for cooling by a small change in the cycle, i.e. both as an air conditioner and as a heater.

The refrigerant used determines the central properties of a heat pump, such as the temperatures that can be reached or the pressures required for this. In addition to the thermodynamic properties, the environmental compatibility of the refrigerant used also plays an important role. This means that it must have the lowest possible greenhouse gas potential (Global Warming Potential GWP), must not contain any ozone-depleting substances (Ozone Depletion Potential ODP = 0) and that other potential hazards such as flammability and toxicity must be taken into account. Neither the synthetic refrigerants commonly used to date, such as the still widely used R 134a (GWP value of 1600), nor the ‚natural' refrigerants favoured in the future, such as ammonia, water, propane or even $CO_2$ (GWP value of 1), fulfil all the desired properties. Actually, the refrigerant remains in the cycle; only in case of leakage or improper disposal does refrigerant escape. However, due to the billionfold occurrence of these cycles as refrigerators, air conditioners or as heat pumps, environmental compatibility also plays an important role in the legislation on refrigerants.

## The heat pump research landscape in and at LUH

The search for new, environmentally friendly refrigerants is one of the research tasks to which the IfT is devoting itself in the project described at the beginning. The ammonia/water mixture currently favoured here makes special demands on the process, but is thermodynamically very effective. Another focus at the institute is the design of possible innovative cycle processes of the refrigerant, which can be used as a basis for future heat pumps. For this purpose, the changes of state that the refrigerant undergoes are predicted by means of simulation and validated in experiments.

At the Institute for Solar Energy Research (ISFH), heat pumps have been studied as a component of modern heat supply systems for 15 years. Central topics are optimised system integration, sustainable source heat supply and independent evaluation and quality control of heat pump systems. At the ISFH heat pump test stand (see *Figure 4*), heat pumps and systems are tested according to established standards or examined in hardware-in-the-loop procedures under dynamic ambient conditions. The monitoring of real systems enables the evaluation of heat pumps in the field.

The project „Demonstrator for the Solar Heating tipping point (DESWENDE)" on the topic „Solar Heat Pumps - Heating and Cooling with the Help of the Sun", carried out by the Institute for Meteorology and Climatology, is intended to familiarize citizens as well as commercial enterprises with the operation and applications of heat pumps. The demonstrator of the DESWENDE project was highly appreciated during the Open Day at the Federal Ministry of Economics and Climate Protection (BMWK) on 20 and 21 August 2022. Dr. Habeck, Federal Minister for Economic Affairs and Climate Protection, personally visited the stand with the demonstrator and informed himself about the project and its goals, see *Figure 5*. The idea of the project is that heat pumps become more tangible for citizens by appealing to several senses. Combined with solar-generated electricity they have the potential to be operated without the emission of greenhouse gases. The demonstrator consists of an air-to-air heat pump with PV system with a very low greenhouse gas potential, battery and, if necessary, a solar simulator to convey how the system works. The project is supported by the Lower Saxony Climate Protection and Energy Agency (KEAN) and the Institute for Physics Education at LUH.


Figure 4
*DESWENDE in operation at the Open Day of the Federal Ministry of Economics and Climate Protection (BMWK).*
*Photo: IfT*

The ISFH and the IfT, together with the Energy Research Centre Lower Saxony (EFZN) and the Climate Protection and Energy Agency KEAN, have founded the Lower Saxony Heat Pump Initiative (WIN), a network to support the faster dissemination of heat pumps. This initiative was also born out of the insight that, from the point of view of the urgently required decarbonisation of the important heating sector, the heat pump plays a central role, but that there is still a great deal of educational work to be done, as well as a need for research and funding, in order to realise the desired spread of this interesting thermodynamic machine.

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# Appreciate instead of throwing away

## Saving energy and resources by repairing capital goods


In today's world, the shift from fossil to renewable energy sources is inevitable. This presents us with major challenges, as new technologies have to be developed and familiar approaches to energy generation have to be rethought. But what about the entire energy value chain of a product? Is it possible to reduce energy consumption over the overall lifetime of a product? Let's take an aircraft engine as an example.
An engine should of course consume little fuel during flight. Yet, it is necessary to consider the entire life cycle. Energy is not only required during the operation and manufacture of the engine, but also during the repair and disposal of its components.

### Regeneration of complex capital goods

A reduction in the use of resources for the entire life cycle of a capital good can thus start at various stages during the entire life cycle. The primary focus is usually on the new part, which should be developed and designed in the best possible way in order to obtain the most efficient product. But even in the development process itself, attention can be paid to ensure that resources are used as sparingly as possible.

This is where the Collaborative Research Centre (CRC) 871 "Regeneration of Complex Capital Goods" at Leibniz Universität Hannover comes in, which has been researching regeneration processes since 2010 in accordance with the principle "Appreciate instead of throwing away" in order to maintain capital goods in the most resource-efficient way possible and to integrate them into the value chain.
To this end, products are designed in such a way that they can be used for as long as possible and repaired in the event of a defect instead of being disposed of.  This is particularly important in the case of so-called complex capital goods and technically complex products, as these would often have to be replaced with high investments in a resource-intensive manner.
This is the only way to make complex and thus mostly expensive goods economically and ecologically profitable. For this reason, the longest possible service life and net value is of interest, especially for these goods. Examples of such capital goods are shown in *Fig. 1*.

### Ageing reduces efficiency

However, repair is not only an option when a part is defective. The decisive factor here is the wear of the various components, which can reduce efficiency. A good example of this are components in aircraft engines, such as turbine and compressor blades, which are exposed to extreme conditions. Due to high temperatures and pressures, the strong mechanical stress caused by centrifugal forces, as well as damage from foreign bodies, such components can exhibit various types of defects. These include plastic deformation, wear due to environmental influences, material abrasion, crack formation as well as corrosion due to hot gases.

The wear of the surfaces of the blades in the turbine of an aircraft engine alone can increase the fuel consumption of an Airbus A320 by almost 10 tons in a maintenance interval (20,000 operating hours), which increases the cost of fuel by almost 8000 USD. This demonstrates the potential for replacing or repairing worn blades to reduce operating costs. Thus, wear and the associated repairs are highly relevant to the overall consumption of resources and the capital asset and are increasingly coming into focus. However, this requires well-founded knowledge-based decisions.

### Repair or replace?

Whether a part is retained, repaired or replaced depends on various factors. Of course, the question arises: how efficiently does the repaired and the existing part perform compared to a new part? For example, instead of replacing the worn blade in an aircraft engine, the surface can be regenerated. If, for example, only 25 % of the surface is repaired, almost 80 % of the additional fuel consumption can already be saved again without having to manufacture a new blade, which in turn requires a high energy input.

However, it is not only the part itself that is important, but once again the manufacturing and machining process must also be taken into account, as this represents an important part of the overall energy consumption. Thus, it is also important to know what resources are needed for the repair and what are the throughput times for repair. It may even make sense to leave a part in a slightly worse condition if this enables a significantly faster and/or resource-saving repair, which creates capacities for the repair of further parts. For this reason, CRC 871 has also developed processes that significantly shorten the throughput times of repairs.

## Example: Turbine blade repair

Due to the increasing demands on the efficiency and service life of engines, modern turbine blades must be protected against the above-mentioned damage. For this purpose, either pure oxidation-resistant coatings (hot gas corrosion protection coatings) and/or thermal barrier coatings are used. In view of rising costs for raw materials as well as manufacturing and energy costs, the repair of components in the aviation industry and power plant technology is playing an increasingly important role. One repair method used for high-pressure turbines is high-temperature brazing for surface defects and micro-cracks. This involves several complex process steps. The most important steps here are brazing in a high vacuum and the application of a hot gas corrosion protection layer, which is subjected to a further coating process so that the protection against hot gas corrosion is significantly improved (the so-called aluminizing process). However, brazing and aluminizing are very energy-intensive processes. The CRC 871 has successfully developed a hybrid process that makes it possible to shorten the state-of-the-art process chain for repair brazing of turbine blades, which is illustrated in *Fig. 2*. According to the current state-of-the-art, three to four repair cycles can be carried out in this way. In the hybrid technology developed, the worn turbine blade is given a repair coating and then subjected to heat treatment, whereby the brazing and aluminizing processes are carried out simultaneously. On the one hand, this results in mechanical and technological improvements (the number of repair cycles can be increased by 50 % and the adhesion of the coating is also improved) with additional economic advantages. On the other hand, energy costs can be saved by about 25 %. In this way, a component can be used for longer and the consumption of resources can be significantly reduced during repairs.

