23

WERNER SIEMENS-STIFTUNG

100 Jahre WSS

WSS

WERNER SIEMENS FOUNDATION

2023
report

Promoting innovation in technology and the natural sciences

The Werner Siemens Foundation supports groundbreaking projects in the natural sciences and technology. The selected projects in research and education are generally conducted at universities and higher education institutions in Germany, Austria and Switzerland; key requirements include upholding the highest standards and contributing to solving major problems of our time. The Foundation provides generous seed funding to innovative projects with the goal that, after a few years, the projects can be run independently and the results find industrial application. The Werner Siemens Foundation also promotes education and training projects and fosters young talent, particularly in the fields of mathematics, informatics, natural sciences, technology, medicine and pharmaceutical science.

Foreword

The Werner Siemens Foundation (WSS) is looking back on an extraordinary year, one marked by the Foundation's centennial anniversary. It was 100 years ago, in 1923, that the Werner Foundation (as WSS was originally called) was established in Schaffhausen, Switzerland, by Charlotte von Buxhoeveden and Marie von Graevenitz, daughters of Carl von Siemens who worked with his brother Werner von Siemens to build what would later be known as the Siemens Group.

A few years later, the Foundation's future was secured when three additional women from the Siemens family became major benefactors. We had the pleasure of honouring these five visionary women at an unforgettable anniversary celebration held for the descendants of Werner and Carl von Siemens in Baden-Baden in May 2023.

We also observed the centennial by setting a milestone in the Foundation's philanthropic activities. An ideas competition was launched for the WSS "project of the century", a research centre dedicated to the sustainable use of the world's resources; the Foundation will endow the new centre with a ten-year grant of no less than one hundred million Swiss francs.

The call for projects generated a resounding echo in the world of science: a total of one hundred and twenty three high-calibre research teams from Germany, Austria and Switzerland submitted their ideas. Deciding which of the projects would

make it to the final round of six and receive a WSS research prize of one million Swiss francs was no easy task. Still more difficult was choosing the winner from the six innovative final projects.

After careful deliberation, the Foundation selected the "catalaix" project at RWTH Aachen University, where a team led by Regina Palkovits and Jürgen Klankermayer will develop catalysis-driven production processes to enable a multidimensional circular economy in the chemical industry. The researchers are placing their initial focus on the efficient recycling of mixed plastic waste, and I am convinced that the WSS Research Centre in Aachen will meet with great success. I also believe that, through this singular project, our Foundation is making a significant contribution to achieving a sustainable use of our planet's resources.

In the latest edition of our report, readers can learn more about the catalaix project—and about advances made last year in the projects that currently receive financing from the Werner Siemens Foundation.

I thank you for your interest and hope you enjoy reading our report.

Hubert Keiber,
Chair of the Foundation Board of the Werner Siemens Foundation

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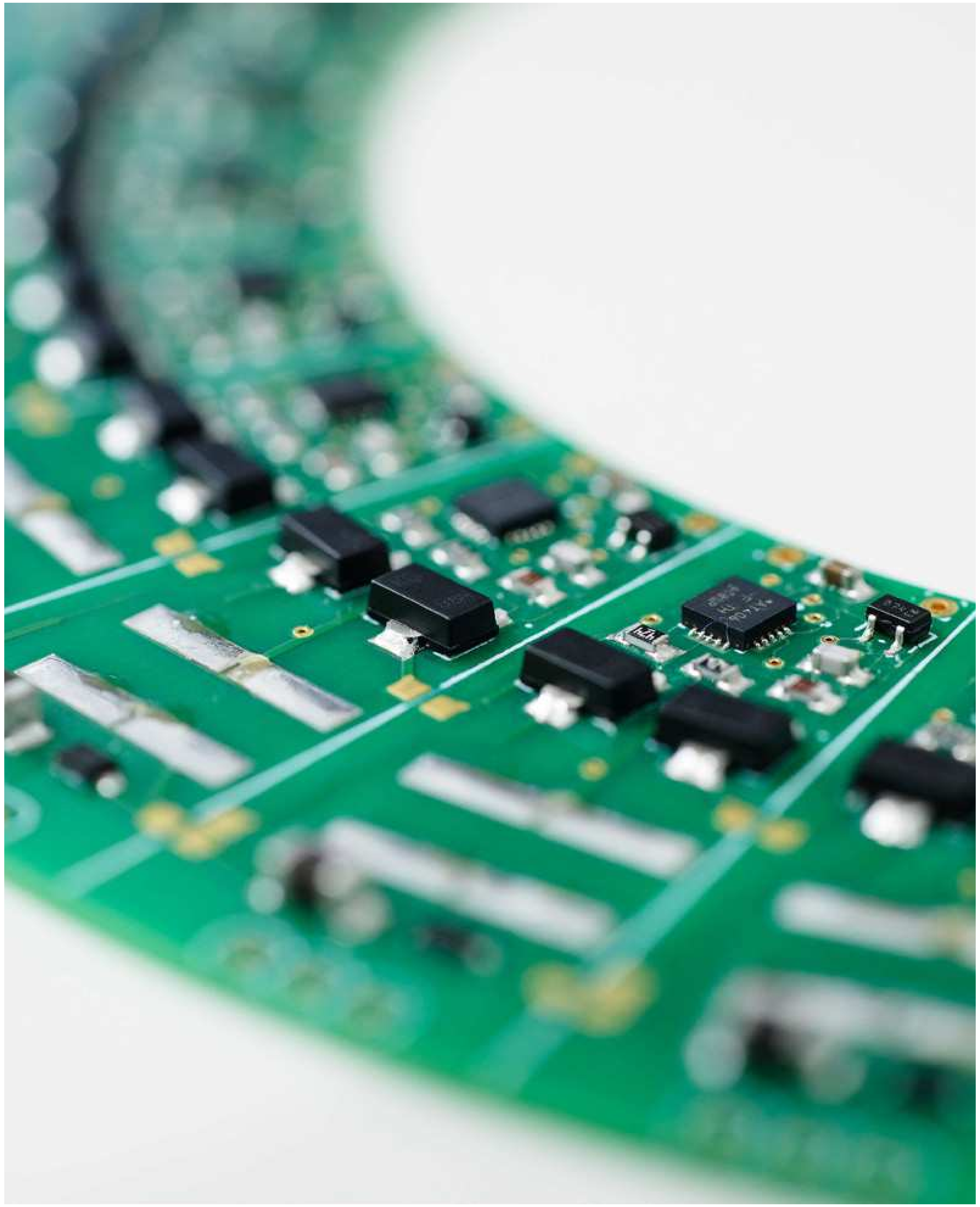
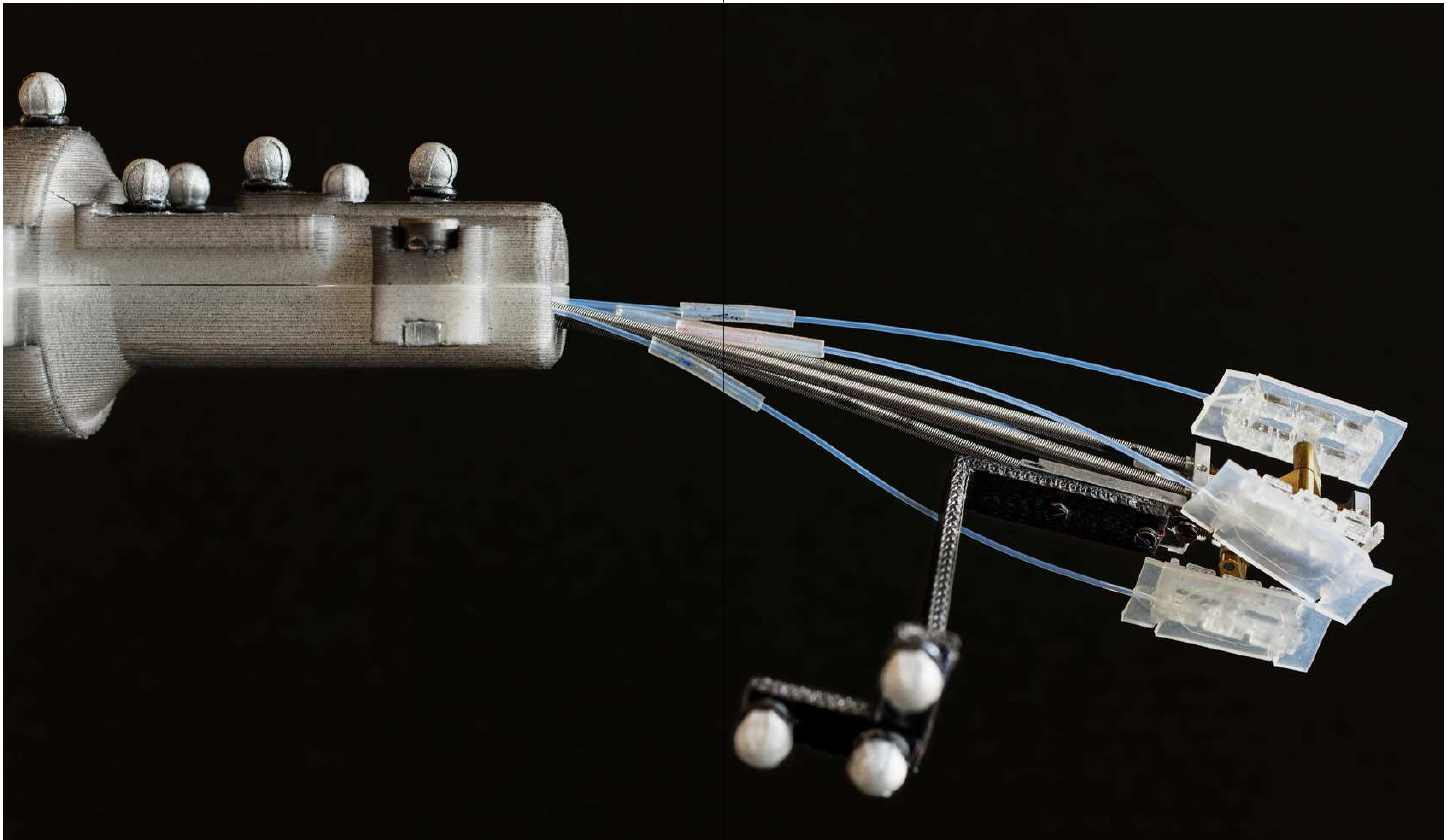
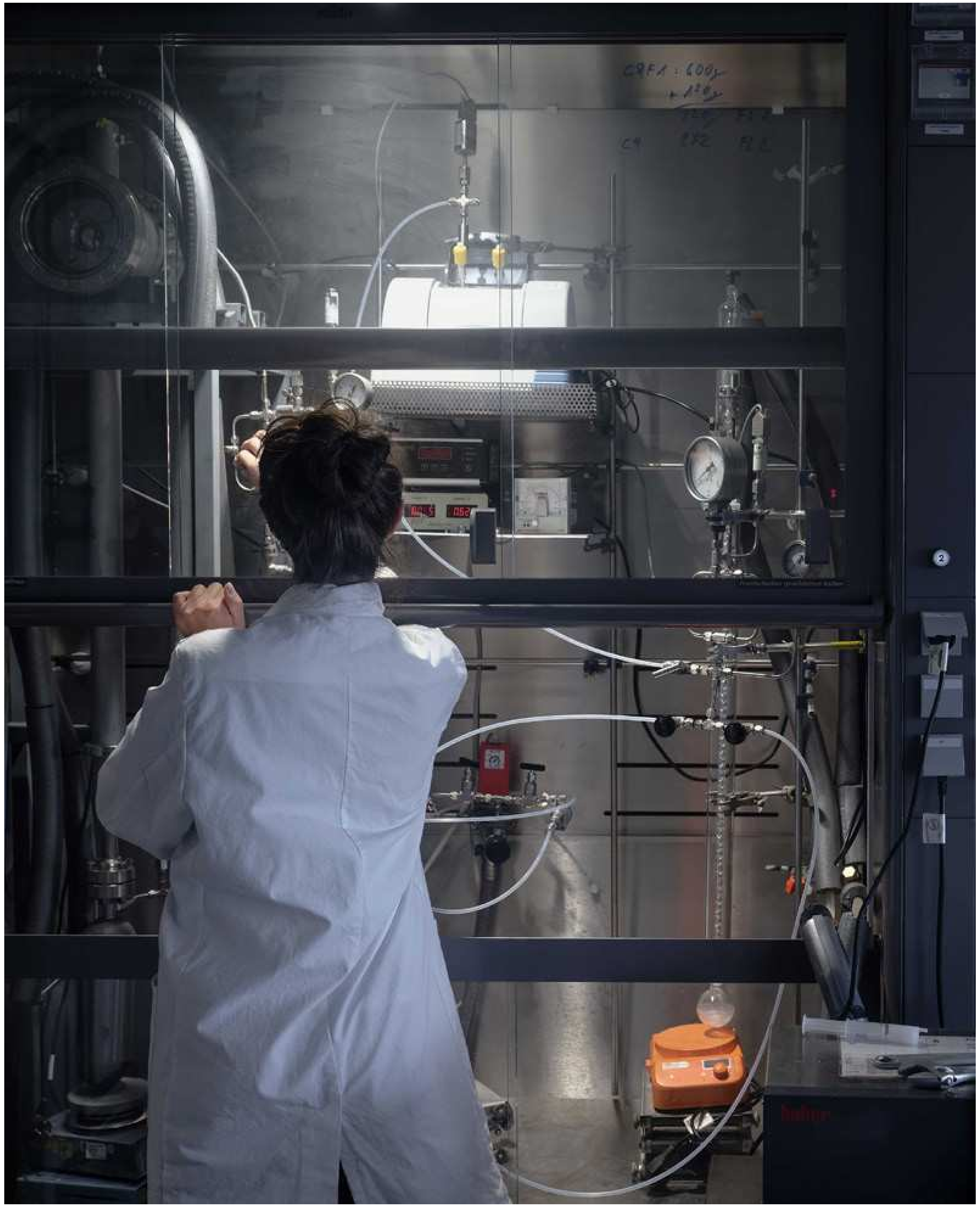


Electronic components are used to control the elastic polymer membrane created at the Center for Artificial Muscles in Neuchâtel.

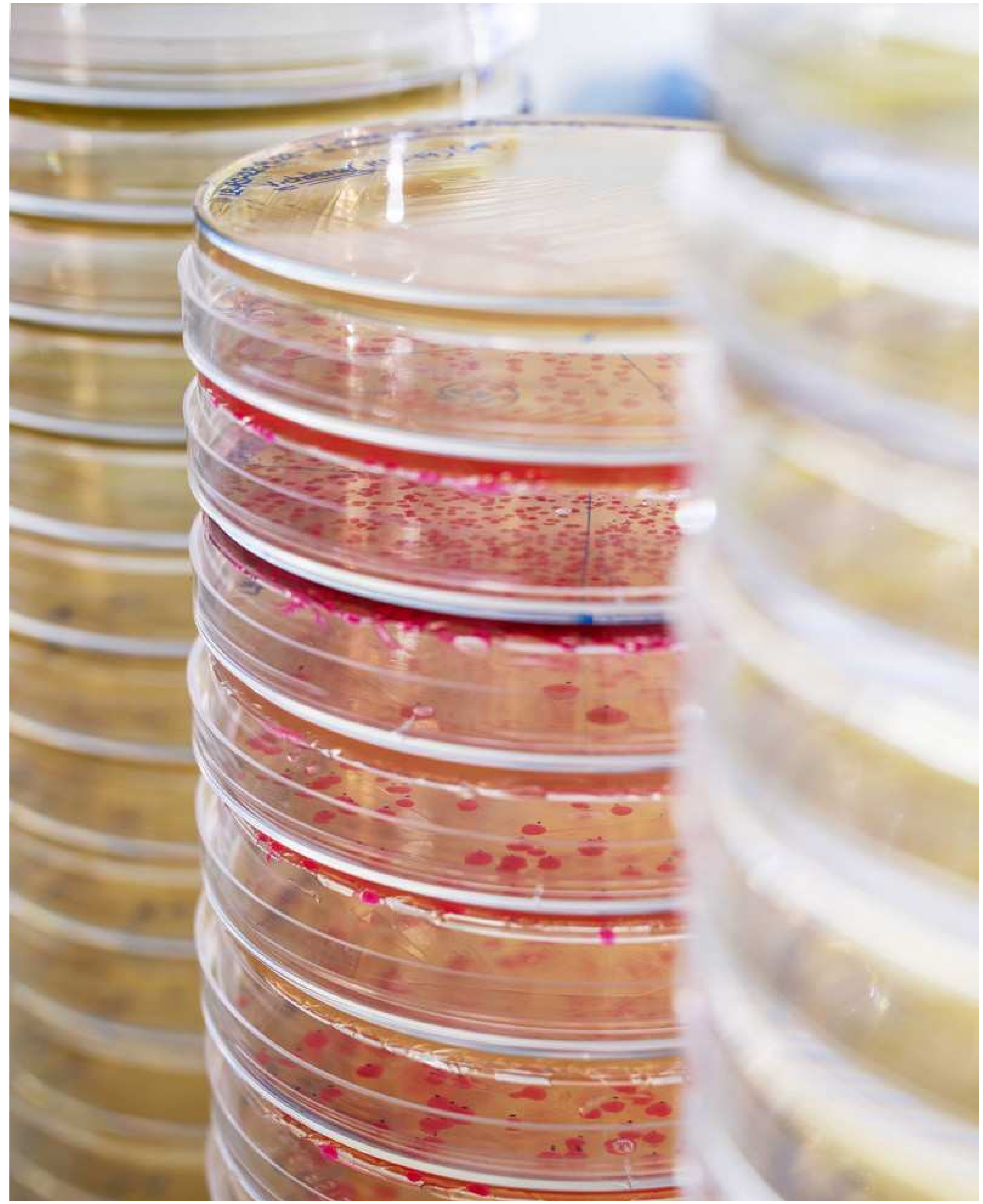
At the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany, Frank Dimroth (left) and his team conduct research into highly efficient solar cells.



Instruments used by the surgical robot in the MIRACLE II project in Basel must be small enough to fit into the tiniest of spaces.



Researchers in Sebastian Hasenstab-Riedel's Halogen Chemistry group at FU Berlin study gaseous reactions under controlled conditions.