## Holistic approach

At the same time, dealing with the wear and repair of individual components has another advantage, as additional conclusions can be drawn about how a part will behave after longer operation in the engine. This can also be used for the design of new parts. In this context, CRC 871 has shown that it is necessary

Figure 1
*Examples of complex capital goods*
*Source: own representation*

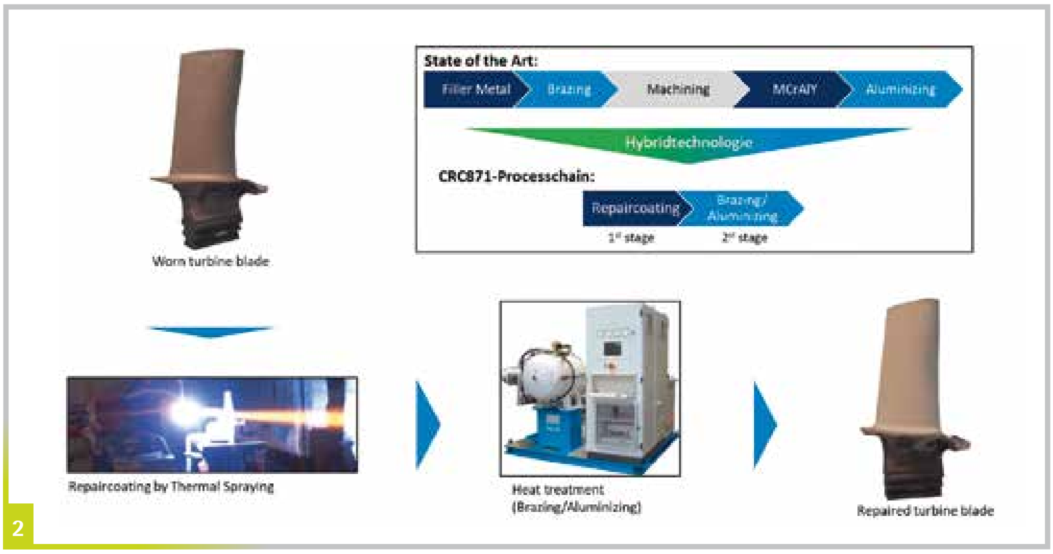



Figure 2
*Principle of the hybrid technology developed*
*Source: IW*

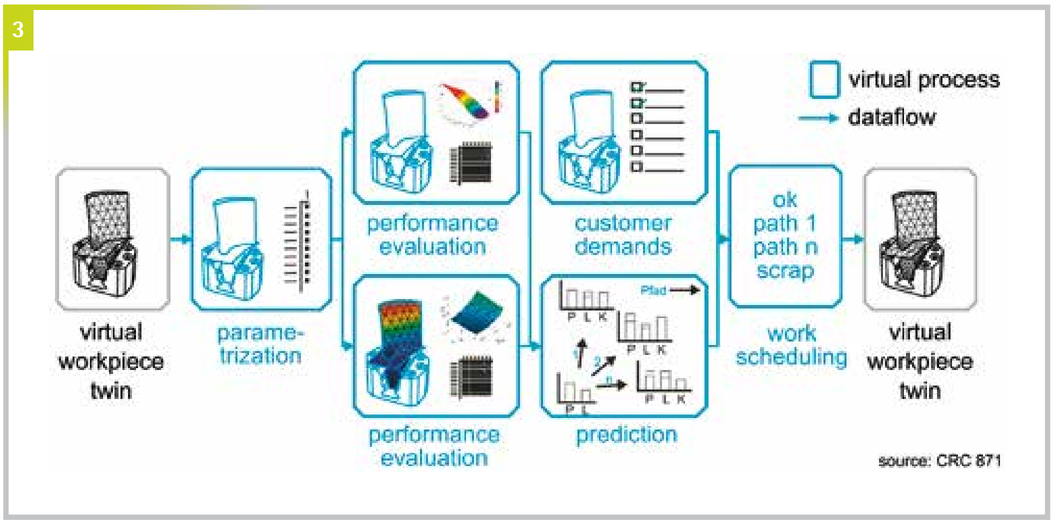
to first consider the large number of sub-steps in a regeneration process of a complex capital good individually in order to reduce the high complexity. Accordingly, both the performance evaluation of the components in the engine, such as the combustion chamber, compressor, and turbine, and the processes of condition detection and regeneration are initially considered separately. To this end, CRC 871 has shown with a system demonstrator that an optimal repair process can only be implemented if the planning of the process is based on a digital twin. For this purpose, the workpiece under investigation is digitised and possible repair paths and their effects are calculated, see *Fig. 3*.

With this approach, an optimal repair path can be selected that best fulfils economic and ecological goals. In the end, however, it is important to bring all processes together again, as this is the only way to examine the impact of a repair decision on the overall system.

### Generalisation of the methodology: Dual digital twins for repair process and capital good.

This can also be transferred to the production process of a new part, so that here, too, a digital twin brings decisive advantages. This basic concept is now deepened at Leibniz Universität Hannover. Specifically, the digital twins of the production process and the product itself will be linked. This dual twin uses data from the design and construction of the products, the manufacturing in the production plants and the condition monitoring during the use phase to enable efficient automated decisions and process planning. Energy and other resources can be successfully saved by balancing energy and resource expenditure holistically over the entire product life cycle and using these balances to find

Figure 3
*Process of evaluation and decision-making for the repair of a turbine blade*
*Source: CRC 871*



and implement the most economical solution in terms of energy and other resource consumption. The prerequisite for this is the digitalisation of both the capital good and the production and repair processes. This methodology was tested using the example of the repair of a turbine blade.
As described above, 25 % of the energy of this repair step could be saved in the coating alone. The approach tested in this way will be extended to other parts of the product life cycle in the future.

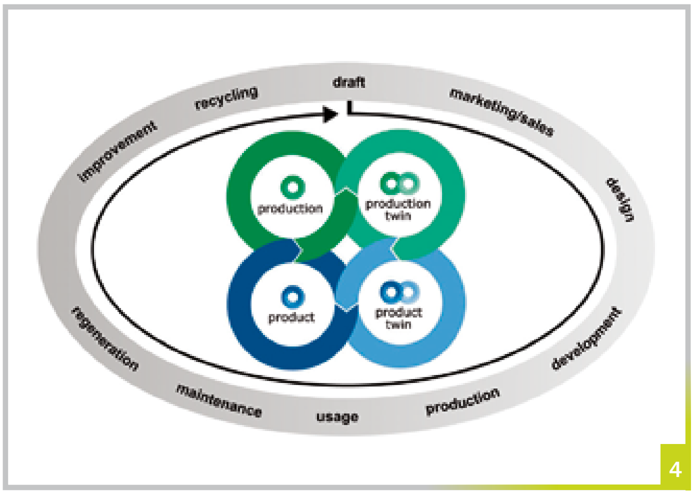



Figure 4
*Saving energy and resources through digitalisation and process improvement*
*Source: IDS*

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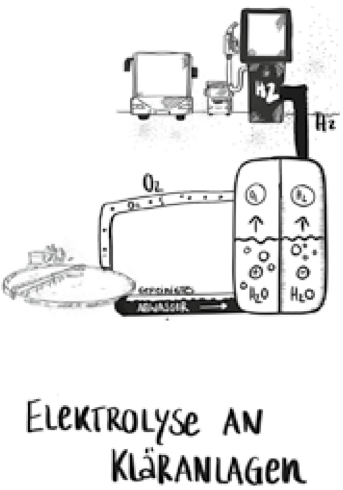
# Hydrogen: An Enabling Force for Sector Coupling

## How hydrogen research brings together waste water, local transport and heat supply




Hydrogen will play a vitalrole in the transformation of our energy system: as a raw and auxiliary material for the chemical industry and in metal production, in the context of energy transport and energy storage, as well as in mobility. The latter is the aim of the present example project SeWAGE PLANT H, in which Leibniz Universitäty Hannover is involved with the Institute of Sanitary Engineering and Waste Management and the Institute of Electric Power Systems.

The core of the project, which is being led by the Hannover Municipal Sewage Department, is the provision of hydrogen by means of a megawatt-scale water electrolysis plant at the Herrenhausen large-scale sewage treatment plant and its subsequent use in local public transport or to meet further future hydrogen requirements in the Hannover Region. The highlight of the sector-coupled concept, however, is the linking of hydrogen production and supply with the optimal use of oxygen and waste heat, which are by-products of hydrogen production. These by-products are to be used directly at the Herrenhausen sewage treatment plant. In particular, the project will investigate how the oxygen produced can be used most efficiently in the waste water treatment process. Oxygen can be used either as a supplementto the aeration of the existing biological treatment stage or as an oxidizing agent in a so-called 4th purification stage with the aim of disinfection and elimination of pharmaceutical residues. Municipal wastewater treatment plants are currently responsible for an average of 20 % of the electricity consumption of all common municipal facilities, with aeration energy (i.e. the energy used to introduce atmospheric oxygen) accounting for between 50 and 80 % of the total energy consumption of the wastewater treatment plant, depending on the size of the plant and the pumping requirements. The direct use of the by-product pure oxygen can thus contribute to a significant reduction here.

Its use in a 4th purification stage would further improve the quality of the sewage plant effluent and create the conditions for using purified wastewater, for example, for the irrigation of the Herrenhausen Gardens. Another advantage of setting up the plant directly at the sewage treatment plant is that the water that is continuously needed for the water electrolysis process does not have to be taken from the drinking water network, but directly treated wa-

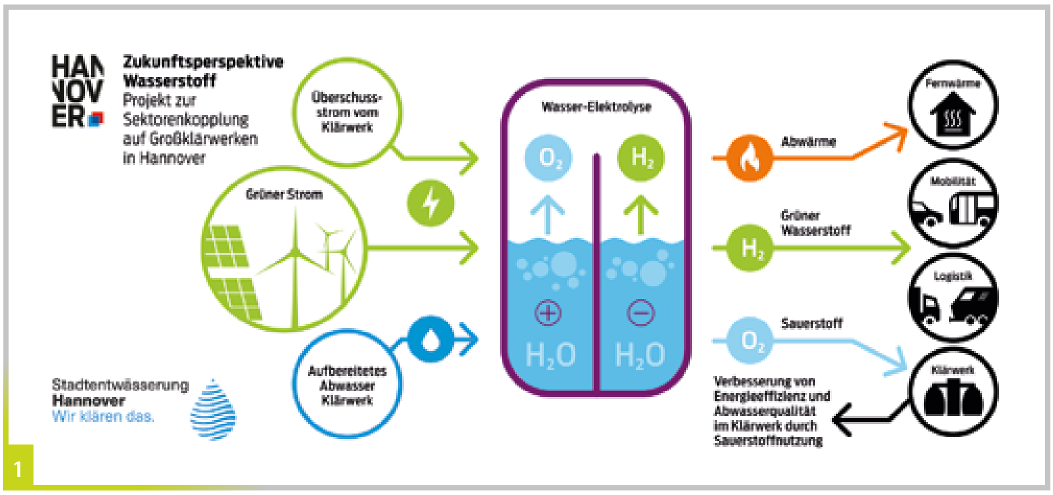



Figure 1
*Hydrogen, together with other green gases, can become the backbone of the urban energy transition. From an energy point of view, an attractive overall system results from a high utilisation of the energy used and the coupling of three sectors (mobility, heat, wastewater treatment). Source: Stadtentwässerung Hannover/BUSCHBRAND grafikdesign.*

ter from the treatment process can be used. It becomes apparent that the sector coupling pursued here is a convincing approach with regard to the use of resources and energy both in hydrogen production and at the sewage treatment plant, and also contributes to improving the economic efficiency of both processes.

The plant will initially be able to produce about 400 kg of hydrogen per day. This corresponds to the daily demand of about 15 hydrogen buses that could be used in the future on routes of the local transport companies ÜSTRA and regiobus Hannover, which cannot be operated battery-electrically due to the route and deployment profile. The electrolyser and the associated infrastructure are planned in such a way that they can be expanded in a modular fashion in order to be able to respond to a future increase in demand for hydrogen, for example from logistics companies or other users in the Hannover Region.

The waste heat from the electrolyser, which is in the order of 10 – 15 kWh per kg of hydrogen, will in future be fed into the district heating network of the local energy supplier enercity AG by means of a heat pump system, thus contributing to the defossilisation of the district heating supply. By 2035, enercity AG wants to obtain half of its district heating from renewable sources.

The dynamic interaction of the hydrogen generation process, wastewater treatment and district heat supply and the resulting operating strategies are being studied and developed by the Institute for Electric Power Systems (IfES), which is working very closely with the manufacturer of the electrolysis plant, the Hannover-based company Aspens. In addition, IfES and the Institute of Sanitary Engineering and Waste Management (ISAH) are working together on the creation of a toolbox for the design of such systems at sewage treatment plants, taking ecological and economic aspects into account. With the help of the toolbox, it should be possible in future to transfer such concepts to sewage treatment plants throughout Germany and beyond. The technical implementation of sector coupling with regard to aeration optimisation and advanced purification is being tested by ISAH and another research partner from the Technical University of Dortmund in close cooperation with Stadtentwässerung Hannover in semi-technical trial operation and in practical operation at the Herrenhausen sewage treatment plant site. This project is funded by the state of Lower Saxony within the framework of the hydrogen directive. However, it not only contributes to solving the factual questions associated with the project, but also forms an important lighthouse project in the context of the hydrogen programme of the Hannover Region and the associated network "Generation H2" (www.generationh2.de). Under this label, the regional economy, administration, research and education have joined forces to make green hydrogen usable in the Hannover Region, to build regional value chains and to develop joint projects. Leibniz Universität is a founding member of this network.


Figure 2
*The hydrogen produced at the Herrenhausen sewage treatment plant is to be used to power buses operated by ÜSTRA and regiobus Hannover, among others, from 2023 onwards in order to reduce emissions in Hannover's public transport system.*
*Source: Stadtentwässerung Hannover/ creanovo – motion & media design.*

### Supraregional, national and international projects

Apart from regional projects, such as the "SeWAGE PLANT H" project presented here, Leibniz Universität is also involved in supraregional, national and international projects on the topic of hydrogen.

One example from the supra-regional environment is the project “Innovation Laboratory Water Electrolysis (InnoEly)” funded by the Lower Saxony Ministry of Science, in which the universities of Braunschweig, Clausthal, Hannover and Oldenburg are working together with selected Lower Saxony companies. The aim is to create a characterisation and modelling toolbox for the further development of technical water electrolysers of all three technology lines for the production of green hydrogen. Furthermore, the joint project “H2-Wegweiser Niedersachsen”, which is presented in more detail in the article ... (No. 15/Brendel) and is closely interlinked with InnoEly, should also be mentioned in this context.

At the state level, Leibniz Universität is also involved in other collaborative projects that have arisen under the umbrella of the Energy Research Centre of Lower Saxony – EFZN within the framework of the EFZN Hydrogen Research Network Lower Saxony. Leibniz Universität played a leading role in setting this up. It is worth mentioning in this context that the cooperation at the state level not only relates to research, but that the joint professional development programme “Hydrogen for specialists and managers” was recently launched, which started its first fully booked course in September 2022.

At national level, Leibniz Universität is currently involved in the so-called hydrogen lead projects of the Federal Ministry of Education and Research (BMBF) with a funding volume of several million euros. The objective of this funding line is to implement the Federal Government’s National Hydrogen Strategy. To this end, a large bundle of projects has been set up between relevant industrial companies and established players in hydrogen research. In this context, the work at Leibniz University is concerned, for example, with the optimisation of water electrolysers, across all projects with the aim of reducing material costs, increasing service life and reducing energy requirements for hydrogen production. The unifying methodological element of all the work is the combined use of modelling/simulation tools and experimental characterisation and validation.

In the area of sector coupling, the provision of green energy via biogas and the synergetic use of by-products are particular focal points of various LUH institutes. For example, in addition to the issue of optimal oxygen utilisation in sewage treatment plant operation, the ISAH is currently involved in the “EnZaH2” project in Steyerberg as part of the BMBF SATELLITE project with the issue of regional biogas provision – a project for the production of climate-neutral fuels according to the CAPHENIA process, in which methane is split into carbon and hydrogen and then processed into synthesis gas.

On an international level, the recently launched EU project “MacGhyver” is an example. Together with four other university partners from Spain, the Netherlands, Poland and Germany and a French company, Leibniz Universität is working on a concept for hydrogen production using waste water. At the heart of this is an electrolyser concept that exploits the approaches of microfluidics and is modularly scalable. Leibniz University is designing the overall system and developing and testing an electrochemical compressor for post-compression of the product hydrogen.