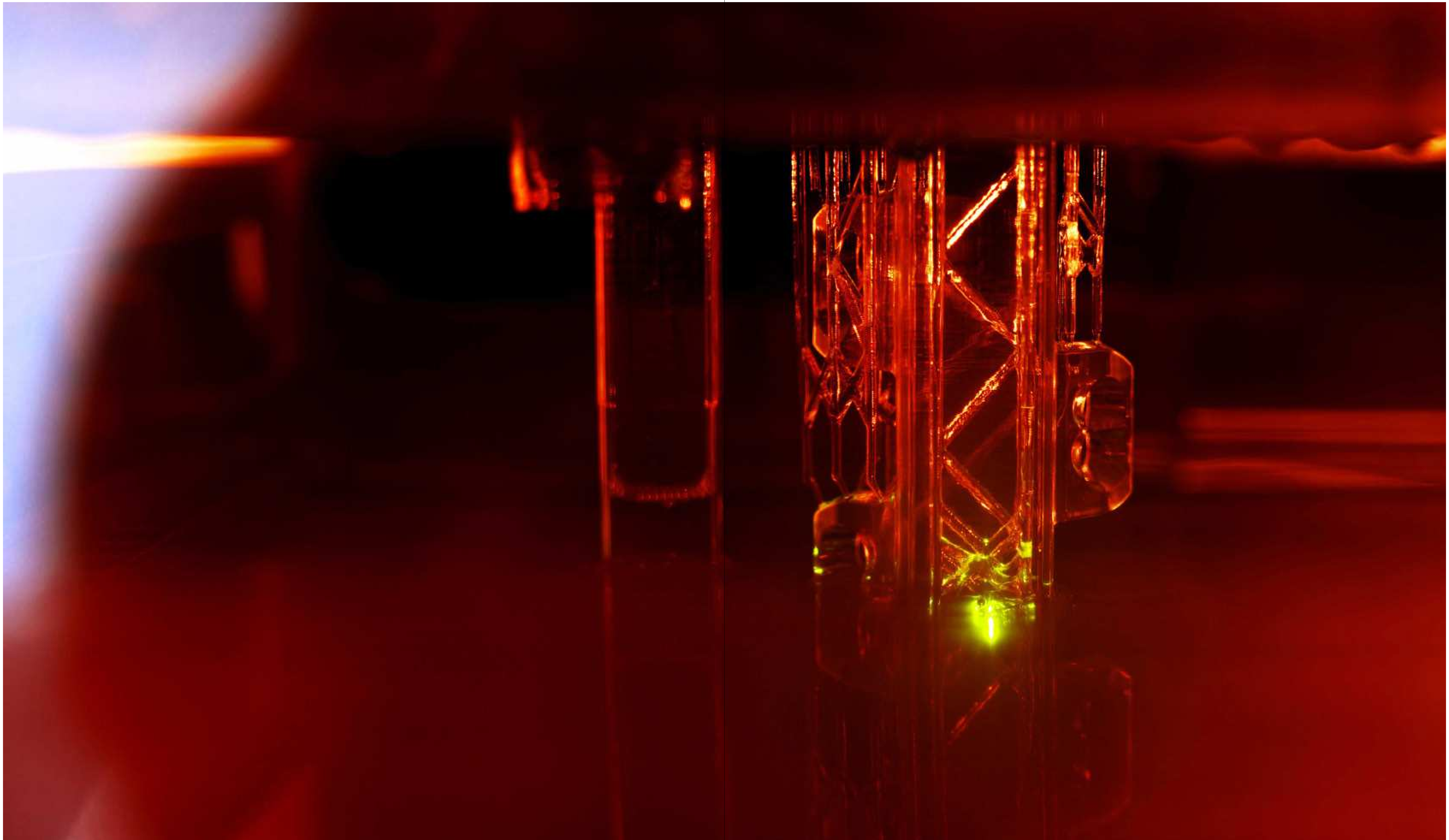


The Stone Age in a Petri dish: researchers in the palaeobiotechnology project in Jena introduce ancient substances into living bacteria.

The CarboQuant project team in Dübendorf use scanning tunnelling microscopy to study potential quantum electronic components.

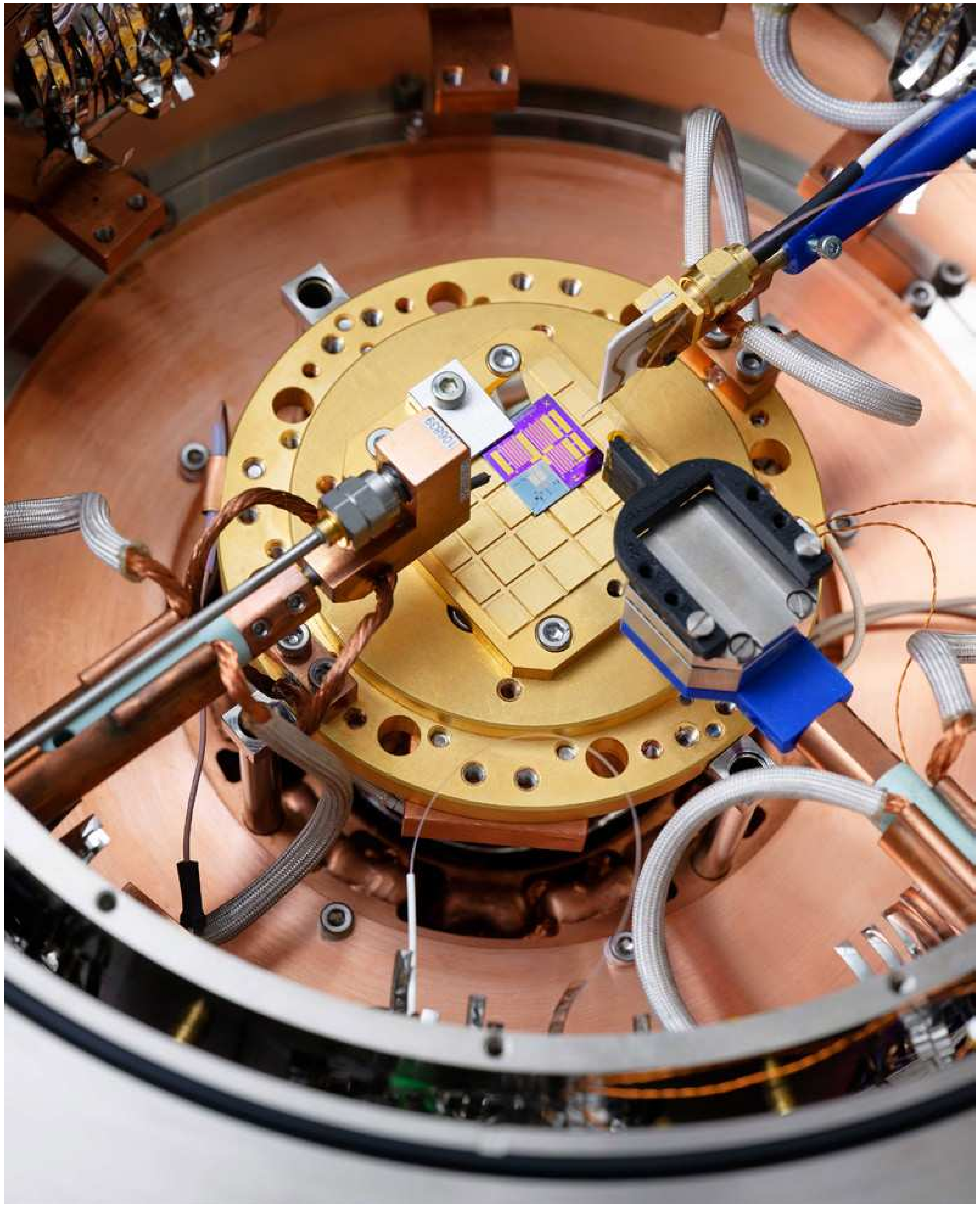
At TU Munich, a research team led by Senthold Asseng are creating the wheat of the future.

Plastic, pulverised and deep-frozen, in the catalysis lab headed by Regina Palkovits and Jürgen Klankermayer at RWTH Aachen University.



An implant prototype being created by a 3D printer in the smart implants project at Saarland University.

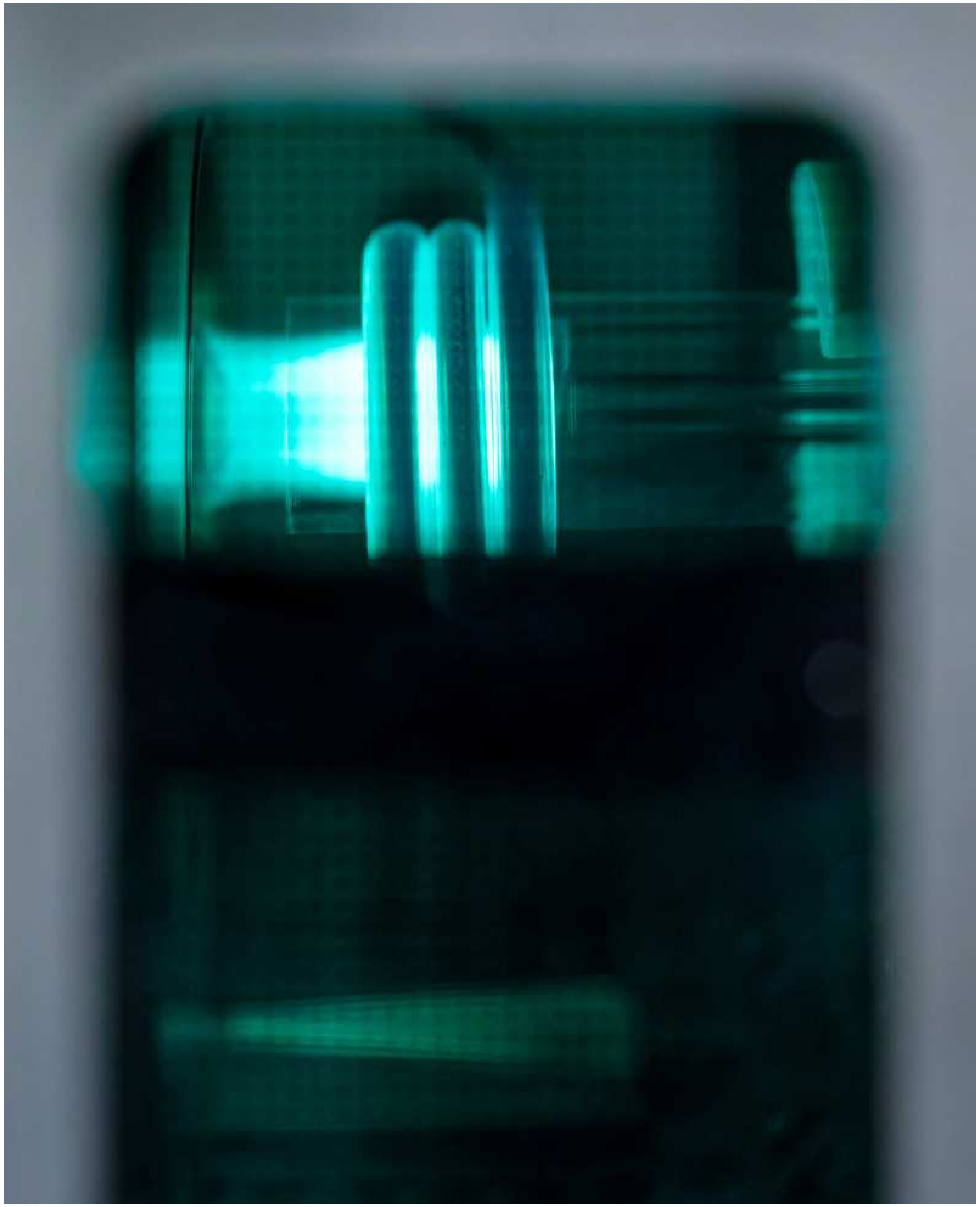
Ueli Angst's research group at ETH Zurich examine small mortar samples to learn more about corrosion processes in reinforced concrete.



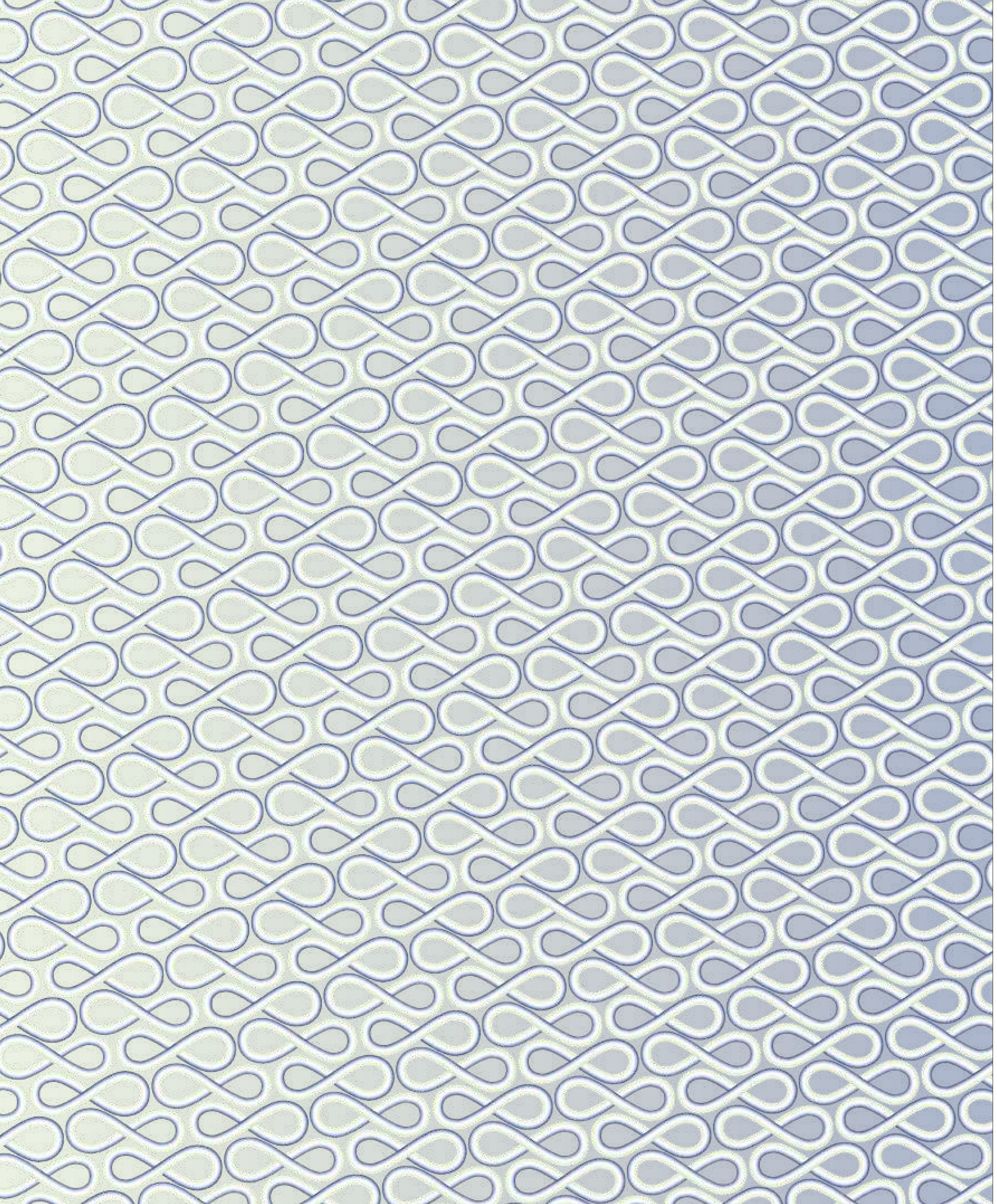
The team in the single-atom switch project at ETH Zurich are developing microchips that function with mind-boggling energy efficiency.

Teamwork at Lake Lugano: a group of students at the Swiss Study Foundation's summer camp in Magliaso.

Greta Patzke and David Tilley conduct experiments on water splitting in their labs at the University of Zurich.



The team led by Lutz Ackermann at Georg August University of Göttingen use a mass spectrometer to seek metal impurities in catalysts.



Sustainable future

Achieving a sustainable use of our planet's resources is probably the greatest challenge facing humanity today. Energy, air, water, food, habitats and raw materials are all limited natural goods that must be managed with care. In our special focus on the future of energy, we show how researchers in projects supported by the Werner Siemens Foundation are developing innovative solutions to better protect and utilise these valuable resources.

WSS 100

WERNER SIEMENS-STIFTUNG
JAHRHUNDERTPROJEKT

To celebrate its centenary anniversary in 2023, the Werner Siemens Foundation launched a unique ideas competition — a call for projects to establish a research centre that the Foundation will endow with a ten-year grant of one hundred million Swiss francs. One hundred twenty-three proposals were submitted, six of which made it to the final round. In the end, the grand prize was awarded to the “catalaix” project at RWTH Aachen University, where researchers plan to develop catalysis methods that will enable a circular economy in the chemical industry. Recycling technologies in the plastics sector is the team’s first research focus.

Professor Matthias Kleiner developed the concept for the WSS "project of the century" and served as project manager. He believes the call for proposals was unique in the research landscape, and that only a private foundation has the ways and means to carry out an ideas competition on this scale.

"The project is unique"

An ideas competition with a prize of one hundred million Swiss francs to mark the Foundation's 100th anniversary: project manager Matthias Kleiner explains how the Werner Siemens Foundation's "project of the century" came to be—and why he believes it's one of a kind.

Matthias Kleiner, how did the idea for a WSS project of the century come about?
The centennial anniversary of a foundation is always special, particularly in the research sector, where only a few institutions can look back on such a long history. We on the WSS Scientific Advisory Board held a meeting to discuss ways the Foundation could honour its anniversary in due fashion. That's where the idea for a "project of the century" ideas competition first formed—and for the winning project to be endowed with one hundred million Swiss francs. We felt comfortable with the bold idea, as the Foundation already—by every measure—funds large-scale, exceptional projects, generally with ten million francs over a ten-year period. So we agreed to propose our plan to the Foundation Board.

How did the Foundation Board react?
That was in spring 2022, and the Board members were convinced from the very start. Because my term of office at the Leibniz Association ended that summer, I offered to be in charge of the project of the century—and then developed a concept for it.

What did the concept look like?
I proposed a two-pronged approach: first, an ideas competition that would conclude with the awarding of up to five WSS research prizes of one million Swiss francs each; and second, a competition between these prize winners for a ten-year grant of one hundred million francs to set up a WSS Research Centre. I also made a suggestion for the general topic: technologies for the sustainable use of natural resources—after all, we have just this one world, and it's crucial that science, business and society all work together to counter the dire exploitation of our planet's resources. We discussed the concept in the Foundation's various bodies and agreed on this approach fairly quickly. From the questions and comments we received, I saw how much support there was for the topic—also from the Family Advisory Board.