On the subject of hydrogen, there is intensive cooperation at Leibniz Universität Hannover not only between the Faculty of Electrical Engineering and Computer Science and the Faculty of Mechanical Engineering, but also at the Faculty of Civil Engineering and Geodesy (e.g. underground storage of hydrogen, Institute of Geotechnics), at the Faculty of Architecture and Landscape (e.g. environmental analysis in the context of hydrogen supply, Institute of Environmental Planning), at the Faculty of Economics (e.g. economic implications of providing hydrogen for global air transport, Institute of Environmental Economics and World Affairs, Institute of Environmental Economics and World Planning). e.g. environmental analysis in the context of hydrogen supply, Institute of Environmental Planning), at the Faculty of Economics (for example, economic implications of providing hydrogen for global air travel, Institute of Environmental Economics and World Trade) and at the Faculty of Science (see article ... (No. 7/Horn)).

The latest activity of the hydrogen “family” at Leibniz Universität Hannover is a collaboration between the Institute of Physical Chemistry and Electrochemistry and the Institute of Electric Power Systems. The aim of this interdisciplinary cooperation is to improve electrode materials for fuel cells. To this end, new materials are being developed using a cryogelation process developed at the Institute of Physical Chemistry and Electrochemistry, which is based on colloidal nanoparticles and allows unprecedented control of the micro- and nanostructure through targeted cross-linking of the nanoparticles (*Fig. 3*).

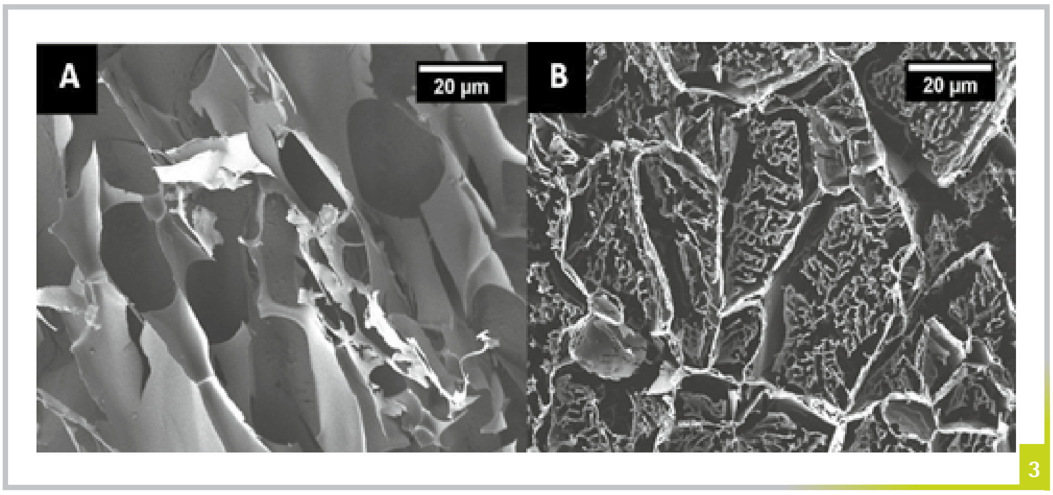



Figure 3
*Electron micrographs of two different cryogels with different microstructures.*
*Source: Müller et al. (2021), Langmuir 37 (17), 5109*

Hydrogen research will continue to gain in importance, since hydrogen is of great significance in terms of both energy policy and industrial policy. In the future, there will be numerous value-added potentials, both in the local hydrogen supply and its application and from the perspective of an equipment supplier industry, which will be able to serve a developing global market with components, apparatus and plants in the future. At Leibniz Universität, we will continue to accompany and promote this development and contribute our expertise so that we as a society can benefit from hydrogen from both a climate protection and an economic perspective.

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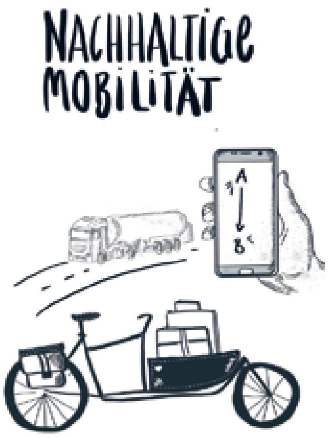
# Delivering goods efficiently and sustainably:

## The USEfUL web application




As urbanization continues to rise globally, with 55 % of the world's population residing in cities and urban areas, the challenges associated with urban logistics are becoming increasingly complex. This is particularly evident in megacities, where populations exceed 10 million. The United Nations predicts that by 2050, 68 % of the global population will live in urban areas.

The surge in e-commerce and the subsequent demand for goods delivery in urban areas have led to significant challenges in urban logistics. The digital transformation and emergence of new business models in urban food, beverage, and parcel delivery, coupled with the need for 24/7 delivery to retailers and businesses, necessitate a dynamic traffic management system. This system must be capable of handling time-critical deliveries and services.

The global COVID-19 pandemic has further complicated urban logistics, leading to an increased demand for parcel delivery services. Cities are now grappling with transport and infrastructure challenges that impact the health and quality of life of urban populations. These challenges include traffic congestion, noise pollution, local pollutant and greenhouse gas emissions, accidents, and land conflicts. The quality of urban life and the cityscape largely depend on the sustainable and efficient measures implemented by city administrations to make the increasingly complex urban transport system more environment-, climate-, and people-friendly.

One solution to optimize a city's future transport and mobility system is to encourage innovative logistics concepts. As the "last mile" delivery is the most cost-intensive part of the parcel delivery supply chain, logistics providers are eager to optimize their processes through alternative concepts. Municipal decision-makers need to strategically assess which urban logistics concepts and measures are sustainable and efficient. The specific characteristics of a city or district are crucial, and the assessment of future impacts is complex. Testing alternative logistics concepts in specific neighborhoods through individual pilot projects is costly due to the associated planning effort. As the number of urban service providers and delivery companies increases, so does the uncertainty, amplifying the need for data-based decision support for strategic planning of urban logistics initiatives.

The BMBF research project USEfUL and its follow-up project USEfUL-XT (2018-2023) address these challenges. They aim to answer the question: How can a web-based information system support decision-makers in the strategic planning of urban logistics concepts while simultaneously assessing their economic, ecological, and social impacts? Within USEfUL and USEfUL-XT, a web application is developed to evaluate simulated urban logistics scenarios individually and specifically. The simulations demonstrate their impact on urban life, traffic, the environment, and delivery costs.

The USEfUL web application empowers local decision-makers, politicians, and companies to evaluate electrified delivery vehicles and cargo bikes. It provides citizens with accessible information on alternative logistics concepts and their potential impacts. Municipalities can use the USEfUL web application to identify sustainable and efficient measures to make urban logistics quieter, reduce emissions, and lower delivery costs. Another goal of USEfUL is to contribute to the EU target of making urban logistics as greenhouse gas neutral as possible by 2030. A focus is therefore on promoting electrified fleets, the use of alternative light vehicles such as cargo bikes, or sharing systems.

The USEfUL web application integrates a simulation-based micro- and macro-scale pool for scenarios of urban logistics concepts and an integrated

rule-based expert system to ensure scalability and transferability to individual problem specifications.
It also includes an encyclopedia of urban logistics and an interactive clustering of urban and rural space types based on selected specifications.

In addition to selecting sustainable and efficient logistics concepts, decision-makers must also consider their optimal implementation in future urban planning. The synergies between the USEfUL(XT) and 5GAPS projects (BMDV, 2022-2025) play a crucial role. While USEfUL(XT) focuses on urban logistics, 5GAPS concentrates on creating a digital twin of the city of Hannover in the form of a cubelet world (3D space, time, and attributes). The insights and results gathered in USEfUL(XT) will be utilized in 5GAPS to develop optimized 5G communication-based logistics scenarios. Among other things, 5G technologies will assist in reserving flight corridors for UAV deliveries and introducing a digital parking management system to reduce traffic congestion caused by "second row parking".

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Figure 1
*Innovative and Sustainable Logistics Concepts for Low-emission Urban Traffic*
*Source: fuchsundhase*

Figure 2
*Decision support through the USEfUL Web Application*
*Source: unsplash/Michael Dolejs*

# Flexible and robust pathways to the energy transition

New transformation routes to a sustainable energy system


For the transition to a sustainable and climate-neutral energy and economic system, we need convincing and robust pathways to achieve our goals. These transformation scenarios must also provide sufficient flexibility to be able to react to developments in the technological, economic and geopolitical boundary conditions that are not yet foreseeable today.

## Modelling the energy system transformation

The energy system modelling software "ESTRAM" (abbreviation for "Energy system transformation model") allows the design and optimisation of energy system transformation paths for European regions and countries up to the consideration of the entire continent. ESTRAM was developed by an interdisciplinary team at Leibniz University (LUH). It is based on a broad database on the current European energy system as well as technical and economic data on current and future technologies and components of the energy system. Thanks to the close connection to LUH energy research, new results on the function, performance and further development of system components can quickly flow into scenarios as technical input.

A major current geopolitical challenge for the energy transition is the gas and energy crisis in Europe caused by the Russian invasion of Ukraine. Natural gas power plants are a good fit for energy systems with a high share of fluctuating renewable energy (RE) due to their characteristics (flexible operation and lower emissions than hard coal). The loss of Russian natural gas is creating a supply gap in Europe, which in Germany alone amounts to 291 TWh and thus about one third of the current and future demand for natural gas. The question is whether and how it is possible to use significantly less natural gas while at the same time leading the energy transition to success.

In the medium and long term, green energy sources (hydrogen, synthetic fuels) will take over the role of flexible natural gas. Renewable energy capacities must be made available for the production of these. The varying distribution of RE potential worldwide offers sun- and wind-rich regions the opportunity for very cost-effective production. On the other hand, transport costs must be considered, especially for hydrogen, which in turn tends to favour production close to the consumer. The quantities in which green gaseous energy carriers will be available in the medium term are still unclear. In the next few years, demand will probably exceed supply. The current situation on the energy markets clearly shows that energy prices can rise very quickly if there is a shortage.

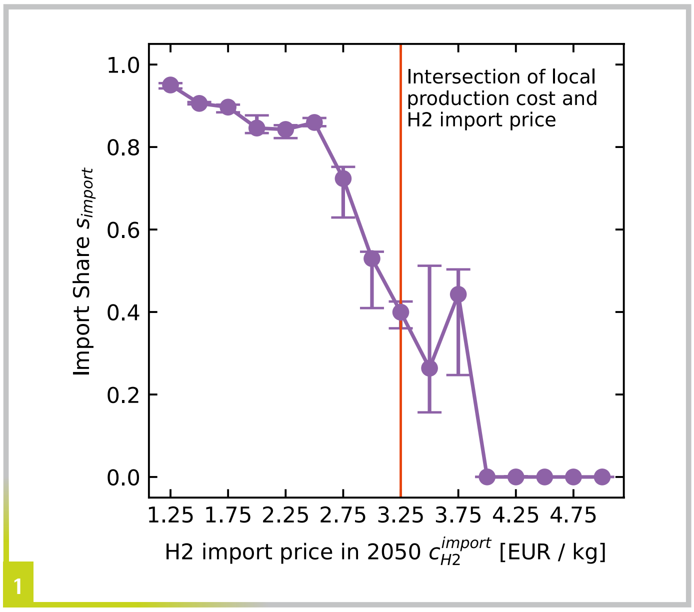



Figure 1
*Import shares of green hydrogen in the cost-optimised energy system depending on the import price.*
*Source: Florian Peterssen/FKP*

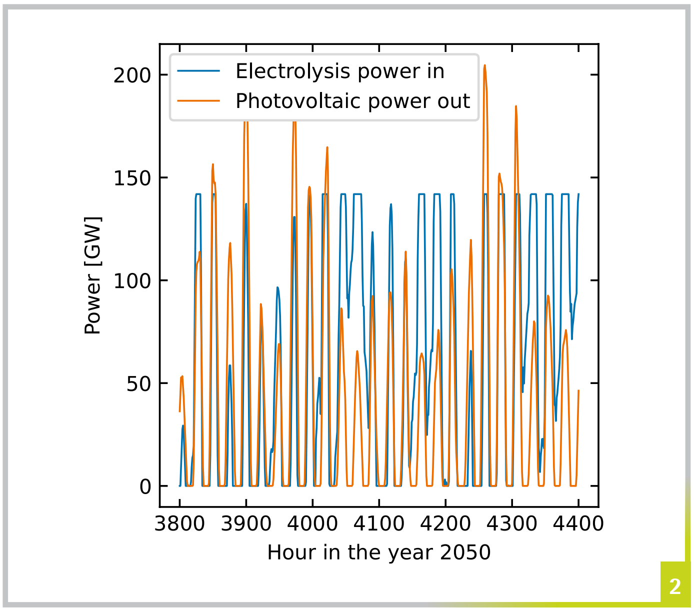
At the Institute of Solid State Physics, together with the Institute of Electrical Energy Systems, we investigated how the import price of green hydrogen will affect the German energy system. *Figure 1* shows how the share of imported hydrogen changes with the price. While imports are preferred for particularly low hydrogen prices, the modelling tool for high hydrogen prices suggests producing all hydrogen domestically. This is accompanied by a massive expansion of RE.

Since the energy system model also maps the operation of the energy system over the year in temporal resolution, conclusions about the role and deployment profile of energy system components can be drawn from the simulation. For example, in the scenarios with relevant domestic hydrogen production, there is very often a clear correlation between electrolysis and the photovoltaic (PV) feed-in profile (see *Figure 2*). Hydrogen is produced in these scenarios mainly in summer to store the then abundant PV yields for use in autumn or winter. The strong correlation with PV means that electrolysis will be operated with far fewer (2500) full load hours in the future than today (5000).

## An international joint task

Even if it would be cheaper to produce green hydrogen exclusively in Germany, it is at least challenging to build up sufficient RE capacities for it in densely populated Germany. Especially for countries with large RE potential areas in northern Africa, the Middle East and south-eastern Europe, in geographical proximity to the important energy market of Europe, green hydrogen therefore offers an opportunity for economic development. However, the development of RE capacities in third countries for the export of GHG-neutral energy sources should also be sustainable and linked to an accelerated local energy transition. Energy system analysis can also be used to address this issue. The EE100 model developed at the Institute of Environmental Planning supports the sustainable spatial allocation of RE plants and calculates area-specific sustainable RE potentials for individual regions or entire states. The amounts of energy that can be generated in this way calculated for Germany would be sufficient to cover a projected demand in 2040 with wind energy, rooftop PV and biogenic residual and waste materials alone. At the local level, the model serves as base for a participation tool implemented as a planning game, which can be used to achieve an energy target calculated for the municipalities or regions.

The global transition to renewable energy sources also has implications for the international economic and trade system. The Institute of Environmental Economics and World Trade uses macroeconomic equilibrium models to examine the effects of macroeconomic changes on key figures of economic development (for example employment, GDP, imports, production in economic sectors, consumption). This enables a macroeconomic assessment with regard to changes in the energy sector. The development of energy partnerships with intra- and extra-European partner countries can be examined in this way. The results can help policy-makers to set the right framework for an internationally sustainable energy system transformation and economic development.




## Exploiting regional opportunities

Within Germany, Lower Saxony has particularly large potentials for RE generation and storage. The energy system transformation therefore holds special opportunities for our federal state, both in energy generation and in the development of hydrogen, bioenergy and residual energy technologies.

In order to expand RE technologies in Lower Saxony, decentralised investments in existing and new buildings

Figure 2
*Application profiles of electrolysers (blue) and PV plants (yellow) during a summer week in the future energy system with a total of 300 GW installed PV capacity.*
*Source: Florian Peterssen/FKP*

and coordinated neighbourhoods are also needed. NESSI ("Nano-Energy System Simulator"), developed at the Institute for Business Informatics (https://nessi.iwi.uni-hannover.de/de/), takes the necessary perspective. NESSI is web-based, "open access" and intuitive to learn and use for owners and tenants of buildings, tradespeople, energy consultants and political decision-makers. NESSI calculates required investments and energy supply costs as well as contributions to climate protection and thus enables the quantification of three-fold sustainability (ecological, economic and social) and the determination of decentralised transformation scenarios.

Measurements in a heat-pump-supplied district in Lower Saxony show what can already be achieved with today's technology. Due to the good conditions for RE in Lower Saxony, 90 percent of this could already be supplied by RE from the region. For the remaining 10 percent and for economic sectors that rely on chemical energy sources, green hydrogen or green gases could then be used.