What aspects were most important when the ideas competition was launched?
Sending the message that the Foundation was prepared to take a risk—and to fund unconventional, audacious projects. We wanted ideas that researchers might not dare to propose elsewhere. Apart from the general theme, we set relatively few conditions. One requirement was a sponsoring institution to guarantee basic infrastructure and adequate facilities for the project. This was critical, because the Foundation has no interest in investing in bricks and mortar; as much as possible, funding should be channelled directly into research. We also didn't make interdisciplinary collaboration a requirement, as is often the case in similar calls for proposals. We want research-based needs to steer all these matters. I received a lot of feedback saying that the call was highly unusual—not only because of the scope of funding but also due to the Foundation's open-mindedness and willingness to take a risk.

A total of 123 ideas were submitted. Were you expecting more?
No, to the contrary, I was surprised by the 123 submissions—both in terms of quantity and quality. I initially had reckoned with around fifty proposals. A few days after the call was launched I thought: maybe we'll only be getting thirty. But in the final two or three days before the submission deadline, I sat at my computer practically day and night to confirm receipt of proposals or answer last-minute questions.

What kinds of questions?
Often concerning formalities. We had set a limit of ten pages for the proposals, and some researchers tried to negotiate the limit, or they wanted to know what the smallest permissible font size was, or whether we really needed both language versions—English and German. But in the end I was

A festive ceremony was held in Lucerne to present the award for the WSS project of the century to the Aachen researchers.

absolutely thrilled to receive so many proposals. And only a few of them were ruled out from the start. Roughly two-thirds were from genuinely outstanding researchers in Switzerland, Germany and Austria.

One hundred million Swiss francs is a considerable sum. A number like that could tempt a few people to promise the moon and stars. Were any obviously over-the-top proposals submitted?
Of course. That will always happen. You'll even get people claiming to have invented a perpetual motion machine. But while many ideas were indeed bold, they still had a solid basis. One excellent researcher told me he had been carrying around an idea since he was a boy, but this was the first chance he had to pursue it. And exactly that is how we choose to operate at WSS. Our question is always: if you had the opportunity to pursue your interests with absolutely no practical concerns, what idea would you work on?

How were the proposals assessed?
I put together a small, external team of experts experienced in the evaluation of research and science, the "Hanover team". They reviewed all 123 proposals and made a preliminary selection. Their excellent work enabled the Scientific Advisory Board to focus its in-depth discussions on the best ideas. That said, we on the Advisory Board also read all the proposals.

Six projects in the first round of the competition were awarded a WSS research prize of one million Swiss francs. What was it that made these proposals particularly interesting?
That the ideas were far-reaching and rooted in excellent science. That they were a little daring, but nonetheless gave us the impression they could be realised in the long term. If ideas like this work, they have the potential to fundamentally change a scientific, technical or economic area and effect a real breakthrough.

The six finalists were from the fields of chemistry, solar technology and agriculture. They were given another six months to hone their ideas and bring their proposals into sharper focus. Where did you see the biggest changes or improvements?
The original proposals were ten pages long, but the teams had up to fifty pages for their final concepts for a WSS Research Centre. That means they could go into greater detail. They fine-tuned, perfected and polished. Some researchers focused once again on the core part of their concept, or they even used the prize money to launch an experiment or two. I visited each project team twice—early on and then shortly before the deadline. We wanted the competition to be as tight as possible. That's why I tried to help optimise the concepts by providing neutral advice and feedback.

In the end, the "catalaix" project from RWTH Aachen University won the overall prize. What was the deciding factor?

The project proposes a marvellous idea with the potential to be a real game changer, especially when it comes to recycling mixed plastic waste—the kind that forms massive floating islands in the world's oceans. In addition, the project has already taken actual shape, and yet it still bears a considerable risk. It's highly relevant to society and science, and of even greater interest for the economy. Another advantage is that the conditions at RWTH Aachen University are outstanding. And the Werner Siemens Foundation can also identify with the subject area, which is a very important factor in my view.

What scientific and societal advances do you hope to see from the WSS Research Centre?
I don't want to go into detail, as that might put a constraint on the research. But in general, I hope that the centre's work will give rise to a viable, cost-effective method of recycling mixed plastic waste at a high production level—while also preserving the maximum value of the material to enable a truly circular economy in the plastics-chemical industry. In the end, I'd like to see the project grow into a business for collecting plastic waste from both landfills and garbage patches in the oceans, and then channelling it back into plastic production processes.

During your terms as president of the German Research Foundation and as president of the Leibniz Association, you gathered considerable experience with research funding instruments. How complex, or how demanding, was the WSS competition compared with other calls for projects?
It was precisely thanks to my past experience that we were able to simplify and specify many aspects. This enabled us to reduce complexity without losing quality in our decision-making. But I'm also convinced that only a private foundation can afford to adopt this kind of funding procedure; unlike public institutions, a private foundation doesn't have to consider intricate house rules, nor does it have to repeatedly justify its processes to an audit office. It was a complex, fair and transparent process, but by far not as complex as others with the same or even a smaller amount of funding on the line.

What place does the WSS project of the century occupy in the general landscape of large-scale research projects?
I think the WSS project of the century is unique—in the freedom it offers, in its willingness to take a risk, but also in that it reduces administrative costs. Because the idea is to minimise bureaucracy and maximise science.

Matthias Kleiner speaking at the dinner held at the Bürgenstock Resort as part of the festivities in Lucerne.

A sustainable chemical industry

In Aachen, Germany, the Werner Siemens Foundation's "project of the century" is taking shape: the multidisciplinary team at "catalaix", the new WSS Research Centre, are developing catalysis-driven methods to enable a multidimensional circular economy in the chemical industry—in particular for the mixed plastic sector. The researchers have already attained the first positive results for various kinds of plastics, as a recent visit to the lab has revealed.

Jürgen Klankermayer and Regina Palkovits, two experts in catalysis, are leading the new WSS Research Centre at RWTH Aachen University.

The catalaix headquarters at Melaten Campus in Aachen. At present, the catalaix teams are housed in separate buildings. A new research centre will be built on the meadow to the left.

From the outside, the Institute of Technical and Macromolecular Chemistry (ITMC) at RWTH Aachen University makes none-too modern an impression. But sometimes looks deceive: although the building dates back to the 1970s, the labs it houses are state of the art. And on the inside, researchers are doing no less than constructing the chemistry industry of tomorrow.

The ITMC facilities are the nerve centre of “catalaix: Catalysis for a circular economy”, the Werner Siemens Foundation’s project of the century and winner of the high-calibre ideas competition the Foundation held to mark its centennial anniversary. Endowed with a ten-year grant of one hundred million Swiss francs, catalaix is led by Regina Palkovits, Chair of Heterogeneous Catalysis and Technical Chemistry, and Jürgen Klankermayer, Chair of Translational Molecular Catalysis at RWTH. Now, the Aachen team are setting up a research centre that has the ambitious goal of enabling a recycling-based chemical industry.

Put very simply, today’s chemical industry uses ingenious, technically complex procedures to transform petroleum-based raw materials into a wide range of products. “These are products with maximum functionality and high economic viability,” Regina Palkovits says. “Until now, however, little thought has been given to what happens after they reach the end of their life cycle.” As a result, most chemically manufactured goods are thrown away as waste. “Society can no longer afford to do this,” Palkovits continues. “It’s critical that we move away from a linear economy and towards a circular economy.”

Mountains of plastic waste

The first research priority of the catalaix team is the plastics sector, which provides a prime example of both the advantages and the problems inherent in today’s chemical industry. Modern life would be unthinkable without plastics: we find them in packaging, pipes, flooring, insulation, car dashboards, tyres, medical products, cosmetics, upholstery and textile fibres. Indeed, there’s hardly an industrial sector that does without plastic. And with 400 million tonnes of new plastics produced every year, by mid-century, the quantity churned out since 1950 will come to some sixteen gigatons, as much as the combined weight of all the animals and fungi on earth.

This onslaught of plastic causes two main problems: first, its manufacture consumes vast amounts of energy and second, it generates massive mountains of waste. “A volume equal to fifty kilograms of plastic per capita is fabricated every year, and for every citizen in industrialised countries like Germany, the plastics industry consumes 1.2 tonnes of crude oil—these are enormous figures,” says Jürgen Klankermayer. In 2050, it’s estimated that emissions from the plastics sector will equal those caused by 800 coal-fired power plants. And in the same time frame, the floating islands of plastic waste in the world’s oceans could mushroom to the size of France.

Today, only nine percent of all plastics are recycled; examples include PET bottles that are shredded and remade as new PET bottles. However, one-dimensional cycles like this are unsuitable for a holistic, multidimensional approach, mainly because plastics belong to a highly complex, heterogeneous class of materials with very different chemical structures. Indeed, there are more than 200 different plastic classes on the market. In addition, various quantities are manufactured, hundreds of additives are used and the products’ lifespans differ: while packaging film may have done its job within a few weeks, building insulation is expected to last thirty years.

Modular recycling

The core concept in catalaix is to develop a type of modular principle for recycling these diverse materials: the idea is to break down the various kinds of plastic waste into molecular building blocks that are so versatile that they can be utilised for making a wide range of very different new materials—all according to demand. “This way, previously isolated cycles of matter can be linked together and a flexible circular economy can be created,” Jürgen Klankermayer says.

Regina Palkovits adds that it’s vital to look at waste materials as valuable resources. “A considerable amount of energy and valuable synthesis reactions are stored in plastic materials; it’s not wise to throw them away or burn them.” That’s why the researchers want to instrumentalise recycling technologies to produce molecular building blocks that retain the greatest possible chemical value. At the same time, they want to make these future building blocks more sustainable, ideally even biodegradable, especially when transport routes are long or when the carbon footprint caused by collection would be unjustifiable.

Catalysis—the process that accelerates the speed of chemical reactions or makes them possible in the first place—is at the heart of catalaix. “Up to now, chemists have mainly sought new catalysts to create bonds,” Jürgen Klankermayer explains. “In our work, we’re seeking catalysts to selectively break bonds.”

Beyond plastics

The capacity to break existing bonds is also important for the goal of developing new chemical products that are sustainable and easier to recycle than today’s plastics. “For these new products, it’s critical to think about recycling from the outset,” Palkovits says. One idea is to insert a type of predetermined breaking point into newly developed molecules to make it easy for a catalyst to act on the bond at the end of a product’s life cycle. “These methods can also be applied on other materials, not just plastics,” Palkovits says. “That’s why catalaix shouldn’t be seen as only a plastics project. It will have much

In the labs of Regina Palkovits (centre), the research revolves around so-called heterogeneous catalyses in which catalyst and reactant are in different phases.

broader implications for driving the chemical industry towards sustainability."

Indeed, the general idea behind catalaix goes far beyond experiments in the chemistry lab, and the aim is to test the real-world potential of the ideas and developments as quickly as possible. "RWTH Aachen University offers ideal conditions for the translation from basic research to developing a prototype," Klankermayer says. "Thanks to the quality of process engineering and technical infrastructure here, we can carry out tests on a scale that would be unthinkable in our regular lab." To ensure catalaix has the greatest possible impact, the project team also includes experts in the fields of sustainability and system evaluations who assess which newly created molecules are sustainable, how material flows might look, and where there is demand on the market.

Platinum electrodes to break bonds

A tour of the Aachen labs reveals how the researchers are planning to realise their multilayered idea over the next ten years. To be sure, a considerable amount of preliminary work has already been done—for instance, the team have demonstrated that catalysis-driven bond splitting is feasible in several types of plastic. And in their research, the techniques they use to chemically break down plastic materials are as varied as the plastics themselves. For instance, in the labs where the research group of Regina Palkovits work, the experiments currently revolve around heterogeneous catalysis. This means the catalyst and the reacting substances in the reaction are in different phases—often the catalyst is a solid, while the reactants are liquid solutions.

The researchers are working on the idea of breaking down plastics through electrochemical catalysis, a somewhat neglected method whose great advantage is its sustainability: the reactions take place via green electric energy sources such as wind power rather than fossil energy. In the lab, the experiments are conducted using small glass containers with two metal platinum pins (electrodes) in the lid that go down far into the container. The container is then filled with a predefined type of plastic—the reaction medium. When voltage is applied to the electrodes, the reaction takes place on their surface.

Recently, the Palkovits group have demonstrated that the procedure can be used to split off polylactic acid (PLA), a chain-like compound consisting of the biodegradable molecule lactic acid that is used to manufacture packaging, cans and bottles. For their study, the researchers worked with a commercial bioplastic cup that they mechanically shredded and then placed in a solvent. As an end result, they achieved a maximum lactic acid yield of eighty-seven percent with the platinum electrodes. What's more the conversion also worked on titanium, which is less expensive than platinum. Now, the team plan to find out whether this splitting method also functions with other kinds of plastics.

In the cryogenic mill, two balls grind plastic materials to a powder. The temperatures are kept low to prevent the plastic from melting.

To avoid contamination when working with plastics and chemicals, precision and caution are of the utmost importance.

Reactions at 100 bar

In the labs of Jürgen Klankermayer's group, the team are experimenting with what is known as homogeneous catalysts: catalysts and reactants that are in the same phase. With this approach, the aim is to break down plastics, in particular plastics from the polyoxymethylene (POM) class, which are used to manufacture zippers and backpack fasteners. POM is also important in the automotive industry, as it's used to make door handles, rearview mirrors and the buckles on seatbelts. In a first step, the researchers take these kinds of products as starting materials in their experiments and grind them in their in-house cryogenic mill, which has two balls that crush a material into a powder. The process takes place at low temperatures to prevent the mill from warming up, as heat can alter a material.

The plastic powder thus created is then poured into an autoclave—a gas-tight container used for chemical reactions. For the team's initial experiments with a newly developed catalyst, these reactors are small, with a capacity of just a few millilitres. A magnetic stirrer mixes the catalyst and the plastic powder to trigger the reaction, generally at a pressure of 100 bar or more, which corresponds to over one hundred kilograms of pressure per square centimetre. In these experiments, Jürgen Klankermayer and his group were able to demonstrate that POM can be converted into so-called cyclic acetals when renewable diols—organic chemical compounds obtained from biomass—are added. For their part, acetals can act as solvents, polymer building blocks or pharmaceutical intermediates.

Another positive result in Klankermayer's group was achieved in an experiment to break down polyethylene (PE), the world's most commonly manufactured plastic. Used mainly for plastic bags and films, PE has a market share of some thirty percent. Together with a partner group, the catalaix researchers added biomass to polyethylene waste products to produce lactic acid, the building block of the bioplastic polylactic acid (PLA). In other words: the method developed by the Aachen team converts a conventional, non-degradable plastic into a biodegradable material that is suitable for a sustainable, recycling-based chemical industry of the future.

Looking inside molecules

Whether, how well and how efficiently these degradation processes function depends to a large extent on the catalyst that has been developed or selected for an experiment. These catalysts are often complex metal compounds, and even minimal adjustments to their chemical make-up can greatly accelerate or slow down a reaction. In addition, a catalyst's form also contributes to its efficacy: in many cases, porous materials are suitable as solid catalysts due to the particularly large surface-to-volume

In nuclear magnetic resonance spectrometers, molecules can be studied down to the tiniest detail—and researchers can even watch chemical reactions occur in real time.

ratio. The reason this is important is that catalyses generally occur on the surface of the catalyst.

This is also the reason it's vital to understand exactly what the catalysts look like and how they work. A basement room at ITMC houses equipment that is essential for this purpose: seven vats of different sizes—so-called nuclear magnetic resonance spectrometers. Inside the instruments, a powerful and homogeneous magnetic field is applied to excite atomic nuclei, causing them to alter their state. "With this equipment, we can see the molecules, as it were," Jürgen Klankermayer explains. And in the lab's most modern spectrometers, reactions can even be carried out directly. The benefits are twofold: the researchers can see precisely what happens to their catalyst when it comes into contact with the reagent, and they can identify which bonds between individual chemical elements are formed or broken.

Microbes to build plastic molecules

Catalysis can also be carried out with non-chemically developed substances, referred to as biocatalysts. Indeed, many functions in the human body are impossible without biocatalysts—the microbes that inhabit our body—and people have been making commercial use of these biocatalysts for centuries to brew beer or ferment wine. Now, Lars Blank, Chair of Applied Microbiology at RWTH Aachen University and member of the catalaix core team, is applying the same principle and using enzymes to degrade plastic. In addition, his research group use genetic engineering to insert enzymes into microorganisms, which can break down specific plastic compounds or assemble them into larger molecules.

"Our approach is best suited for application on mixed plastics," Blank says. Using several different enzymes that other research partners have contributed to the catalaix project, mixed fragments or microplastics from the environment can be broken down into various kinds of monomers (molecules that can be bonded to other identical molecules to form polymers). Blank's research group is already testing these systems in so-called fermentation apparatuses: within just a few hours, pieces of plastic are converted into aqueous solutions. This interplay between chemical catalyst and biocatalysis represents additional possibilities for researchers in the catalaix project to chemically degrade plastic into its monomers. In a further step, Blank envisions that microbes will absorb these monomers and assemble them into biomolecules. "This means we're creating new building blocks and polymers at a place that gets very complicated for chemists, because they would have to run various reactions one after the other or under different conditions—or because the substrates are impure or their composition is unstable," Blank explains.

Everything can change in the reactor

To attain the project aims, however, lab results demonstrating that a plastic compound can be broken down using catalysis or a specific enzyme are just a first step. It's at least equally as challenging to translate these findings into a method that businesses can use to recycle the kind of waste products consumers throw away every day. This is why the catalaix team want to transfer their findings from the lab to real-world applications as quickly as possible.

Polyethylene is an example of one such process. At the "Technikum" in Aachen, directly adjacent to the ITMC building, the researchers have ideal facilities for conducting larger-scale experiments. Diverse high-pressure chambers are located along a narrow corridor, and in one of the chambers, a PhD student has installed a complex reactor unit that is roughly two metres wide; inside the reactor, polyethylene admixed with ethylene is broken down via a catalytic reaction into propylene, the basic building block. This work is the continuation of an experiment on plastic degradation that was recently concluded in the ITMC lab. However, rather than holding just a few millilitres, the autoclaves at the Technikum have a capacity of one litre.

Volume, however, is not the only difference between experiments conducted in the ITMC lab and those at the Technikum. A particular problem is that the parameters of an experiment change with the size of the autoclave. For instance, the agitator to mix the materials is different, the flow conditions shift, mixing can become more difficult. The goal is to find out whether new problems arise due to the larger scale. But that's not all: with an eye to a later industrial application, the researchers are already taking initial measurements to learn whether the method has the potential to be economically viable. How much substrate can be converted? What temperatures and pressures deliver the best results? What are the precise reaction conditions?

Maintaining constant processes

Answers to these questions are needed for the next stage: building a pilot plant that will be operated by process engineers—and that will mark the transition to production on an industrial scale. This step, too, was part of the original catalaix concept, as process engineering plays a pivotal role in the project. Unsurprisingly, it's also only a short walk from ITMC to the Aachen process engineering building, where testing units that can convert volumes of fifty to one hundred litres are being built. In the experiments conducted here, the main focus is to go beyond processes conducted under ideal conditions. "We're also looking into aspects like control systems—in other words, how we can run these processes in such a way that overall quality is guaranteed even when certain dimensions or the make-up of the input product change," says Alexander Mitsos, who is Chair of Process Systems Engineering at RWTH Aachen University—and also a member of the catalaix core team.

In this test reactor located in a high-pressure chamber, a catalytic reaction is triggered to break down polyethylene admixed with ethylene into the basic building block propylene.

At the ITMC Technikum, experiments are conducted in autoclaves under high pressure, and reactor systems for catalytic reactions are operated on a larger scale. Jürgen Klankermayer (centre) speaking with two team members.

Mitsos's research group are focused on developing methods and algorithms to optimise chemical and electrochemical processes, enabling them to make predictions that are of particular benefit to other researchers in the project. For instance, Mitsos and his team have already used machine learning to predict the fuel properties of molecules on the basis of their atomic bonds.

The potential challenges arising in the catalaix project on the journey to developing a marketable chemical-catalyst system are also seen in the biorefinery operated at Aachener Verfahrenstechnik—the building for systems engineering containing several demo units in which processes based on renewable raw materials are run and tested on an industrial scale. In one of the demo units, lignin—a key component of wood—is currently being degraded. In these experiments, details that might seem negligible in an ordinary chemistry lab can balloon into major stumbling blocks. For example, sometimes steel containers are damaged by reactions when a corrosive reagent is added. And sometimes solvents used to work on solids turn out to be too expensive in the amount needed for large-scale operations.

Life cycles and value chains

The data provided by the process engineering studies represent yet a further step in the team's journey towards a successful product launch: acquiring an in-depth understanding of operational aspects. This includes investigating how a new plastic or molecule is fabricated, how much energy and resources are needed for production, and what the corresponding value chains look like. These are some of the questions that Grit Walther and her group must answer in order to do their job. Walther is Chair of Operations Management at RWTH Aachen University, and she, too, is a member of the catalaix core team. Her specialisation lies in modelling and assessing production and value chains.

The analyses she conducts are often complex and highly intricate—for example, in cases when the task is estimating a product's impact on and in the environment on the basis of its life cycle. For this, she draws on criteria such as carbon emissions, acidification, eutrophy cation, land use and water consumption. "Sometimes," Grit Walther says, "we also work with social criteria." If, for example, a business collects plastic waste in Asia, she and her team study how jobs and the general levels of acceptance in the region are impacted if waste purification occurs in Europe rather than locally.

That the ten-year duration of catalaix is adapted to the challenges is important to Walther—and also that the chemists in the groups led by Jürgen Klankermayer and Regina Palkovits have prepared several products that are already being tested on a larger scale. "The more scaled their findings, the better our predictions," is how she summarises the connection. "If we only have lab data, the unknowns in our calculations are very large." However, the path from lab to modelling and assessing is a two-way street, an iterative undertaking, as Grit Walther explains: "Based on the data we get from the lab and from process engineering experiments, we create models—and then feed them back to the researchers, who in turn adjust their experiments to reduce environmental impact or improve marketability."

This kind of interactive collaboration is more or less the essence of catalaix: innovative research calls for teamwork, and in order to make key advances in science and society, it's critical that experts from various disciplines work together and that they respect, trust and support one another. Over the next ten years, the WSS Research Centre in Aachen will serve as a prime example of how this kind of modern collaboration delivers results.

WSS100

catalaix

Most chemically manufactured products are thrown away at the end of their life cycle. The research team led by Regina Palkovits and Jürgen Klankermayer at RWTH Aachen University want to change this—with the help of catalysts that speed up chemical reactions, or make them possible in the first place. Their primary goal is using novel catalyses to break down plastic materials and mixed plastic waste into versatile building blocks. In the process, they plan to develop a modular system that will pave the way for a multidimensional circular economy in the chemical industry.

Funding from the Werner Siemens Foundation 100 million Swiss francs
Project duration 2024 to 2034
Project leaders
Prof. Dr Jürgen Klankermayer, Chair of Translational Molecular Catalysis, RWTH Aachen University
Prof. Dr Regina Palkovits, Chair of Heterogeneous Catalysis and Technical Chemistry, RWTH Aachen University

“We want to generate knowledge that matters”

Ulrich Rüdiger, rector of RWTH Aachen University, says the WSS grant for the “catalaix” project is a fantastic outcome—and that the new WSS-funded research centre is an ideal fit at RWTH, both in terms of the university’s organisational structures and its long-term strategy.

Prof. Dr Ulrich Rüdiger, rector of RWTH Aachen University

Ulrich Rüdiger, what does the WSS grant signify for RWTH Aachen University?
The grant is a fantastic outcome—on different levels. Transforming linear value chains into a holistic, multidimensional circular economy is the challenge of a century. I’m convinced that the new WSS-funded catalaix research centre will make a significant contribution to meeting this challenge. In addition, the grant also demonstrates that we at RWTH have the institutional capacity to deliver this kind of cutting-edge research. And catalaix dovetails well with our structures.

How so?
With our Profile Areas, we’ve developed highly effective instruments for facilitating collaboration between researchers across disciplines and departments; thanks to these structures, the findings from excellent basic and applied research can be used to lay the foundation for socially relevant innovation. At RWTH, scientists coordinate their research activities, benefit from state-of-the-art infrastructure and form large research networks with academic and industrial partners. Our goal is to generate knowledge that matters and, in doing so, to make a positive impact on society. And because we understand this is impossible to do alone, we rely on our strong network of partners—in this case, WSS. In keeping with this philosophy, the title of our excellence proposal contained the three key terms: knowledge, impact and networks.

What role will the catalaix research centre play in RWTH Aachen University’s long-term strategy?
For one, catalaix as a research centre is in perfect alignment with our understanding of how interdisciplinary research should be conducted. For another, RWTH has adopted a sustainability strategy, including an implementation roadmap, that we are now absolutely committed to—and here, too, catalaix is an important building block that underpins our ambitions. Our goal is achieving climate neutrality by 2030, and the sustainability roadmap defines concrete measures and targets that support the overall strategy and that can be implemented at operational level. These targets and measures apply to all university areas: governance, teaching and studies, research and business operations. catalaix will unite many aspects here.

What results do you yourself hope to see at the centre?
My personal expectations of catalaix are research findings of the highest calibre, but I also hope to see a major strengthening of the structures at our university. The WSS project of the century focuses on a topic of the century that affects today’s society. RWTH Aachen University is committed to addressing major global challenges, and a circular chemical industry is a key factor when it comes to getting to grips with climate change. The ideas generated in catalaix will certainly be extremely interesting. The way the project team puts research, innovation—even inspiration—into practice has the potential to play an essential role in preserving a world that is fit for us to live in.

At the new WSS Research Centre at RWTH Aachen University, the focus is on catalytic reactions carried out in fume hoods (to the left) for example.

A festive award ceremony: on 16 June 2023, the Foundation Board, the Scientific Advisory Board and the Siemens Family Advisory Board of the Werner Siemens Foundation welcomed the finalist teams in the “project of the century” competition to the Hotel Astoria in Lucerne. For their innovative ideas, each of the six research groups received a WSS research prize of one million Swiss francs.

The five runners-up

Berlin

A new chlorine technology

Munich

Indoor wheat on 100 storeys

Zurich

The “golden” path to hydrogen production

Freiburg, Germany

High-efficiency solar energy

Göttingen

Technology for sustainable chemistry

Researchers in a team led by Sebastian Hasenstab-Riedel (centre) at Freie Universität Berlin have developed a new chlorine technology with the aim of promoting sustainability in diverse chemical processes.

Chlorine technology for a cleaner world

One invention, so much potential: researchers in the WSS100 final project "ChemSysCon" want to use a new chlorine-based technology as the basis not only for making the chemical safer to store and transport, but also for recycling electronic scrap and waste products, rendering biomass usable and developing large-scale batteries.

Chlorine is much more than just a disinfectant for swimming pools. As one of the most important commodity chemicals, the element is found in over half of all products made in the chemical industry—for example in plastics, pharmaceuticals and agrochemicals. Around one hundred metric tons of elemental chlorine (Cl_2) are produced every year, mostly by electrolysis from common salt (NaCl) and water (H_2O).

But manufacturing the chemical is an extremely energy-intensive process—Germany's annual production of 5.5 million metric tons of chlorine accounts for around 2.3 percent of the country's overall electric power consumption. Moreover, chlorine gas is also toxic and, despite numerous safety regulations, storing and transporting it poses major risks. In mid-2022, for example, a container of chlorine fell from a crane while being loaded onto a ship in the port of Aqaba, Jordan, causing chlorine gas to escape. Thirteen people died and two hundred and fifty were injured.

A team of researchers led by Sebastian Hasenstab-Riedel from Freie Universität Berlin have now developed a technology to store and transport chlorine safely. The basis of the technology is a so-called ionic liquid—an ammonium salt that is liquid at room temperature and that can absorb large quantities of chlorine gas and release it again easily, as needed.

"Green" chlorine and hydrogen

Simplifying the storage and transportability of chlorine opens up a whole range of new possibilities for this key bulk chemical, as Hasenstab-Riedel explains. And manufacturing it using renewable power sources will become ever easier in the future: in Central Europe, for example, the chemical industry can produce it using surplus solar power and then store the chlorine until it's needed, while in the Global South, it could be produced on a large scale with cheaply available solar energy and shipped safely from the production site. Another advantage is that the two by-products of chlorine production—hydrogen and caustic soda—are also valuable energy carriers and commodity chemicals.

But that's only the start. "The ionic liquid underpins the development of a whole new chlorine-based technology," Hasenstab-Riedel says. Together with a team from Freie Universität Berlin, the German Bundesanstalt für Materialforschung und -prüfung (BAM) and the Fraunhofer Institute for Applied Polymer Research (IAP), he has come up with four action areas for his WSS100 proposal—ChemSysCon—in which he believes the chlorine storage platform can make a substantial contribution to creating a sustainable chemical industry.

Dissolving metals from electronic scrap

The first action area concerns the urban mining of high-tech metals. Electric motors, wind turbines and mobile phones contain large quantities of valuable metals such as rare-earth elements. "Europe is dependent on countries like China for these raw materials," Hasenstab-Riedel says. "We need to develop methods that make it easy to extract these metals from discarded electronic goods for future re-use." This is where his new chlorine-based technology could prove extremely helpful—because it's based on a highly reactive liquid. He explains that initial tests have shown it can be used to dissolve high-tech metal compounds at low temperatures and separate out the individual metals.

The second action area is the exploitation of biomass, or renewable organic material, that would otherwise be disposed of. Take the four million metric tons of glycerine created every year as a by-product of biodiesel generation, or the one hundred million metric tons of lignin from paper manufacturing. Hasenstab-Riedel says that by using the ionic liquid the team have developed, both of these waste products can be converted into valuable, functional materials.

Waste chemical products and batteries

The third area is the conversion of chemical products that have outlived their use. "By applying electrochemical processes, we can remove the chlorine from existing compounds and store it again in our ionic liquid," Hasenstab-Riedel says. One example of a chlorine-containing waste product is the insecticide lindane: no longer used in the EU, up to seven metric tons of the pesticide lie in spoil tips across Europe. Chlorinated plastics could also lend themselves to being recycled via this dichlorination process.

The last action area is a chlorine platform that holds great potential for use as a starting material in the manufacture of stationary storage batteries—to store solar or wind energy, for example. The ionic liquid can absorb two electrons from metals such as calcium or aluminium and easily release them again. "Years ago, we showed that batteries of this kind based on metal halides like bromides are possible on a large scale," Hasenstab-Riedel says. However, polychlorides offer even greater possibilities and are significantly cheaper, as chlorine is more abundant than bromine.

In sum, chlorine could soon play a key part in our efforts to create a cleaner world and more sustainable future.

WSS 100

ChemSysCon: New chemical systems for the conversion of sustainable resources

Funding from the Werner Siemens Foundation 1 million Swiss francs
Project leader
Prof. Dr Sebastian Hasenstab-Riedel, Institute of Chemistry and Biochemistry, Freie Universität Berlin

One hundred storeys of wheat

Growing wheat and saving space: researchers in the WSS100 final project "Revolution of food production" want to systematically drive the further development of vertical farming technologies forward to attain indoor harvests that are six thousand times larger than crop yields from conventional outdoor farms.

A team led by Senthold Asseng (right) at Technical University of Munich are seeking cost-effective and ecological ways to produce wheat crops in vertical farms – and drastically reduce agricultural land consumption.

How can we feed the world's growing population without depleting natural resources like water and soils—and destroying valuable ecosystems? This question is the research focus of the team led by Senthold Asseng at Technical University of Munich. In their WSS100 proposal, they set out a concept for agricultural food production in a meticulously controlled environment—a radical expansion of already existing vertical farming systems.

"Today's vertical farms consume an enormous amount of energy and are extremely labour-intensive, hence costly. If at all, cost-effective operations are only possible when growing premium leafy produce like lettuce and herbs," Senthold Asseng explains. To make the indoor production of food staples such as wheat competitive, however, he says the entire system needs to be rethought, automated and made much more efficient. With this type of comprehensive approach, Asseng calculates that one hundred vertically stacked indoor planting fields with five to six harvests per year would yield up to six thousand times more wheat per square metre than outdoor farms.

Large-grain dwarf wheat

To realise their innovative idea, every single aspect of vertical farming must be optimised—starting with the plants themselves. Wheat is the source of one-fifth of all calories consumed by humans and also the most extensively studied crop. To date, however, it has been cultivated for outdoor farming, rarely for a controlled environment. "Because temperature, light, humidity, fertilisers and all other factors are controlled in our system, we can reimagine how the plant should look," Asseng says.

For example, the ideal wheat would be as short as possible, making it possible to stack numerous cultivation layers on top of each other in a production facility. "The height of wheat grown outdoors is instrumental in keeping weeds at bay," Senthold Asseng says. "However, there won't be any weeds in our facilities." He and his team are already working with a wheat variety modified by the US space agency NASA in the 1990s for potential missions to Mars. Rather than being 1.1 metres high, like conventional, field-grown wheat, this variety measures just 50 centimetres. "But we want our wheat to be even shorter," Asseng says.

Redesigning the wheat's root system is another key aspect in the project. Whereas conventional wheat needs deep roots of up to two metres to absorb the necessary water and nutrients from the soil, an indoor variety that doesn't have to work so hard to get what it needs would probably do well with roots of only ten centimetres, maybe even less, Asseng says. The energy the optimised plants save by not having to find their own nutrients can instead be invested into growing the grain.

Just as important as cultivating the right wheat variety is identifying the conditions in which the plants thrive while using the least amount of energy possible. The researchers aren't at a loss for new ways to achieve this aim, many of which are related to lighting, as it's responsible for almost all of the energy costs in vertical farming. One option they're testing is to reduce the light spectrum emitted in the facilities to only those wavelengths that the plants actually need to conduct photosynthesis. A fully automated conveyor could then move the light sources up and down so that they remain close to the plants at all times. "This is important, because light intensity, and consequently energy consumption, decreases by a power of two at this distance," says Senthold Asseng, who wants to reduce energy use by ninety-three percent.

Another focus in the project is the principle of circularity. Highly efficient circulation systems will ensure that vertical farms function with ninety-five percent less water and sixty percent fewer fertilisers. Special wall coatings for dehumidification are one way of achieving this aim. Another is unused biomass broken down into minerals that can be utilised as fertiliser.

In barns and in the desert

To avoid wasting energy while also guaranteeing automated production systems, an optimised building is essential. The Munich team propose building the modular farm facilities of wood, an ecologically sustainable material choice. "The smallest unit will be five layers of planting space measuring ten by ten metres," Asseng says. Thanks to their small size, the units could even be fitted into a barn at a conventional farm, where solar panels installed on the roof would supply the system with electricity. Large facilities with up to one hundred stacks would be used for large-scale food production—even in regions where crops were previously unthinkable due to a lack of water, or because the soils are contaminated with heavy metals.

If we could grow high-quality wheat, and later other foods, without using up so much space, it would be a quantum leap for global food security. At the same time, it would also reduce the need for field-based industrialised agriculture—all of which brings benefits to nature.

WSS[100]

Revolution of food production

Funding from the Werner Siemens Foundation 1 million Swiss francs
Project leader
Prof. Dr Senthold Asseng, director of the Hans Eisenmann-Forum for Agricultural Sciences, Technical University of Munich

David Tilley, Greta Patzke and their team at the University of Zurich want to split water directly into oxygen and hydrogen – in novel reactors that use only energy from the sun.

Water splitting, made simple

Converting water and sunlight into hydrogen in just a single step: researchers in the WSS100 final project "Solar fuels and commodities" want to use innovative reactors to produce environmentally friendly energy carriers and materials.

Hydrogen is widely regarded as the energy carrier of the future—but only if there's a way to produce it without burning fossil fuels. The most elegant method would be using only the energy of the sun to directly split water into hydrogen and oxygen molecules. Indeed this is the principle at the heart of the WSS100 proposal developed by Greta Patzke, David Tilley and their team at the University of Zurich. The researchers have devised a concept to make solar production of hydrogen and other commodities ready for market entry.

The team's research focus is the production of so-called solar particulate panel reactors (SPP reactors). Put simply, these reactors are novel, cost-effective solar panels in which catalysts generate hydrogen through the direct utilisation of sunlight. The approach based on photocatalysis is called the "golden" route to hydrogen production, and it's viewed as a continuation of "green" technologies stemming from clean energy sources.

"Although the concept has fascinated researchers across the globe for a hundred years already, no one has yet achieved a commercial breakthrough," Greta Patzke explains. However, studies have demonstrated that solar hydrogen production via these types of catalysts can indeed compete with hydrogen produced using fossil fuels. The team have already developed several catalysts that greatly accelerate water splitting while also making the process more efficient—and they're convinced that many more significant improvements are possible.