Literature references had to be omitted from this article. Interested readers will be gladly provided with a list of background literature. Contact: niepelt@solar.uni-hannover.de

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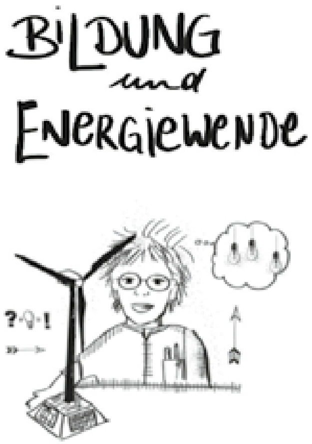
GOTTFRIED WILHELM LEIBNIZ UNIVERSITÄT

# Energy research boosts schools

## The Leibniz4U Student Research Centre as an educational transfer measure




### Introduction

Knowledge about the concept of energy is important for making informed decisions in everyday life. For example, it is assumed that knowledge about energy transfer and conversion can help to understand the factors that influence the greenhouse effect and thereby change environmentally related behaviour. Furthermore, insights into the concept of energy are necessary for structuring knowledge about other scientific concepts and is thus central to learning. However, the energy concept is complex and its scientifically adequate description may contradict everyday ideas, such as the idea that energy is assumed to be material-like in cycles rather than as a flow of energy.

Therefore, knowledge about the energy concept is promoted as part of a basic science education in class. Socio-scientific issues such as climate change are a particular challenge. In dealing with them, informed decisions about one's own behaviour require not only the inclusion of scientific knowledge. They also require the weighing of individual and societal values and norms. Especially in the context of education for sustainable development, extracurricular activities that go beyond school learning opportunities have the potential to promote informed decision-making. However, such offers are still too rarely implemented.

### Raising awareness of sustainable energy production outside of school

Socially relevant topics such as climate change and renewable energies are part of the research focus at Leibniz Universität Hannover. In order to reduce the burden on the environment, interdisciplinary research groups investigate intensively hydropower, solar energy, wind power and electric mobility at Leibniz Universität Hannover. To bring this topic further into the public eye and to sensitise and inspire the next generation, the topic of sustainable energy generation is part of the Gauß-AG's course offering for students at school. The generation of electricity through wind power and the functioning of an electric motor are focus of attention. For a whole week interested students can try out, experiment and discuss for themselves in the Gauss energy generation group. With the help of tasks and questions, they practise scientific work and craft their own projects in small groups. As a rule, four different workshops are offered per holiday course. The participants are supervised by university student tutors.

### Knowledge transfer through extracurricular activities

Extracurricular activities are particularly suitable for the transfer of knowledge on current research topics. In contrast to school lessons, these activities are not bound by formal requirements such as time limits, learning level

Figure 1
*In the Gauss-AG, school students work in small groups on their own project.*
*Photo: uniKIK Schulprojekte/LUH*

tests and strict adherence to the curriculum. Moreover, they promote – in contrast to the usual practice in school – interdisciplinary work. The school students participate and learn from existing problems from their real life. This is why extracurricular activities are part of the transfer model at Leibniz Universität Hannover. This model identifies the areas of knowledge that are currently the subject of research at the university and are of particular relevance to society.
A further element is the target group-specific didactic reconstruction of this knowledge.

The interaction and coherence of extracurricular activities with school learning opportunities are important for sustainable learning. In such a learning ecology, school students develop conceptual knowledge and apply it repeatedly in different contexts. The activities of the Team School Projects therefore build on each other in stages and range from a low-threshold introduction with demonstration experiments in LeibnizLAB to student research projects, for example in the Gauss-AG plus (see *Figure* 3). The aim is to enable students to work independently on questions in a student research centre. In the future, such extracurricular activities will be conceptually integrated into an online platform as part of the Leibniz4U student research centre, thus enabling coherence in the use of extracurricular activities and in the learning processes of students.

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**The Gauß-AG**

The Gauss-AG of the Team School Projects at the *Leibniz School of Education* is a holiday course for school students who are interested in science, technology and mathematics (STEM). It is offered annually and focuses on broad promotion by allowing students to work on STEM topics beyond the school curriculum.

→ Radio report on the Gauß-AG: **http://go.lu-h.de/radiobeitrag**

→ **https://www.lse.uni-hannover.de/de/transfer/schulprojekte/gauss-ag/**

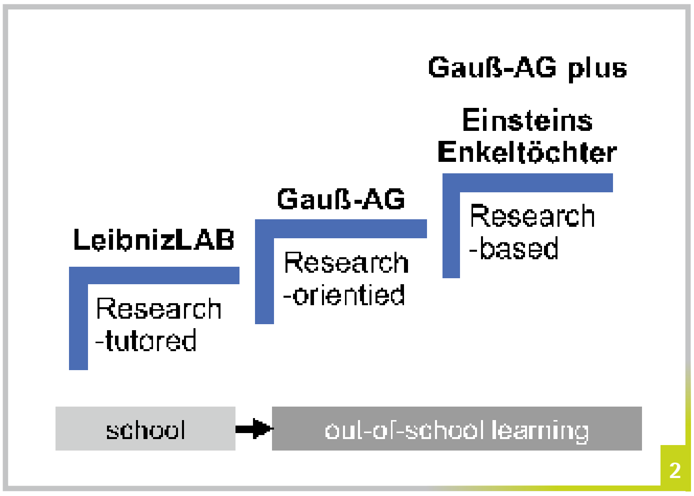
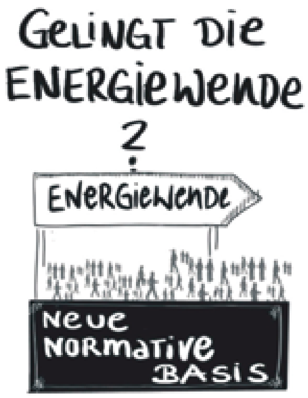



Figure 2
*QR code for the radio report on the Gauß-AG*
*Source: Till Bruckermann/LSE*

# Recursive norm formation in the energy transition

## Project examining social and legal negotiations




**Prof. Dr. Margrit Seckelmann**
*(Professorin Öffentliches Recht und das Recht der digitalen Gesellschaft an der Leibniz Universität Hannover, LUH)*

→ Further information at: **https://www.project-renew.org/**

In connection with the Russian war of aggression on Ukraine, renewable energies have recently received an enormous amount of attention, since they can be produced in Germany or in the European Union. This has been accompanied by a considerable semantic re-evaluation. For example, the German Finance Minister Christian Lindner recently no longer referred to renewable energies as expensive and volatile, as he did during his time as leader of the FDP parliamentary group in the last legislative period, but rather as "freedom energy".

This semantic reinterpretation fits in with the focus of our DFG-funded project on the energy transition: ReNEW: Recursive Norm Formation in the Energy Transition – On the Transformation of Energy Supply. The transformation of the energy supply in the process of the energy transition is characterised by the fact that relevant actors in the energy transition are not only struggling with technical and economic issues, but also over the underlying social and legal norms.

The interdisciplinary research project "Recursive Norm Formation in the Energy Transition – On the Transformation of Energy Supply" (ReNEW) focuses on three important processes of the energy transition in Germany: (1) the process that is developing through the Renewable Energy Sources Act (EEG) from 2000 and its amendments; (2) the processes that address the consequences of the Fukushima nuclear disaster in 2011; and (3) those that address the current processes of digitalisation of the energy industry. However, we are now broadening our perspective to include a look at the events mentioned at the beginning, in which values such as security of supply and national energy autonomy are once again becoming more central to the public debate.

Our project management team consists of Prof. Dr. Cristina Besio (Sociology of Organisations, Helmut Schmidt University, Hamburg), Prof. Dr. Margrit Seckelmann (Public Law, Law of the Digital Society, LUH) and Prof. Dr. Arnold Windeler (Sociology of Organisations, TU Berlin). We are supported by an interdisciplinary team consisting of Jana-Maria Albrecht and Florence Eyok (TUB), Timo Hoffmann and Dr. Dorothea Steffen (LUH) and Anna Skripchenko and Svenja Bauer (HSU).

Our basic assumption is that the success of the energy transition depends largely on whether a new normative basis can emerge. In this context, we analyse the ongoing negotiations of the normative order between different values and maxims, such as between security of supply and sustainability, between market principles and the common good, or between climate protection and nature conservation. The current global political conditions clearly show that the normative order is constantly being renegotiated.

We not only examine the changes in the legal framework itself, but also use guided interviews to analyse how heterogeneous actors (non-governmental organisations (NGOs), industry associations, etc.) help shape the normative ideas of the energy transition. We also focus on the main addressees of the new energy supply norms: the energy suppliers themselves. We are interested in how energy companies, medium-sized enterprises, municipal and regional utilities as well as energy cooperatives interpret external normative requirements differently and use existing freedoms (e.g. through investments). Theoretically, we deploy the concepts of "recursivity" and "respecification" as a basis, reflecting central mechanisms of the development of the normative order of the energy transition, and aim to develop these concepts further.

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# Energy transition in practice:

## Photovoltaics on the campus of Leibniz University Hannover


Leibniz Universität Hannover (LUH) has been using 100 per cent green electricity since 2017, thus making a contribution to sustainable energy supply. The existing photovoltaic systems were a first building block for the energy transition on campus. However, the aim is to make greater and better use of the existing potential in the future by retrofitting the roofs of the entire LUH building stock with photovoltaics, combine this with green roofs where possible, and making photovoltaics the construction standard for new buildings – including considering PV on walls. A corresponding Executive Board resolution from July 2021 reinforces this plan. In addition to renewable self-generation, greater independence from market-related price fluctuations is also an objective of these efforts, the necessity of which was recently underlined by the war in Ukraine. This article shows the current developments at LUH.

Since November 2021, the Building Management Department and the Green Office, which was set up in May 2021, have been working with the Klimaschutzagentur Region Hannover GmbH to prepare for the expansion of photovoltaics on the roofs of the LUH. For this purpose, among other things, a prioritization list was drawn up for the roof areas of the university buildings, which will be supplemented with further data and successively worked through in the coming years. The aim of the cooperation is to accelerate the installation of photovoltaic systems on campus. Currently (as of August 2022), the preliminary plans and tender documents for six roofs on the main campus are being processed. The solar potential of these systems to be installed is around 500 kWp with an estimated electricity yield of around 450,000 kWh/a, which corresponds to a $CO_2$ saving of around 282 tonnes per year. The special feature is that demonstrators for teaching and research are also being considered and the performance data of the systems are to be made visible to the users of the buildings as well as the public. The preliminary planning for the installation of photovoltaic systems at the Garbsen site has already been completed, so that construction will begin in 2023. The systems will also serve as a source of energy for a student laboratory for the storage of sustainable energy, which is run by Prof. Dr Junker from the Institute for Continuum Mechanics at the Faculty of Engineering.

In addition, new photovoltaic systems on two buildings were completed and put into operation in mid-2022 (see photo 1). The project was funded by the European Regional Development Fund. With 115.2 kWp and an output of around 96,000 kWh/a, the systems enable a saving of almost 60 tonnes of $CO_2$ per year.

The topic also has been taken up in courses. A special highlight at the beginning of 2023 was the „SOLAR Summer School", which took place via the LUH's Central Institution for Continuing Education under the direction of Prof. Dr.

Elke Wittich. In the first week of the Summer School, students were taught the basics of solar consulting, which was applied in small groups to a building at LUH as an example in the second week. LUH's long-term goal is to establish a „real laboratory“ for sustainable development on campus. In the microcosm of the campus, research, teaching, campus development and exchange with society in the region are to be thought together more strongly than before. Cooperation with other institutions such as the Institute for Solar Research Hameln (ISFH) as a non-university research institute will play a central role, as will the exchange of knowledge with members of the European University Alliance EULiSt.

Based on the experience gained with the Klimaschutzagentur Region Hannover GmbH, potentials and challenges for the expansion of photovoltaics on the campus can be collected. The Building Management Department and the Green Office are also examining other options for generating energy from renewable sources, as well as the heat transition and its feasibility on campus. This includes, for example, the installation of (vertical) wind turbines, geothermal energy and the use of ambient heat.

News and information on the expansion of renewable energies on campus or on selected projects can be found on the Green Office website at www.sustainability.uni-hannover.de. For questions or opportunities for cooperation, please contact greenoffice@uni.hannover.de.

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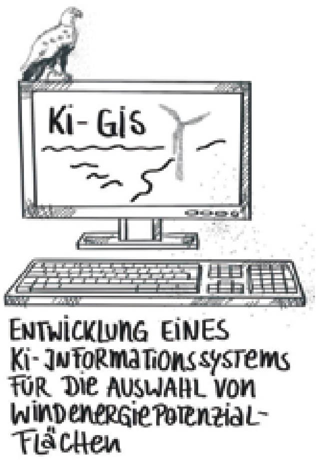
→ Info and contact details see page 58

Photo 1
Photovoltaic system on buildings 3703
*Source: Dezernat 3/LUH*

# WindGISKI –

## Can Artificial Intelligence find new areas for wind turbines?




The German government has set itself the goal of doubling the amount of electricity generated from renewable energies by 2030. Wind energy, in combination with photovoltaics, plays the decisive role in strengthening independence from fossil imports and achieving the climate targets. With the "Wind-an-Land-Gesetz" (Onshore-Wind Act), the federal government wants to establish binding area targets for the federal states for the first time and thus advance the expansion of wind energy in Germany significantly faster than before.

Nationwide, about 0.8 percent of the land area is currently designated as priority areas for wind energy, although only 0.5 percent of the land area is actually available due to various conflicting spatial resistances. The federal government therefore wants to significantly expand the designation of land with the "Wind-an-Land-Gesetz". By the end of 2032, two percent of Germany's land area is to be available for wind energy. The law recently passed by the cabinet therefore also contains an explicit new conception of for regulations on minimum distances for Wind turbines from residential areas. In addition, on the occasion of the cabinet decision, the responsive Federal Minister Robert Habeck affirmed a fair regional distribution among the federal states that takes equal account of wind conditions, nature conservation and species protection as well as the respective spatial orders.

From the point of view of both project developers and planning authorities, who are responsible for land development on the one hand and land designation on the other, the question of exactly where to locate the most suitable two percent of Germany's land area for wind energy is now more urgent than ever.
This is precisely where the joint project "WindGISKI", funded with a total of two million euros by the Federal Ministry for Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) in the funding programme AI-Lighthouses, comes in. Since December 2021, a total of eight research institutions, companies and associations have been pursuing the goal of innovating the land use designation for wind turbines in the interdisciplinary consortium:

- the Institute for Statics and Dynamics at Leibniz Universität Hannover as consortium leader,
- the IPH – Institute for Integrated Production Hannover gGmbH,
- Nefino GmbH,
- fk-wind, the Institute for Wind Energy at Bremerhaven University of Applied Sciences,
- the LEE Landesverband Erneuerbare Energien Niedersachsen | Bremen e.V.,
- ARSU-Arbeitsgruppe für regionale Struktur- und Umweltforschung GmbH,
- the Institute for Information Processing of the Leibniz University of Hanover and
- the Chair of Organisation and Innovation at Carl von Ossietzky University Oldenburg.

WindGISKI focuses on the joint development of a geographic information system (GIS) based on artificial intelligence (AI) for the selection of wind energy potential areas considering the conflict between species, environmental and climate protection. With the use of AI, WindGISKI is explicitly intended to address the main limitations of current practice in site designation. By mapping and systematising the complex weighing process at the level of the planning authorities, the biggest hurdle for wind energy should be overcome in the future: At both regional and municipal level, processes for the designation of new areas for wind energy plants still begin with the definition of high, general minimum distances from residential areas. In many places, however, these minimum distances exceed by far the necessary distances that would prevent a visually oppressive effect and ensure a reasonable shadow cast and noise pollution. As a result, only a few remaining areas are available to the planning authorities for consideration, which must be prioritised with regard to the remaining spatial resistances of nature conservation and species protection, and which are ultimately often insufficient to come close to achieving the area targets.

WindGISKI therefore starts from a "white" map and assumes that, at least theoretically, the construction of wind turbines is possible everywhere in Germany. The AI learns from the current wind turbine portfolio and the already designated area where and under which spatial resistances the construction of wind turbines was possible in the past - and also where and why there were considerable delays in some places, for example due to lawsuits by different stakeholder groups. In turn, the AI applies the learned knowledge to the entire land area of Germany, which is divided into 50 x 50 m tiles for this purpose. For each individual tile, the AI simulates a separate consideration process based on the respective spatial resistances, which does not require the prior definition of minimum distances to residential areas. In the GIS, it is thus possible to identify completely new potential areas for wind energy plants, especially where larger clusters of a large number of particularly positively assessed tiles can be found after the weighing process. As a result, WindGISKI has the potential to uncover significantly larger potential areas for wind energy in Germany, which at the same time take into account the concerns of immission control, nature conservation and species protection in a much more balanced way – if successful, an innovation that could make it much easier for the federal states to achieve the area targets in the future.