Demonstration in the reactor

To achieve their aims, they're conducting research into new kinds of photocatalysts made of various materials: some of high-tech semiconductor materials and some of graphene-like carbon nitrides. The latter are especially interesting, because they consist of carbon and nitrogen—two of the most common elements on the planet. This is relevant, as there are other factors to consider in addition to conversion efficiency. For instance, the panels should be built to last, and the catalysts should be made of widely available, cost-effective and eco-friendly materials, in keeping with the "benign by design" principle.

To demonstrate that solar hydrogen production is technically feasible, the researchers are planning to use demonstration reactors of at least one hundred square metres. The outcome will then serve as the basis to further develop the SPP reactors. "Using the same principle but other reactors, we can also convert the generated hydrogen, CO_2, biomass and other primary materials into additional valuable base chemicals," David Tilley explains. Fertilisers as well as renewable building blocks for the plastics industry are examples of the materials that could be produced.

Innovative separation technology

Numerous challenges await the researchers as they move forward, including separating and purifying the hydrogen. For this work, the research team are planning on further developing a new technology based on hydride compressors in which hydrogen is accumulated on modified metal hydrides at low temperatures and low pressure. Once the system has reached saturation, the hydrides are heated—whereupon they release pure hydrogen at high pressure.

The development of innovative technologies always goes hand in hand with economic, social and environmental risks, and these risks often cause promising research projects to fail. To prevent this outcome, the Zurich team are designing a comprehensive, future-oriented concept that will serve as a benchmark for developing new technologies. Their system covers economic viability, international interdependencies and impacts on ecosystems as well as public opinion.

AI lends a hand

Separate research teams are responsible for addressing these complex questions: they explore aspects such as whether the high-tech materials created for the SPP reactors could pose risks to humans and the environment in the long term. In addition, issues related to economic viability, life cycle assessments, dependencies on supplier nations for essential raw materials and public perception are closely examined from the very start.

Various methods will be applied in this work, including a new tool based on artificial intelligence. "With the AI tool, we're able to calculate and weight all factors involved," Greta Patzke says. This is also useful in choosing the right materials from the outset. For example, if catalyst material A performs better than catalyst material B in all assessment categories, the researchers will work with material A.

The aim is for these tools and technologies to enable the simple and ecological production of hydrogen and other materials—by literally snatching them from thin air.

WSS100

Solar fuels and commodities out of thin air

Funding from the Werner Siemens Foundation 1 million Swiss francs
Project leader
Prof. Dr Greta R. Patzke, Department of Chemistry, University of Zurich
Prof. Dr David Tilley, Department of Chemistry, University of Zurich
Prof. Dr Stefan Seeger, Department of Chemistry, University of Zurich
Prof. Dr Kathrin Fenner, Department of Chemistry, University of Zurich, and the Swiss Federal Institute of Aquatic Science and Technology

Maximising efficiency in the energy transition

Highly efficient solar cells, virtually loss-free electricity transport, innovative energy storage: researchers in the WSS100 final project “Solar energy” want to develop new technologies to drive the energy transition forward.

Frank Dimroth (left) and Andreas Bett at the Fraunhofer Institute for Solar Energy Systems and the Albert Ludwig University of Freiburg conduct research into highly efficient solar cells.

Right now, solar power is booming and is generally viewed as the key technology for carbon-neutral energy production. In order to satisfy the global need for electricity, however, massive photovoltaic plants will have to be built. “From 2037 onwards, we’re reckoning with an annual increase of 3.4 terawatts in new solar modules. Using today’s technology, that corresponds to an expanse larger than a third of Switzerland’s total surface area,” says Frank Dimroth from the Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg, Germany.

In addition to taking up a lot of territory, such an increase would also eat up huge amounts of material and energy. And what’s more, converting sunlight into electricity is only half the battle, says Andreas Bett from ISE Freiburg and Albert Ludwig University of Freiburg: “We also need systems to transport electricity—or to use electric power for producing energy carriers like hydrogen and synthesis gases.”

For their WSS100 proposal, a team led by Dimroth and Bett have developed a concept for more efficient and less extractive technologies—all in the interest of promoting a sustainable energy transition. One of the team’s initial research priorities is in the area of photovoltaics. Today’s solar cells are generally made of crystalline silicon. However, due to physical constraints, their efficiency is less than thirty percent, and the purification processes for silicon consume a great deal of energy.

Ultra-thin solar cells

The team in Freiburg are proposing a more efficient, less extractive alternative: what they call “III-V tandem photovoltaics”. These are solar cells consisting of several semiconductor layers made up of elements from the third and fifth main groups of the periodic table, including gallium, indium, arsenic and phosphorus. Because each layer absorbs a different spectrum of sunlight, these kinds of tandem solar cells attain high conversion efficiency. “Compared to today’s cells, the output with the tandem solar cells is about a third higher per area,” Frank Dimroth explains.

In addition to boosting efficiency, the researchers also want to make the solar cells ultra-thin and thus reduce the amount of material needed to a minimum. Today, a silicon solar cell is roughly 150 micrometres thick; the future III-V semiconductors will measure just 1.5 micrometres. Here, the researchers developed a method in which the thin semiconductor layers can be detached from their growth substrate. This enables the substance to be used multiple times, which saves on valuable materials.

Compact light

Combining the III-V semiconductor tandem solar cells with high-concentration photovoltaics (CPV) technology is particularly promising. In this process, economical lenses are used to amplify the sunlight by a factor of one thousand before a tiny solar cell converts it into electricity. “Although we still need a little silicone on glass to construct the lenses, we now use one thousand times less semiconductor material,” Andreas Bett explains. The team have recently produced a CPV solar cell that attains an efficiency of 47.6 percent when exposed to sunlight concentrated 665 times—a world record. Overall, the researchers estimate that these new technologies will reduce energy consumption in solar cell production by seventy-five percent.

The team also have another major research priority: energy transport. Because once electricity is generated, it also has to be fed into the grid. One of their ideas is cutting out the transformation of direct current into alternating current and thus attaining higher voltages in solar cells, modules and leads. “This would minimise resistance losses, and we could use thinner cables,” Andreas Bett says. Large amounts of copper and aluminium could be saved, especially in applications that use direct current, such as electrolysis.

Hydrogen and syngases

CPV in particular work well in regions with intense solar radiation, including southern Africa and Australia. And these regions are also ideally suited to convert cheap solar power into hydrogen or other energy carriers that are easy to transport and store.

This is yet another area of research for the project team. They want to investigate new systems for hydrogen production, in particular electrolysis using electrolysers with a membrane exhibiting ionic conductivity properties able to separate the hydrogen from the oxygen. “We plan to develop new polymers for stable, more ecological membranes and combine them with catalysts made of non-critical metals like nickel and iron,” Dimroth says.

Downstream, sustainable and energy-saving synthesis processes will be developed to produce molecules like ammonia, methanol or dimethyl ether that can be used to store hydrogen—hence energy—and transport it over long distances.

Attaining maximum efficiency, achieving high voltage, perfecting innovative technologies: this is how the researchers in the “Solar energy” project are aiming to drive the energy transition forward.

WSS[100]

Highly efficient generation of electricity and hydrogen from solar energy

Funding from the Werner Siemens Foundation 1 million Swiss francs
Project leaders Dr Frank Dimroth, head of the Department for III-V Photovoltaics and Concentrator Technology, Fraunhofer Institute for Solar Energy Systems ISE Freiburg, Germany
Prof. Dr Andreas Bett, Institute of Physics, Albert Ludwig University of Freiburg, director of the Fraunhofer Institute for Solar Energy Systems ISE Freiburg, Germany

A team led by Lutz Ackermann (centre) at the University of Göttingen want to make catalysis – the acceleration of a chemical reaction – better, faster and "greener". A development with the potential to revolutionise the entire chemical industry.

Sustainable catalyses

Using electricity and light instead of gas and oil, developing short synthesis pathways, employing catalysts made of common metals: researchers in the WSS100 final project "RenewSusCat" want to create innovative technologies capable of boosting sustainability in the chemical industry.

In Germany, the chemical and pharmaceutical industries alone are responsible for around thirty percent of industrial energy consumption—a large proportion of which stems from fossil fuels. For their WSS100 proposal, a team led by Lutz Ackermann from the University of Göttingen have developed a concept to improve sustainability in these two industries. Key to the concept are catalyses—which increase the speed of chemical reactions and even enable completely new reactions. Indeed, catalyses are involved in almost nine out of ten industrial chemical processes.

The team behind the RenewSusCat project are proposing two lines of research to help decarbonise the chemical industry. One step is to develop new, innovative catalyses that consume less energy and raw materials and that generate fewer waste products; the second is to replace the fossil fuels used in the catalysis process with renewable energy sources.

To make chemical syntheses more efficient, the researchers are aiming to reduce the number of intermediate steps in reactions. "Today, it often takes more than ten synthetic steps to produce a typical pharmaceutical agent," Lutz Ackermann says. On the basis of several examples, he and his research group have proven that such lengthy production processes can be avoided—while at the same time minimising the use of chemical reagents from fossil sources.

Less effort, fewer solvents

At the crux of this approach is a reaction technique called C-H activation. Bonds between carbon (C) and hydrogen (H) form the backbone of organic molecules. However, the bond between these two atoms is strong, making it difficult to split them selectively. But once the bond is broken, functional groups that significantly alter a molecule's properties can dock directly onto the molecule.

Because these carbon-hydrogen compounds are so commonplace, the potential scope of application of the breakthrough method is enormous. Using the technology, Ackermann and his team have shown that it takes only one conversion step from one precursor structure to produce several possible agents with different properties. "By drastically reducing the number of synthesis steps, we not only save time, but also large quantities of solvents and chemical waste products," Ackermann says.

However, an essential requirement of making chemical processes as climate neutral as possible is to ensure that the energy used stems from renewable sources. "Today, most reactions are carried out thermally, by heating—with gas and oil," Lutz Ackermann says. As an alternative, he's looking at two other methods: hydrogen production via electrocatalysis and photocatalysis.

Hydrogen as single by-product

Electrocatalysis involves the use of electricity rather than heat to drive chemical activation processes. "As a rule, these reactions take place at room temperature," Lutz Ackermann says. In electrocatalysis, chemical reagents are replaced by protons and electrons, and the synthesis of molecules for the manufacture of medicines or crop protection products is coupled with the simultaneous production of hydrogen as the sole by-product. The hydrogen created can then be reused as a sustainable energy carrier. "This coupling makes such syntheses highly attractive from a commercial viewpoint too," explains Ackermann, whose long-term ideas include using electrocatalysis to tackle the world's mountains of plastic waste—in other words, to break down plastics such as polyethylene or polystyrene into reusable polymers by extracting the hydrogen they contain.

Photocatalysis, on the other hand, uses the energy of light as a catalyst to accelerate chemical reactions. Researchers today often use special LED sources for this purpose, as Ackermann points out. The aim is to one day be able to trigger such reactions with sunlight.

AI-assisted software

But the RenewSusCat team aren't stopping there: they have a whole range of solutions in the pipeline to make chemical processes more sustainable. One example is the plan to replace precious—often toxic—catalyst metals such as palladium, rhodium or iridium with cheaper, less toxic and more readily available elements such as nickel, copper, manganese or even iron.

Or to take advantage of software applications that use artificial intelligence to evaluate chemical reactions, enabling them to predict which new catalysts and synthetic routes will be most effective and sustainable. "Molecular data science is often given short shrift," Lutz Ackermann says. But he's convinced that his field will help the chemical industry harness all the resources at its disposal in the interest of sustainability.

WSS 100

RenewSusCat: Renewable energy for sustainable catalysis

Funding from the Werner Siemens Foundation 1 million Swiss francs
Project leader Prof. Dr Lutz Ackermann, Wöhler Research Institute for Sustainable Chemistry, Institute of Organic and Biomolecular Chemistry, University of Göttingen

WSS^{100}

Future energy

To ensure the future of our planet, it's essential that we reduce our dependency on oil, gas and coal. We must also find new ways to exploit alternative energies—and formulate clear political strategies to drive this massive societal shift forward. Three innovative research projects financed by the Werner Siemens Foundation are seeking solutions.

It's hardly a big secret: planet Earth is getting hotter and hotter. Today, global temperatures are 1.2 degrees Celsius warmer than 150 years ago, with the trend being even stronger in Central Europe. The root cause is human-made: we release vast quantities of greenhouse gases into the atmosphere—mainly by burning coal, oil and gas to generate energy.

Right now, humanity is at an inflection point: if we fail to stop the warming trend, we'll soon be facing dire consequences. There will be more—and more intense—heatwaves, forest fires and storms. Ice caps and glaciers will melt, while floods and droughts will render entire regions uninhabitable. What's needed is an energy transition: a shift away from fossil fuels and towards renewable energies such as solar and hydropower, wind energy, geothermal energy and bioenergy. And time is running out. Signatories to the Paris Climate Accords agreed to keep the rise in mean global temperature to well below 2 degrees Celsius, preferably limiting the increase to 1.5 degrees. To realise the goal, the world's carbon emissions must decrease by fifty percent by 2030 and reach net zero by 2050.

Achieving a transformation on this scale is incredibly challenging, says Ottmar Edenhofer, co-director and chief economist at the Potsdam Institute for Climate Impact Research (PIK) as well as leader of FutureLab CERES, a project that has received funding from the Werner Siemens Foundation since 2022. "It requires a broad portfolio consisting of various kinds of renewable energies but also strategies and technologies." Edenhofer divides the challenges into three action areas, the first of which is decarbonising the electricity sector. In future, electricity must stem from renewable energies rather than fossil fuels.

The second is a transformation in transportation and heating systems. "Here, we're talking about direct and indirect forms of electrification," Edenhofer says. "Direct electrification" means replacing oil heating with heat pumps powered by electricity, or switching from combustion engines to electric vehicles. By contrast, "indirect electrification" refers to the sustainable production of fuels—"green" hydrogen, for example, or synthetic fuels. The third action area concerns negative emission technologies (NETs) such as capturing and storing CO_2 from

the atmosphere. Edenhofer says it will be impossible to entirely eliminate greenhouse gas emissions—those emitted in industry or agriculture, for instance—adding, "We'll have to compensate for them if we want to meet our climate targets."

No crystal ball for energy forecasts

Edenhofer further explains that, at present, not all the technologies necessary for the transformation have been developed. "I have to disagree with people who say all we need is a little political will to get the job done." Carbon storage technologies in particular are by no means available on the scale required. There's also quite a bit of research to be done on synthetic fuels as well as storage and battery technologies.

And, Edenhofer continues, while all these areas are full of potential, it's practically impossible to predict which will ultimately prevail. He illustrates this point with an example from the UN Intergovernmental Panel on Climate Change (IPCC), where he acted as co-chair of the Working Group III from 2008 to 2015. "We analysed numerous scenarios describing which technologies would be best for renewable energies," he says. Only one—compiled by Greenpeace—was based on a major increase in solar energy production. Edenhofer included the peer-reviewed scenario in the final report, a decision that drew quite a bit of ire, as the entire scenario was deemed unrealistic. "And yet," he says, "when we look at it today, this extreme scenario is the only one that came close to predicting how things have actually developed. All others grossly underestimated photovoltaics."

This is why he advises caution when policymakers and society go to great lengths to predict technological advances. "Creating conditions that foster competition for the best new technologies is more important." He would like to see Europe doing more in this area. For instance, he envisions an innovation authority that sets priorities in basic research and organises auctions to drive innovation and help promising technologies achieve a breakthrough.

More electricity—especially in winter

Domenico Giardini, professor of seismology and geodynamics at ETH Zurich, agrees that it's by no means certain which technologies will be viable in the long term. What is clear, however, is that we'll be needing much more electricity in the near future. "Just a few years ago, there were politicians who said we could compensate energy consumption by saving energy. Today we know that this doesn't work." What's more, these additional quantities of energy don't just need to be generated—they must also be distributed and stored.

In particular solar power is much more plentiful in summer than in winter. "However, we consume much more electricity in winter than in summer," Giardini points out. "This means we need to find ways to generate more energy in winter, but also ways to store summer energy." Enter geothermal energy. The technology has two main advantages. First, the heat of our planet is a nearly inexhaustible source of potential energy. Five kilometres beneath the surface, the earth's temperatures range from 160 to 200 degrees Celsius—and that all year round. If we could tap into this heat, we would have a year-round supply of energy.

Second, subterranean rock layers could also be used to capture and store heat, not just release it. "Ten years ago that wasn't a priority, but today, heat storage is an incredibly important aspect in future energy strategies," Giardini says. Storage capacities of batteries or reservoirs are insufficient for long-term solutions, he adds. "That's why we're studying whether we can use underground rock layers as a kind of energy bank: in summer we deposit energy into the rock, and in winter we withdraw it."

Domenico Giardini heads the BedrettoLab, a unique research facility located below the Saint-Gotthard Massif in Ticino, Switzerland's southernmost canton. Thanks to funding from the Werner Siemens Foundation, a former ventilation arm in the Furka Tunnel—part of the Matterhorn-Gotthard railway line—was converted into an underground lab for deep geothermal energy. In the meantime, the lab doesn't only serve ETH Zurich scientists: research and industry partners from all over the world take advantage of the facility as an ideal platform for safely testing deep geothermal energy technologies in near-authentic conditions.

New insights into earthquakes

In addition to experiments with new geothermal technologies, researchers are using the facility to better understand how, and under what conditions, earthquakes occur. Safeguarding against earthquakes is always a concern in deep geothermal energy systems, Giardini explains: "Whenever we build underground, we cause the stress levels in the earth's crust to change, which can trigger earthquakes." And because the BedrettoLab is located more than a kilometre beneath the earth's surface, it's an excellent place to study and measure how rock layers change when exposed to such pressure.

To set up the experiments, the researchers descended even deeper than the lab itself: they drilled several boreholes of up to 400 metres beneath the facility's ground floor, then affixed hundreds of sensors inside the boreholes to measure changes in temperature and stress as well as displacements in the rock. When carrying out their experiments, the researchers inject water into the borehole, where the sensors provide detailed information on how this kind of stimulation triggers microquakes. "Up to now, we had a very unclear picture of what happens. We thought the earthquakes were made up of a kind of cluster of small tremors," Giardini explains. "But the data we collected in the immediate vicinity of the microquakes showed that there are really large faults of eighty to one hundred metres in length. They move in the form of small tremors—it's very craggy rock." Thanks to the findings, the team can now make better models of what happens when water is injected into rock layers.

Gaining more information about these rock movements is also important for the latest endeavour in the BedrettoLab: in collaboration with Azienda Elettrica Ticinese, the energy supplier in Ticino, and with funding from the Swiss Federal Office of Energy, the researchers launched a new project to study seasonal energy storage. The basic idea is to use energy generated from photovoltaics and other sustainable sources for heating water and storing it in underground rock layers.

"It's a demonstration project," Giardini explains. "Next summer we'll start injecting hot water—heated to up to eighty degrees—into the rock and studying the effects." Key questions concern what happens when water is injected and then extracted. Does it cause tremors? If yes, can the tremors be controlled by injecting water in shorter intervals or by being more careful when injecting the water? Does the hot water have a long-term impact on the rock layers? Then, in the following winter, the researchers aim to find out how much energy can be removed from the reservoir and used for heating.

The team in the BedrettoLab now face the challenge of building a new side tunnel, a project funded by the European Research Council (ERC). Construction began in the autumn of 2023 and will take another three years to complete. Progress is slow, as rock blasting operations have to be conducted repeatedly—and, of course, there are also experiments to be conducted. Because the new side arm will run parallel to a large fault in the rock, the researchers can use it as the starting point for drilling more boreholes up to the fault. They'll then install more sensors in these boreholes for measuring seismic activity. "This will deliver yet more information about what happens in a fault when the rock starts moving—and about how tremors start and stop," Giardini says.

Carbon dioxide and hydrogen storage

It's fair to say that the two technologies of geothermal energy generation and the underground storage of surplus energy—but also carbon dioxide and hydrogen—generate great interest. Now, to transport the earth's heat to the surface, Martin O. Saar, Werner Siemens Foundation Endowed Chair, and his geothermal energy and geofluids research group at ETH Zurich are exploring potential options other than using hot water (the current method) as a heat conduit. He's even come up with an idea that would create two solutions in one: a method he helped develop known as CO_2 Plume Geothermal (CPG), which combines deep geothermal energy generation and carbon storage—killing two birds with one stone, as it were.

When the greenhouse gas CO_2 is stored between 2.5 and 3 kilometres below ground, it naturally heats up to at least 100 degrees Celsius. With his CPG method, Saar wants to exploit this heat by creating a circuit: the hot carbon dioxide is brought to the surface, where it's used directly to drive turbines. After it cools off, the gas is channelled back into the underground storage facility. As such, the CO_2 injected at the start is permanently stored. And, as Saar explains, because carbon dioxide is less viscous than water, and because it expands much more when heated, it achieves a higher heat production rate—which generally more than compensates for the lower heat capacity of CO_2 compared to water. "It's also a cost-effective way of exploiting rock layers that have both low permeability and low temperatures. And when heated enough, CO_2 rises up to the surface almost on its own." Overall, Saar continues, CPG has the potential to double or triple the energy output for direct heating or power generation.

After investing more than twelve years into researching and developing the method, Saar recently founded the CPG Consortium, a collaboration between industry and academia in which currently two large mineral oil companies are paying members. The aim is to study the method in a large-scale pilot project and then commercialise the technology.

Another of Saar's future goals is the underground injection and conversion of hydrogen. "Although the idea is simple, putting it into practice is very difficult," he says. The concept is to combine carbon dioxide and sustainably produced "green" hydrogen with specific kinds of microorganisms in the subsurface. The tiny organisms utilise the earth's heat to transform the hydrogen and carbon dioxide molecules into methane. If needed, the methane can be retrieved at the surface and used to generate energy. "Methane is well suited and quite safe as an energy storage medium," Saar says. "The big advantage compared to the original hydrogen molecules is that it can be distributed and used via already existing natural gas infrastructures—and that this methane would be carbon neutral.

Like Domenico Giardini, Martin O. Saar, too, is convinced that the energy transition will only succeed if we use a combination of different kinds of available energy and methods. "We need solutions that can be optimised according to region," he says, and adds that studies have demonstrated an energy mix is always more cost-effective than systems that depend on one, or a few, kinds of energy. For example: in order to supply a region with solar and wind energy at any time of the day or year, large overcapacities must be generated.

Generating reserve energy

Saar is also convinced that deep geothermal energy could play a key role in the energy mix of the future. It's capable of supplying both base load and reserve energy, depending on demand. And reserve energy supplies are related to yet another area he's involved in. With funding from the Swiss Innovation Agency Innosuisse, he's leading a consortium of research and industry partners in a project to study how a method called Advanced Geothermal Systems (AGS) could contribute to realising the energy transition in Switzerland—and throughout the world.

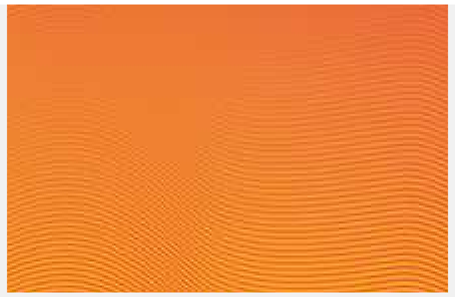
The idea is to build power plants that function much like the heat pumps used in residential buildings: at a depth of five to ten kilometres below the earth's surface, two boreholes are, in simplified terms, joined together to form a U-shaped loop. Inside the loop, heat is extracted from the rock using carbon dioxide as a circulation fluid. The heat is then either used directly or converted into electricity in a power plant and fed into the grid. If employed across the whole country, the method would be an ideal replacement for the unecological gas-fired power plants that currently supply reserve energy, especially as the closed loop enables the system to be started up and shut down again very quickly.

At present, however, the method is too expensive, mainly due to the high cost of drilling, as Saar explains. This aspect has motivated the project consortium to further develop a drilling method known as Plasma Pulse Geo Drilling (PPGD), which works with a type of electric shock rather than mechanically breaking up the rock. The innovative technology requires only about a quarter of the energy consumed in standard drilling procedures, and the electrodes needed for the electric pulses last much longer than standard drill bits.

Much work remains until this type of ecological power plant is ready for the market. On the bright side, however, Saar says lab experiments suggest that the new drilling method will work well at great depths. "Although lab tests demonstrate that the higher temperatures in the earth—the kind we want to access—seem to slow the drilling process a little, the high rock pressures at those low levels are very advantageous," Saar explains. "All in all, it looks like drilling with PPGD will most likely be easier the deeper we penetrate."

CERES off to a good start

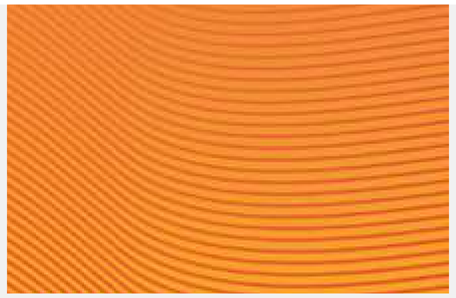
Innovative technologies are naturally essential for the energy transition. However, it's also clear that the shift to a new, sustainable energy future will be expensive—and that society as a whole must commit to change. Indeed, it's essential that new technologies and solutions also find a consensus among policymakers and in society. At FutureLab CERES, Ottmar Edenhofer and his research team want to find out which innovative technologies and which policy instruments can best promote the sustainable management of natural resources. And last year, the project made excellent progress. For example, in June, the FutureLab team attended a large conference in Cyprus, where they presented a detailed overview of their entire project. "Our presentation met with a great deal of interest in the research community," Edenhofer says.



Bedretto Underground Lab

The Werner Siemens Foundation financed the construction of two test beds in the unique underground lab located in the southern Saint-Gotthard Massif, and it continues to fund research projects on deep geothermal energy conducted in the facilities. In the near-authentic conditions of the Bedretto Underground Lab (BedrettoLab), ETH Zurich researchers and their partners from Switzerland and abroad have an ideal environment for studying the physics of earthquakes and for testing methods to safely use and store geothermal energy.

Funding from the Werner Siemens Foundation 12 million Swiss francs
Project duration 2018 to 2024
Project leader
Prof. Dr Domenico Giardini, professor of seismology and geodynamics, ETH Zurich



Deep geothermal energy

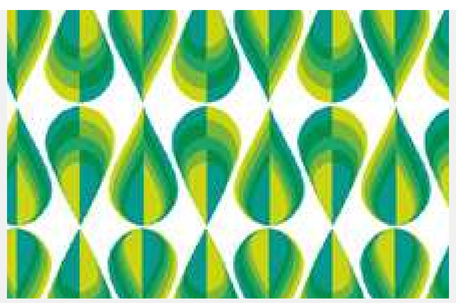
The earth's heat is one of the largest unused energy reserves on the planet. At ETH Zurich, Martin O. Saar and his team are exploring ways to harness this heat for large-scale energy production. In one area of research, Saar teamed up with industry partners to develop a new drilling technology—and an innovative method that can permanently sink carbon dioxide into the earth while also using it to generate geothermal electricity.

Funding from the Werner Siemens Foundation 10 million Swiss francs
Project duration 2015 to 2024
Project leader
Prof. Dr Martin O. Saar, professor of geothermal energy and geofluids at ETH Zurich

To learn more, the researchers have begun examining the dynamics of the coal phase-out in the Global South. One aspect of particular significance for climate policy is how countries like Brazil, Colombia, Vietnam or South Africa can replace coal-fired power plants—or what it is that prevents them from taking this step. Edenhofer explains that phasing out coal is a massive undertaking for these countries—for both economic and political reasons. “This process isn’t only about the power plants themselves. Turbine manufacturers, auxiliary steam systems, power generators and engineering companies are also affected.” In other words, the entire supply chain for production and distribution is already standing, and it’s trimmed for fossil fuel power plants.

To address these issues, researchers at PIK and the Mercator Research Institute on Global Commons and Climate Change (MCC) in Berlin have begun studying aspects such as the role of public credit institutions in the construction of new coal-fired power plants. They discovered that cross-border loans, chiefly from China, Japan and South Korea, are the main drivers for new coal-fired power plants in the Global South. And that these credits are often a means to an end—namely, they benefit exporters of turbine manufacturers and other suppliers in the lending countries.

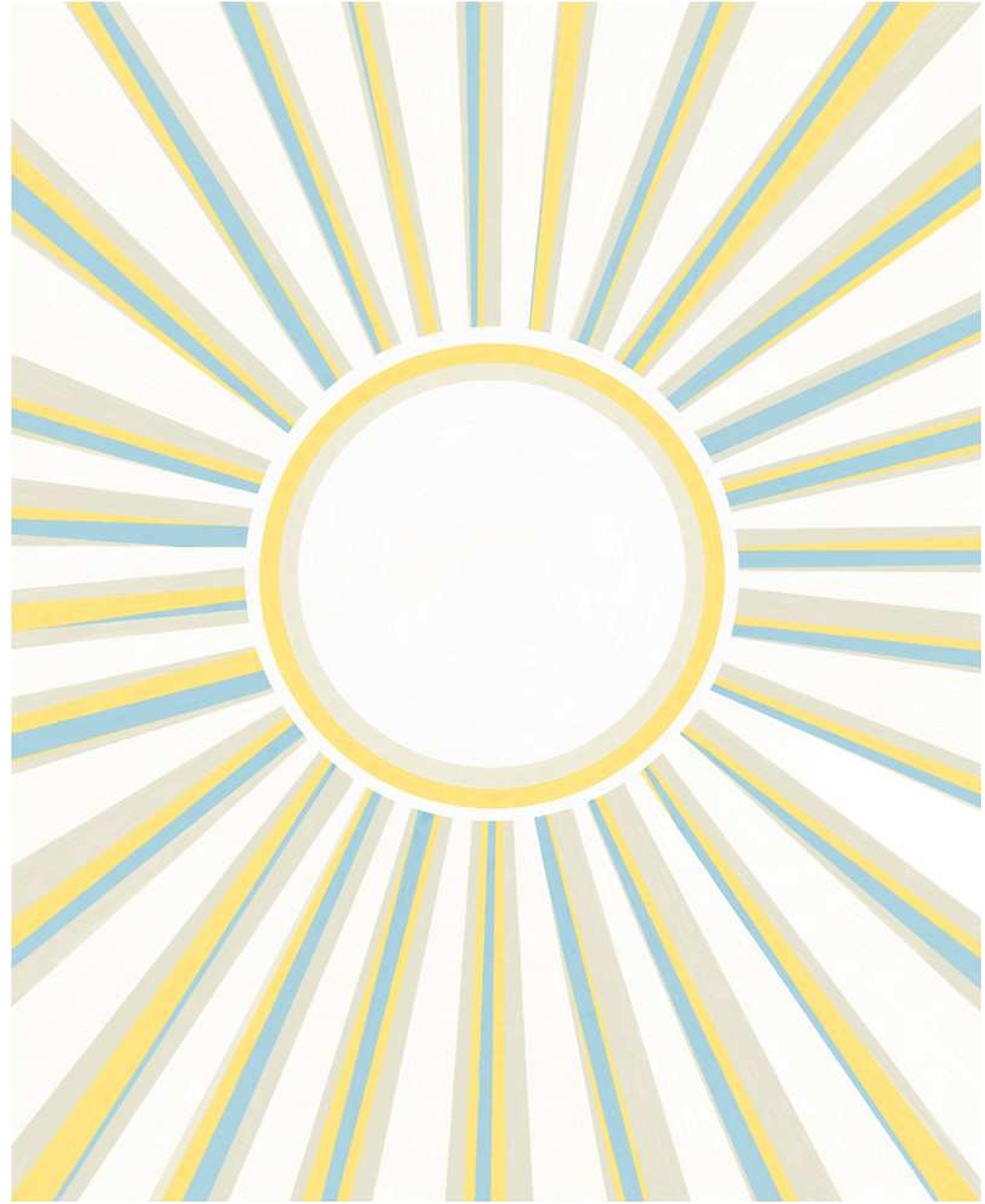
CERES has also made excellent progress in a second area of research concerning policy measures. Governments often enact whole sets of such measures: bans, taxes, subsidies and dialogue. The Potsdam researchers want to understand which factors distinguish impactful energy policy and sustainability measures—and what makes them less effective. “Previously, our data came from Europe,” Edenhofer says, “but now we’ve analysed policy measures in almost every country on the planet, and then interpreted these data using machine learning.” Although the results aren’t yet published, Edenhofer says they basically show that, despite having many differences, effective measures share considerable commonalities. The researchers now plan to draw on the findings to formulate new ideas and proposals—and drive the energy transition forward.

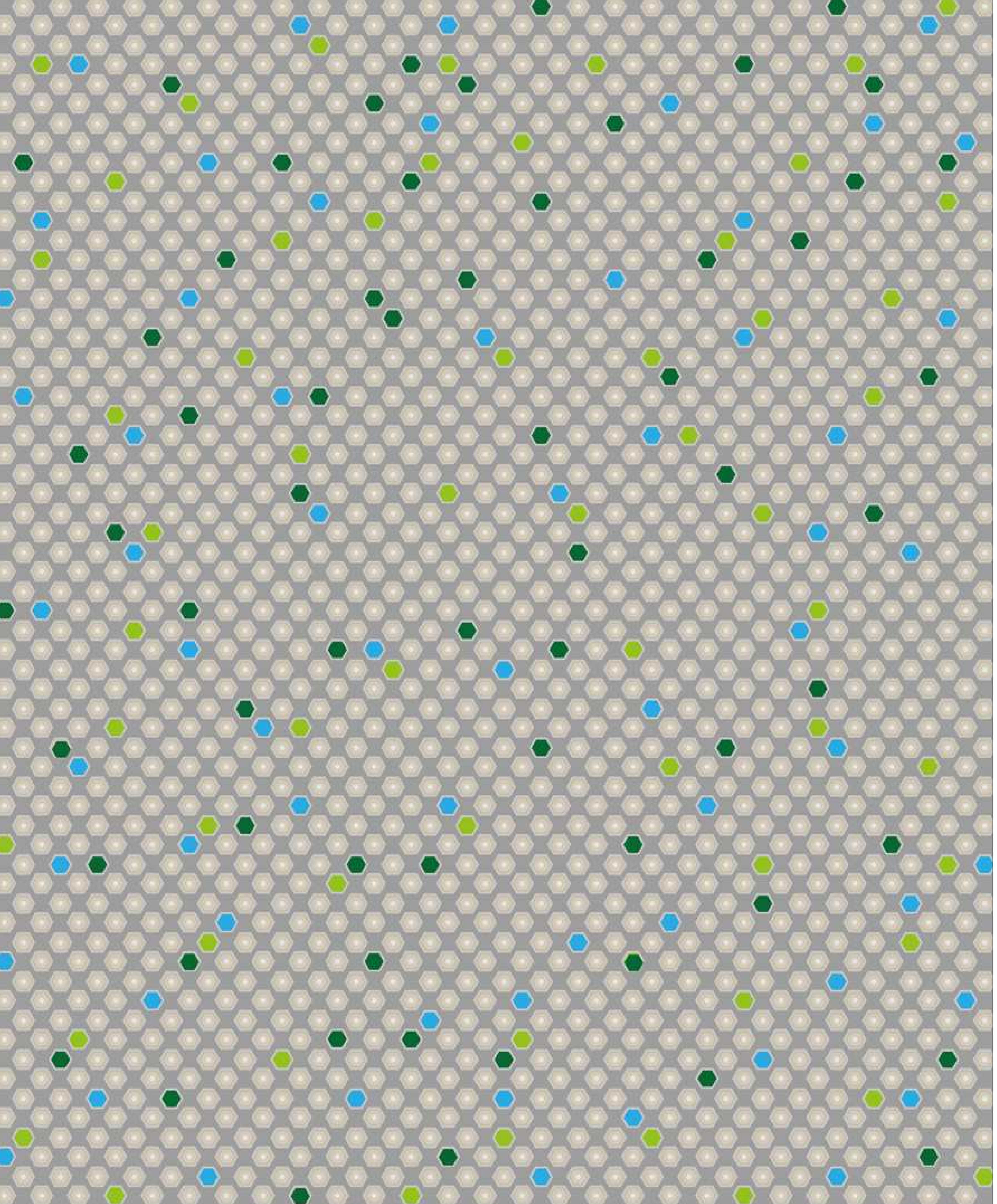


FutureLab CERES

The team at FutureLab CERES at the Potsdam Institute for Climate Impact Research (PIK) are seeking to understand which policy instruments will best promote the sustainable management of natural resources. The spotlight is placed on countries like Brazil, Indonesia and the Democratic Republic of the Congo, where biodiversity is exceptional, where climate change is a particularly large threat—and where huge revenues are generated through the extraction of fossil fuels and other natural resources.