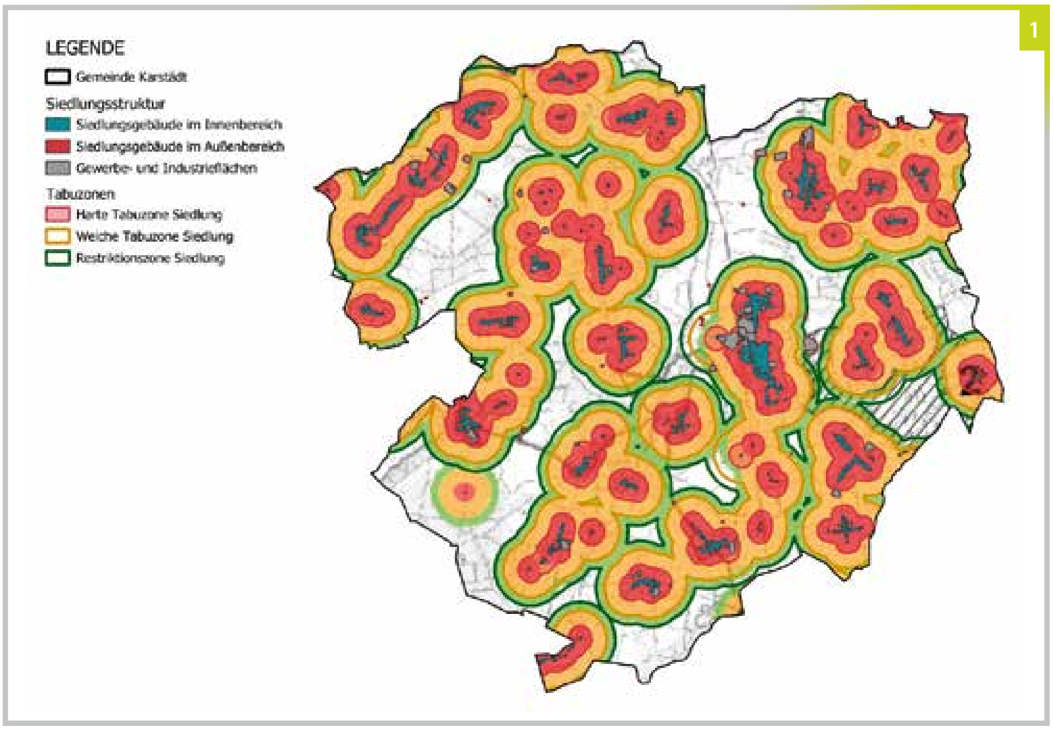



Figure 1
*With WindGISKI, minimum distances to residential buildings should be a thing of the past in the future.*
*Source: Nefino GmbH*

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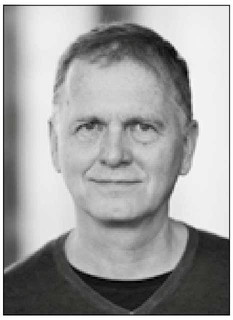

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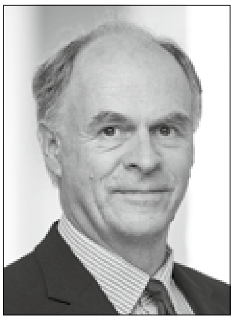

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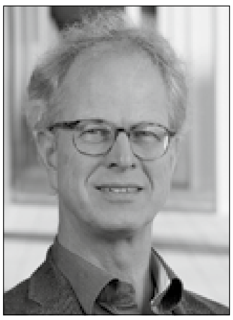

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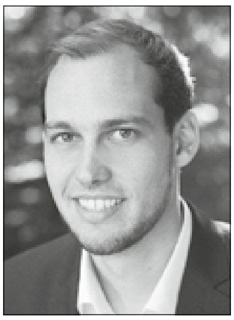

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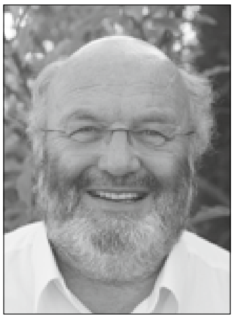

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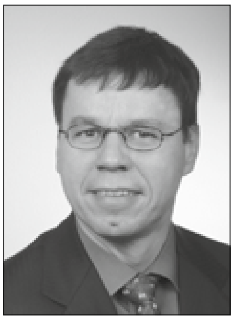

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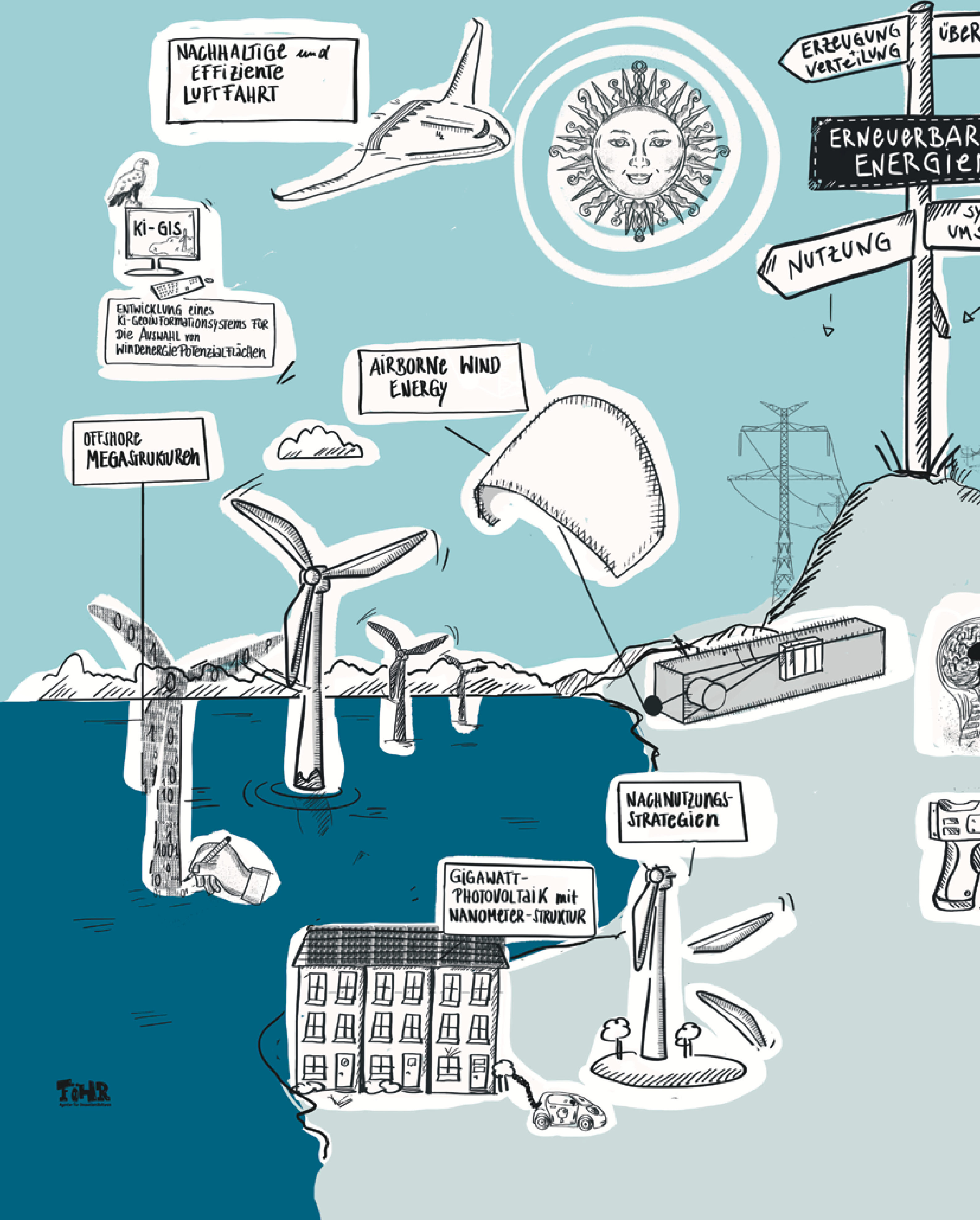

NACHHALTIGE und EFFIZIENTE LUFTFAHRT
ERZEUGUNG + VERTEILUNG
ERNEUERBAR
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ENTWICKLUNG eines KI-GEOINFORMATIONSSYSTEMS FÜR DIE AUSWAHL von WINDENERGIEPOTENZIALFLÄCHEN
AIRBORNE WIND ENERGY
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