Funding from the Werner Siemens Foundation 10 million euros
Project duration 2022 to 2031
Project leader
Prof. Dr Ottmar Edenhofer, co-director and chief economist at the Potsdam Institute for Climate Impact Research (PIK), Potsdam bei Berlin





A novel take on corrosion protection in reinforced concrete

New WSS project “Climate-friendly corrosion protection in reinforced concrete”

Concrete, corrosion and climate change

Concrete is the most widely used building material in the world. However, conventional methods of producing it release massive amounts of carbon dioxide into the atmosphere. What's more, the firmly held conviction that high alkalinity alone protects concrete from corrosion often prevents more climate-friendly concrete structures from being built. Now, in a project recently awarded WSS funding, Ueli Angst, civil engineer and professor at ETH Zurich, is laying the groundwork for novel corrosion prevention.

Professor Ueli Angst from ETH Zurich is researching ways to improve the construction industry's carbon footprint.

Small mortar samples in glass containers are exposed to various highly specific climatic environments—and then studied under controlled conditions.

Ueli Angst, concrete is a massive success story. Across the globe, 600 gigatons of concrete—enough to build a total of ten Matterhorns—have already been used in construction projects. Why has this particular material become so widespread?
Concrete is relatively inexpensive, and its components—limestone, clay, sand and gravel—are found almost everywhere in the earth's crust. That means it can be manufactured locally, eliminating long transport routes. Another advantage is that concrete can be used to create a multitude of forms. And, when reinforced with steel, concrete is incredibly strong and durable, making it ideal not only for constructing offices and residential buildings, but also major infrastructure projects like bridges and tunnels.

Why are traditional types of concrete still chosen over new, less environmentally detrimental kinds?
To this day, there's a firmly held conviction that only highly alkaline concrete—or traditional types of concrete—can safely protect the embedded reinforcement steel, or rebar, from corrosion. This doctrine has rarely been questioned. But now, by conducting comprehensive research into corrosion processes in concrete and steel, we want to topple the old high-alkalinity dogma and pave the way for building more ecological, climate-neutral concrete structures. We're convinced there are better options for preventing corrosion while nevertheless guaranteeing the longevity of a structure.

What makes you so certain that high alkalinity isn't the best way to protect reinforced concrete from corrosion?
Three years ago, we analysed the data from nearly four hundred buildings in Switzerland, Finland and Japan, all of which were older structures. Due to exposure to carbon dioxide in the atmosphere, the concrete where the rebar is embedded was no longer alkaline. And yet, only five to ten percent of these buildings presented relevant corrosion problems. We interpret this as clear empirical evidence that protection from corrosion can be guaranteed in concrete that isn't highly alkaline.

> "We're convinced that high alkalinity in concrete—bought at the price of massive CO_2 emissions—isn't the only way to protect against corrosion."

What factors trigger corrosion?
Humidity is a major cause. In certain conditions, high humidity alone can promote corrosion processes; but in our latitudes, it's mainly rain or spray from the road that damages buildings.

Your aim is to initiate a paradigm shift in protecting reinforced concrete

structures from corrosion. What do other specialists in the field think of your plans?
In the WSS project, we're aiming to develop quantitative models that predict the corrosion risk in reinforced concrete under specific conditions and also to identify which corrosion protection methods are best suited for a given situation. I've introduced our new approach to the scientific community at various events. For example, last September in Thailand, at the International Congress on the Chemistry of Cement—the world's largest trade congress—I was one of the keynote speakers and had the opportunity to demonstrate how current practices in concrete manufacture conflict with climate protection and how we can change that. I've also presented this same view at other international conferences in North America and Europe. Overall, the echo has been very positive, and our ideas have been particularly well received in the cement and concrete industry.

Concrete is hard. How is it possible that moisture infiltrates deep enough to reach the reinforcement bars?
There are complex pore systems in concrete. Moisture travels through the pores relatively quickly—it's sped up by capillary suction, much like in a sponge. And once water has penetrated the concrete, it takes from days up to weeks for it to evaporate again.

What happens to the concrete when moisture causes the rebar to rust?
At the start, the iron ions in the steel are simply dissolved in the water and don't cause any damage. But over time, numerous chemical and electrochemical reactions are set in motion. For example, the iron ions can bond with hydroxide ions or with other ions in the pore solution. This can cause precipitates to form that are then deposited in the concrete's pore system. And it doesn't necessarily have to happen where the steel is—the dissolved ions can also diffuse in the concrete a few millimetres or even centimetres away from the reinforcement steel and first precipitate there. Actual damage to a concrete structure occurs when these processes cause cracks to form or when the steel corrodes to such an extent that it's no longer functional. However, many aspects of what happens aren't yet fully understood. That's why we want to study the processes in detail.

"We're studying corrosion processes in reinforced concrete in minute detail."

What aspects of corrosion need to be understood for your work?
It's crucial to know how far the iron ions "travel". If they make it far into the concrete, the precipitates spread out more with the result that less pressure builds in the concrete than when the reactions occur closer to the reinforcement steel. In the latter case, local stresses arise quickly, potentially causing cracks to form.

Concrete damages the environment

The gigatons of concrete produced across the globe generate massive CO_2 emissions. Most of the greenhouse gas is released during calcination, a chemical reaction that occurs during the manufacture of traditional, high-alkaline concrete. During calcination, the binder material cement is admixed with water and aggregate materials such as sand and gravel. In this mixture, cement poses the greatest problem for the climate. Cement is made using limestone and raw materials like clay, which are fired in a furnace, where the massive heat breaks the limestone down into calcium oxide and CO_2. Overall, calcination is responsible for sixty percent of the carbon dioxide emitted during concrete manufacturing. The remaining forty percent result from heating the furnace, transporting raw materials, and grinding the minerals and cement clinker.

Ueli Angst (centre) and his colleagues conducting electrochemical measurements at the ETH Zurich corrosion lab.

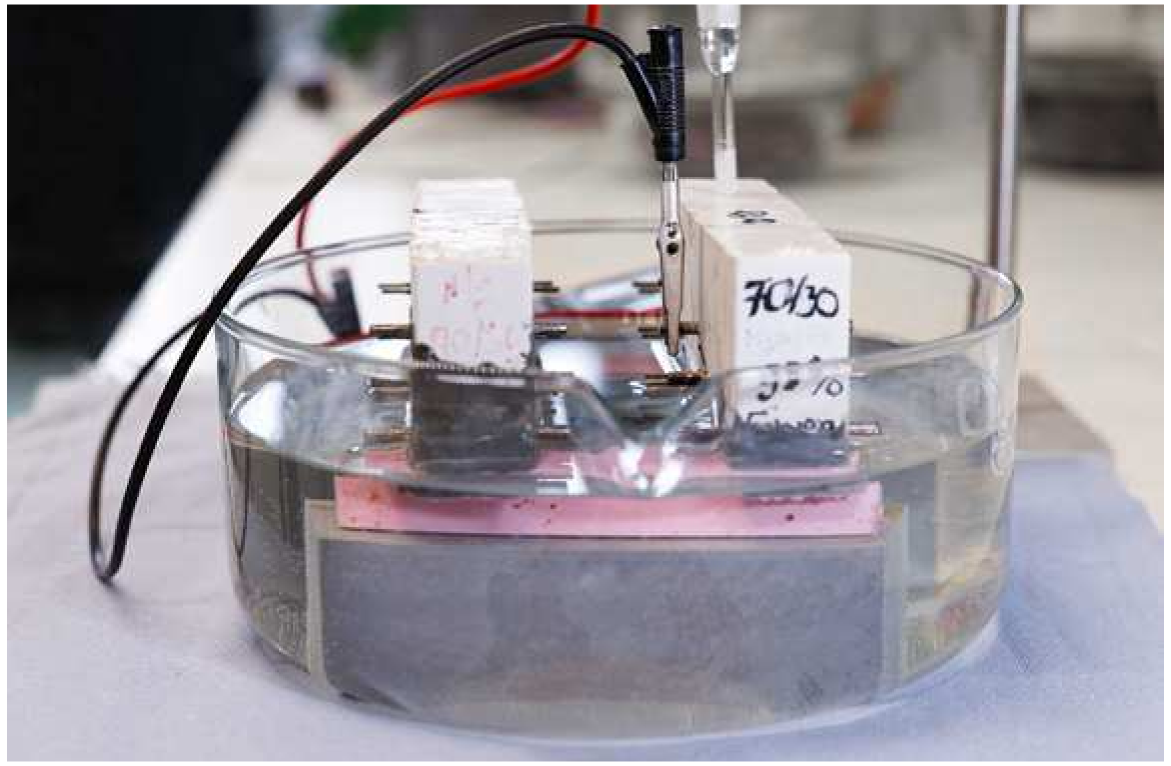
What other aspects of corrosion are you and your team studying?
We want to know more about how the pore systems in different kinds of concrete behave. This includes how well water passes through, how much moisture reaches the steel, how quickly and under what conditions this occurs, how long water stays there, how soon corrosion sets in—and how fast it develops. We also want to know when alternating between getting wet and drying, then getting wet and drying again causes corrosion damage. Because one thing is certain: if we want to use new types of low-alkaline concrete, we have to know how to manage moisture levels and the associated corrosion kinetics.

What parts of the process are particularly difficult to research?
Studying corrosion of metal inside a porous material is a highly complex undertaking. Up to now, the experimental means we have for observing corrosion processes in situ are limited, and they don't provide an accurate picture of what actually happens. That's why we're developing innovative experimental methods for studying corrosion where it occurs.

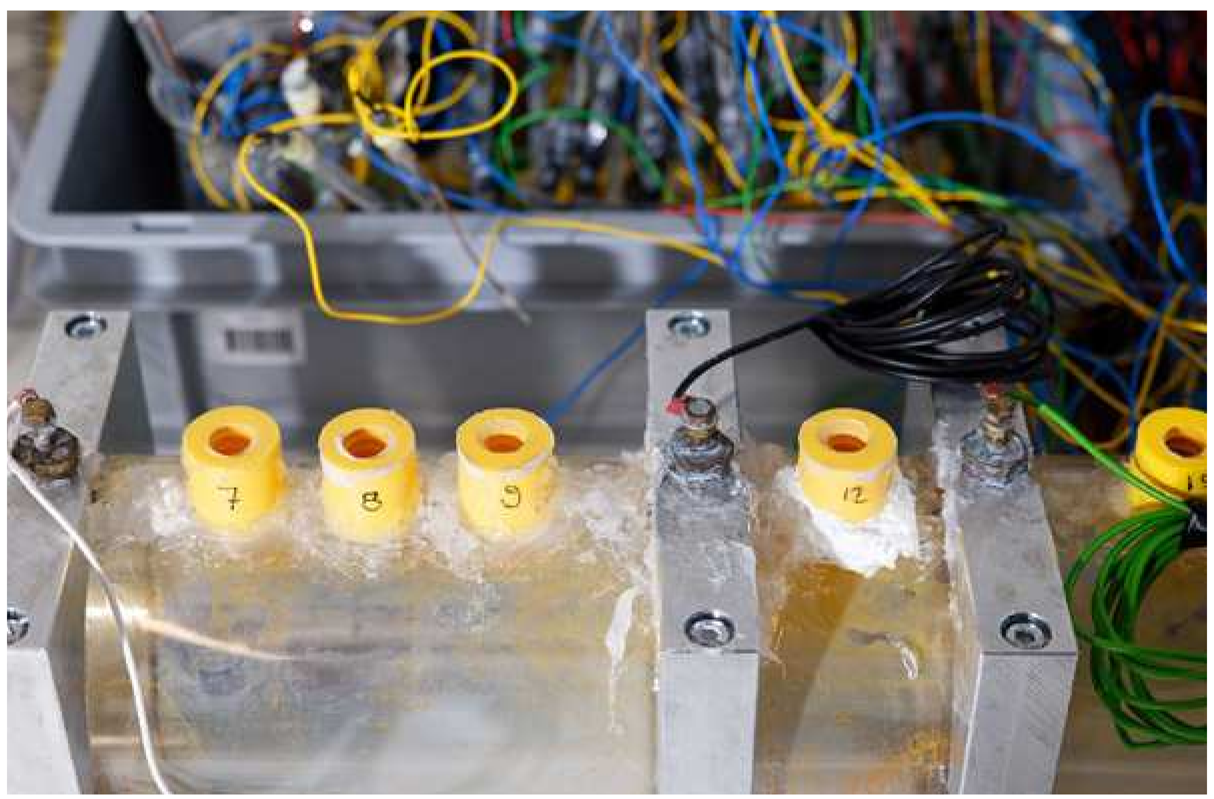
Other problems arise due to large differences in spatial dimensions. Some corrosion occurs in the nanorange, others on a scale of centimetres or even metres, making it extremely challenging to create a digital model of a pore structure that both encompasses and brings all these differences together. But that's precisely what we aim to do in the WSS project: connect all the various dimensions.

How will you go about doing that?
Because corrosion processes are multifaceted and highly dynamic, computer simulations are ideal for conducting a systematic analysis. But they also require a lot of computing power and are expensive—just one reason why the grant from the Werner Siemens Foundation is so important for our project.

What practical benefits do computer simulations have?
We're looking to develop computer simulations that are viable for any and every concrete mix—because, in future, hundreds of different concrete types will be developed and used in construction projects. Ideally, our method will simulate rebar corrosion in these different kinds of concrete across all spatial dimensions. In addition, the models should be designed to incorporate meteorological data like the maximum duration of precipitation in a given country. Our vision is to deliver such accurate forecasts of the long-term behaviours of reinforced concrete in various climates that they'll be of direct use for planning and maintaining infrastructure.



What happens inside concrete when rain falls on the surface? Experiments on how water moves through concrete combined with electrochemical measurements shed light on the processes.



To measure localised corrosion processes on a steel rod, numerous cables are connected to individual measurement electrodes.

Mixing concrete in the lab: to gain insight into processes occurring inside the material, small concrete blocks are produced and then analysed.

Do you already have ideas about corrosion protection in structures made of low-alkaline concrete?
Yes. Instead of focusing on managing alkalinity in concrete for the next hundred years—as is the current practice—we're looking to regulate moisture levels. Up to now, test methods have been based on analysing how quickly alkalinity is lost. I think it's wiser to study and manage the properties of moisture transport in new concrete.

How can you manage moisture in concrete?
Moisture levels depend not only on the concrete itself, but also to a large measure on how exposed a structure is. In places with low average rainfall, even relatively porous concrete can offer enough protection from corrosion. In regions with heavy precipitation, by contrast, denser concrete, more reinforcement, even an additional coating may prove necessary. In order to select the correct parameters during the planning stage, we need to develop numerical models and lab test methods based on the relevant variables and processes.

Aside from adding a coating, are there any other ideas for protecting concrete from moisture?
Other than surface treatments and directly influencing the microstructure of the cement phases via concrete technology, there are many interesting alternatives and approaches. One idea is to add filler materials like cellulose fibres to the concrete mix. In the timber industry, massive amounts of cellulose accumulate, and it's generally disposed of as waste. But if it were mixed into concrete, it could help regulate moisture. Another approach is introducing living organisms like bacteria or fungus-like organisms, that accelerate calcium carbonate precipitation and thus seal the pore system. Enzymes are also another promising possibility in this context.

Using microorganisms to inhibit corrosion—it sounds futuristic!
Yes, and there are also many microorganisms that accelerate CO_2 storage We could apply this basic principle for use in concrete. Currently, a PhD student in our team is working on this aspect.

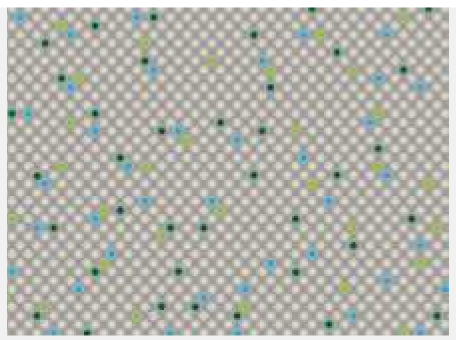
"We want to use sensors embedded in concrete to monitor a structure's health."

And how can you prevent corrosion in the case of already existing reinforced concrete structures?
Our idea is to use sensors that are embedded at various depths in the concrete to monitor the structure's health. The sensors function as an early warning system and are designed to emit a signal should problems

occur—too much water seeping into the concrete, for example. This knowledge equips us with the means to adopt measures to offset the corrosion. The ETH spin-off DuraMon, which I co-founded three years ago, manufactures these kinds of sensors.

You mentioned that concrete could even function as a carbon sink. How is that possible?
A law of nature says that all chemical compounds tend towards thermodynamic stability, a state in which a compound is in chemical equilibrium with its environment. In the case of concrete, the carbon dioxide that splits off at temperatures of over 1400 degrees Celsius during conventional concrete manufacture wants to bond again with calcium hydroxide to form limestone, the starting material.

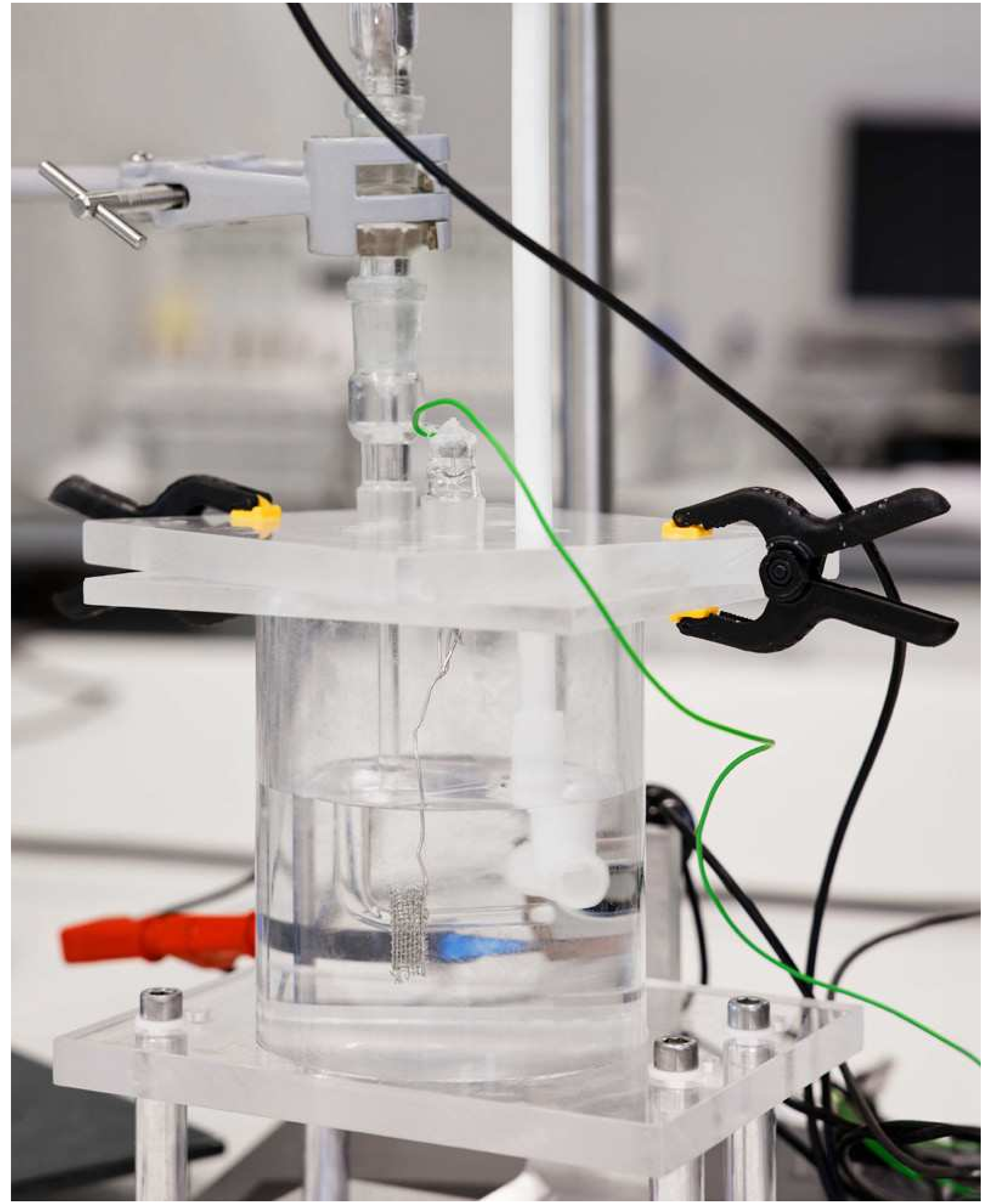
How does that relate to storing carbon dioxide in concrete?
Already today, small amounts of CO_2 from the air diffuse continuously in concrete structures, where they undergo chemical reactions. But this process is extremely slow and it would take millennia for concrete to return to a material that's similar to its original stage. Once we can manage corrosion, however, we can harness this natural process and use innovative technologies to store carbon dioxide in traditional kinds of concrete.



Climate-friendly reinforced concrete

Project leader Ueli Angst is convinced that the old dogma of high-alkaline concrete must be replaced with new, climate-friendly ways to protect the embedded reinforcement bars in concrete structures from corrosion. Thanks to funding from the Werner Siemens Foundation, the civil engineer and his interdisciplinary team at ETH Zurich are now conducting in-depth studies into the complex corrosion processes that occur in various kinds of concrete under different climatic conditions. The new, comprehensive body of knowledge will be used to develop an analytics platform that offers tailor-made corrosion protection measures to practitioners in the construction industry. This approach represents a paradigm shift that will put an end to the era of environmentally harmful building practices and pave the way for new, ecological kinds of concrete.

Funding from the Werner Siemens Foundation 10 million Swiss francs over 10 years
Project duration 2024 to 2034
Project leader
Professor Ueli Angst, Department of Civil, Environmental and Geomatic Engineering, ETH Zurich



Electrochemical analyses, here with the common three-electrode setup in an electrochemical cell, reveal details about each step of a reaction.

The combination of concrete and steel is hard to beat: even large reinforced concrete structures like bridges and tunnels are stable and durable.

Ueli Angst and his fascination for corrosion in concrete

When asked about his qualities as a scientist, civil engineer and ETH professor Ueli Angst answers: "I'm not your typical researcher who's always lived and breathed academia."

After completing his studies as a civil engineer, Ueli Angst worked more than five years in industry, including a stint at the advisory firm Swiss Society for Corrosion Protection (SGK), where he now acts as honorary president. His experience in consulting at SGK lent him deep insights into the real problems facing concrete structures and helped him form lasting ties to industrial practice. At the same time, Ueli Angst is equally knowledgeable about theoretical considerations on how concrete manufacture could be made more sustainable—which led to his appointment as assistant professor at ETH Zurich in 2017. "My aim is to unite theory and practice," he says.

Angst is particularly motivated by the fact that improving concrete manufacture is a key way to tackle climate change and conserve natural resources. "Modern infrastructure is quite literally the pillar of our prosperity," he says. "Without it, we could never transport goods and move people the way we do. The big topics of sustainability and prosperity are virtually embedded in a nation's infrastructure."

A new look at concrete

Our knowledge about concrete has changed drastically over the past fifty years, Angst explains. Up until around the middle of the last century, it was believed that reinforced concrete structures were built to last forever. Then came the realisation that they, too, are subject to corrosion—but that highly alkaline concrete can prevent decay. Starting in the 1980s, engineers began almost solely relying on alkalinity levels in concrete, with standards and textbooks being adapted to reflect this new approach. "At the time, it was most certainly the right thing to do to prevent corrosion," as Angst says. "And one consequence is that we build much more durable structures than we did before."

Indeed, when Angst began studying corrosion fifteen years ago, the issue of sustainability was not yet foregrounded. "Back then, I didn't make a connection between corrosion and climate change," he admits. It was only over time that he understood how the dogma of high alkalinity in concrete had become a problem for the climate.

The right place

Today, Angst says, European countries are leading the way in calls for sustainable concrete manufacture. "But up to now, concrete itself has been the focus, not corrosion processes." Ueli Angst believes that Switzerland in particular is an ideal place for his research. In addition to the country's long-established cement industry, sustainability is a burning issue in Swiss society. And to conduct his interdisciplinary research, Angst has access to top-notch infrastructure and outstanding specialists in related fields at ETH Zurich, EPFL, the Paul Scherrer Institute and Empa.

Ueli Angst believes the construction industry must take action on climate change, saying there are scores of ideas on how concrete can be manufactured more sustainably. He adds: "By studying corrosion, I want to draw attention to another aspect critical to the manufacture of climate-friendly and durable concrete structures. Science and industry have a responsibility to address this issue."

Placing a measurement probe on the surface enables researchers to observe corrosion processes inside the concrete.

Is global warming pushing the seas past tipping point?

Michael Schulz is director of MARUM – Center for Marine Environmental Sciences at the University of Bremen and co-leader of the WSS project "Innovation Center for Deep-Sea Environmental Monitoring".

Gerald Haug is director of the Department of Climate Geochemistry at the Max Planck Institute for Chemistry in Mainz, professor of climate geochemistry at ETH Zurich and president of Leopoldina, the German National Academy of Sciences.

Oceans absorb massive amounts of heat and carbon dioxide from the atmosphere, making them the planet's most important climate buffer. But can they keep up the good work forever—or are there limits to the seas' capacities? In other words, will they reach tipping point? Marine geologist Michael Schulz and palaeoclimatologist Gerald Haug, two experts whose projects are financed by the Werner Siemens Foundation, share their assessment of the situation.

Last year saw one record-high temperature after the other: July 2023 was the hottest month since measurements began, with 3 July marking the hottest day. Which marine ecosystems are most vulnerable to the extreme heat?

Michael Schulz: The physical properties of the world ocean coupled with its sheer volume enable it to store significantly more heat than the atmosphere. Seen globally, this means that extreme weather is currently having only a minor effect on the seas. But, as small as the overall effect is at present, we should by no means underestimate it. An increase of just roughly one degree Celsius in the water temperature can already have a measurable impact on the highly complex marine food chains. And seen on the local scale, the migration of one fish species can have dramatic consequences for the human populations who depend on it for their livelihood.

In 2023, even traditionally cold regions like the Arctic Ocean, Antarctica and the Atlantic Ocean warmed surprisingly quickly to record highs.

Gerold Haug: Global warming is having a major impact on the Arctic. Current calculations predict that by 2050 there will be no more sea ice in summer—the Arctic Sea will freeze over only during the winter months. The melting ice in polar regions will lead to a marked rise in sea levels, and this will become a long-term problem for the human species. And even if we managed to restrict our CO_2 emissions to zero starting tomorrow—which we're far from doing—sea levels would continue to rise for the next several hundred to a thousand years. We have no way of gauging what this will mean for future generations. It also needs to be noted that a third of the world's population lives near a coast.

Is it true that global warming has had only a minor impact on life in the oceans?

Schulz: In coastal regions, the past decades have brought the kind of massive storms we used to see just once in a century. And we've observed a change in marine seasons as well as more frequent occurrences of oxygen depletion in lower water layers.

Haug: We're also increasingly observing a trend towards heatwaves in the ocean waters; for the past few years, these patterns have been growing more intense and lasting longer. Right now, most of these phenomena occur at the water's surface, which has serious repercussions for fish populations. At greater depths, the warming is still progressing very slowly.

At least some good news for the deep sea?

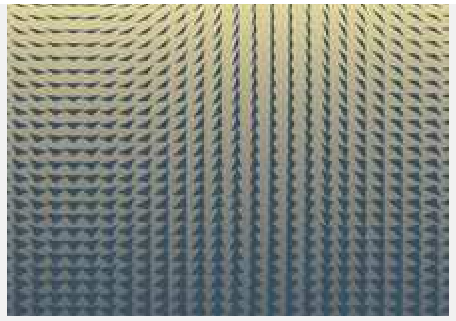
Schulz: I'm afraid not. A warmer surface layer has an indirect effect on numerous marine organisms. It's believed that the amount of organic matter, nutrients, microorganisms and CO_2 transported from the surface to the depths will decrease as will the exchange between warmer and cooler water layers—which is problematic, as this exchange plays an essential role in the emergence and decay of ocean life. Model calculations for the year 2100 forecast that the naturally low biomass in the deep sea will, expressed in percentages, see the greatest drop.

Are there other ways that global warming is impacting the deep sea?

Schulz: Take the greenhouse gas methane. It's made up of organic matter such as the remains of plankton that lived in the ocean long ago and that have sunk to the seabed. In addition, enormous quantities of methane are also found in the oceans' continental slopes in the form of methane clathrate—whitish, ice-like solids created when methane and water bond. When warmer temperatures cause them to melt and release methane, there will also be impacts on the deep sea. But, like so much in the marine world, we don't know exactly what will happen.

What are some possible scenarios?

Schulz: Well, the methane could enter the atmosphere and further exacerbate global warming. Or it could remain in the water and trigger microbial reactions. This is because methane is also a nutrient for micro-



Innovation Center for Deep-Sea Environmental Monitoring

Scientists at the MARUM Innovation Center in Bremen are developing novel technical solutions to identify and monitor ecologically critical deep-sea regions. Last year, co-project leader Ralf Bachmayer and software engineer Pablo Gutiérrez joined the crew on the research vessel *Eugen Seibold*—also funded by WSS—at the ship's base station near Lanzarote, where they conducted tests on the remotely operated underwater vehicle MiniROV. Equipped with an optical sensor capable of identifying deep-sea matter and organisms, the MiniROV transmitted images from the Atlantic directly back to the ship. Ralf Bachmayer is pleased with the results: "Our tests with the MiniROV conducted from the *Eugen Seibold* as well as follow-up discussions on the value of these developments and missions confirm that we're on the right track with our sustainable observation and monitoring systems. And also that this work is more relevant than ever for activities like sequestering carbon dioxide in the seabed." The MiniROV test was the first joint undertaking for the two marine projects financed by the Werner Siemens Foundation. In future, the research groups plan to continue their collaboration when their interests intersect.

Funding from the Werner Siemens Foundation 4.975 million euros
Project duration 2018 to 2028
Project leaders Prof. Dr Michael Schulz, director of MARUM – Center for Marine Environmental Sciences at the University of Bremen
Prof. Dr Ralf Bachmayer, MARUM – Center for Marine Environmental Sciences at the University of Bremen

organisms, including certain kinds of bacteria and archaea that break down methane. Through chemical processes, then, these deep-sea creatures convert gases into organic matter, providing food for other creatures in the deep sea. It's important to understand that there are fundamental differences between how deep-sea organisms and land creatures function. In particular, marine life is partially dependent on chemical processes, and not sunlight.

What marine life is most vulnerable to the rising temperatures right now?
Haug: Any organism that can't just swim to colder regions. Coral reefs and mangrove forests are examples, but so are the people who live near a coast. For them, rising sea levels will have devastating consequences.

In the past eighteen years, the oceans have absorbed twice as much heat as previously, and they're also the world's largest carbon sink. These massive buffer capacities have been able to cushion some of the warming caused by us humans. What's the limit? Can the oceans' buffer system manage global warming of more than two degrees Celsius, as forecast for 2100?
Haug: The only way to avoid more than two degrees Celsius is by complying with the Paris Climate Accords, which is currently not the case. Right now, we're actually steering towards even higher numbers, globally plus 2.7 degrees Celsius on average up to 3.4 degrees Celsius in the worst case, which will drastically compound the climate impacts.

Will the oceans reach tipping point?
Schulz: No. At present, we have no indications that the world ocean as a whole will reach a tipping point. It will undergo radical change, but not in the sense of reaching a critical threshold after which everything will be irreversibly changed.
Haug: I agree. The oceans are changing, climate history clearly shows this. Shallow seas can change very quickly due to the increase in energy uptake, and that will lead to more extreme weather like heavy rains and tropical storms. We'll also notice this on land. But most of the world ocean is located below the so-called thermocline, the water layer that prevents cold deepwater rich in CO_2 and nutrients from rising to the surface. Below the thermocline, the impacts of global warming are still minor.

So the oceans won't reach tipping point? We're constantly hearing about these dangerous thresholds.
Schulz: One frequently mentioned tipping point exists in a major ocean subsystem—the "large Atlantic meridional overturning circulation". If the water in the Northern Atlantic doesn't cool down enough, it will become less dense. Eventually, this will progress to a point where water density isn't high enough to ensure the critical overturning process, and vertical circulation can no longer take place. Although some researchers believe this will happen in a few years, this prediction is at variance with all long-term measurements and realistic models.

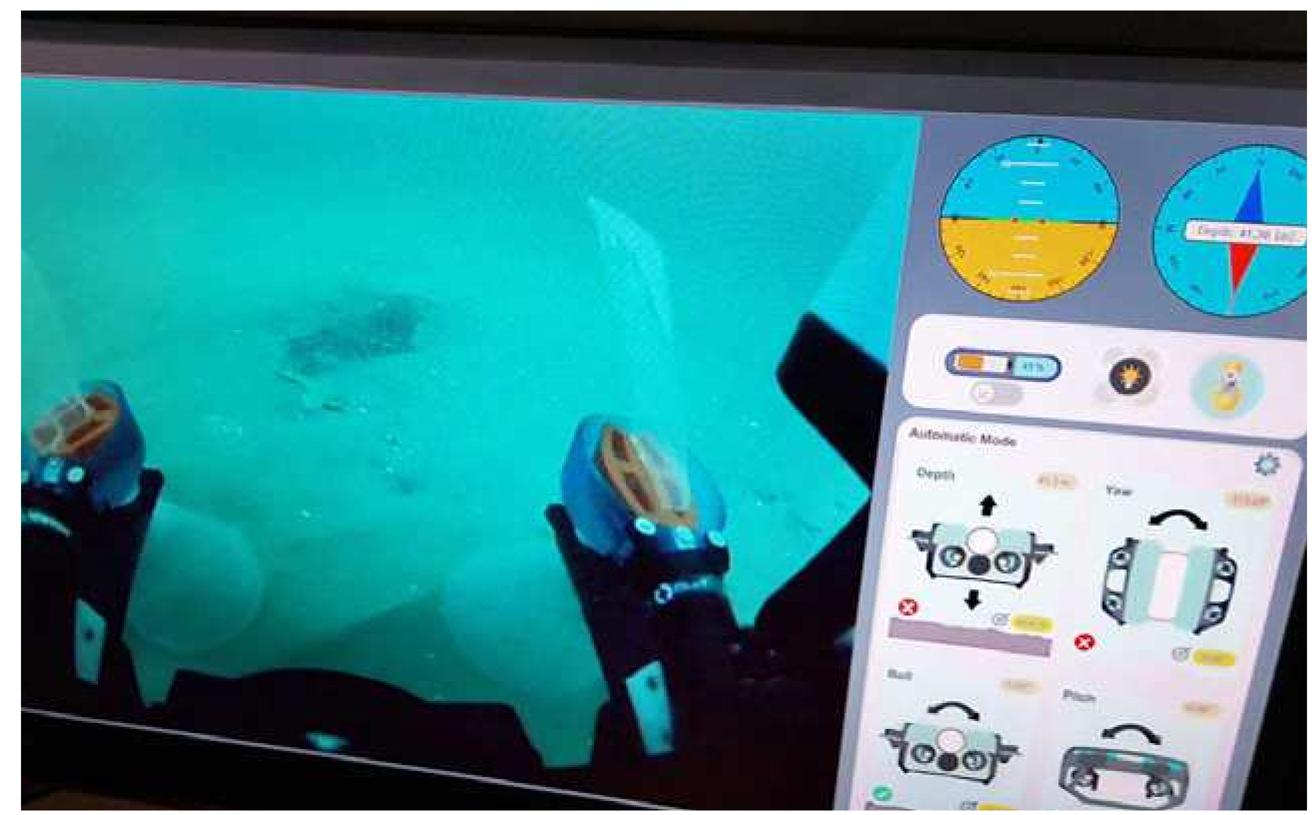
Can you explain what's wrong with the idea that this will happen?
Schulz: For one, changes in the ocean take place on a time scale of hundreds of thousands of years so it's completely irrelevant for our society. In addition, the idea of irreversible change is incorrect. When we look at the oceans from a geological perspective, we can make the long-term prediction that Earth will outlive humans and that our blue planet will host some sort of life for as long as it endures. As such, the better question is whether the changes are happening so quickly that we humans will be unable to adapt.

What's the most urgent step we should be taking to not—literally—poison our own well?
Haug: We need to enact immediate reforms in our energy systems and drastically reduce the amount of fossil fuel we burn, especially coal. But we're not doing any of that.
Schulz: In the West, we're attempting to use renewable energies to cover our energy needs. But it's delusional to think this will be enough. It won't work if we don't lower our current energy demand by two-thirds. We need to adopt a completely different lifestyle.

What's your position on technological approaches to slowing climate change?
Schulz: Ralf Bachmayer at our Innovation Center for Deep-Sea Environmental Monitoring is currently exploring whether it's possible to sequester large amounts of CO_2 in deep-sea basalt rock layers. Liquefied carbon dioxide reacts relatively quickly with the basalts, generating carbonate rock. If you ask me whether I think this is necessary, my answer is clear: there's not a single scenario that doesn't involve removing CO_2 from the atmosphere. The oceans will almost certainly play a major role, as they have great potential as a carbon sink.

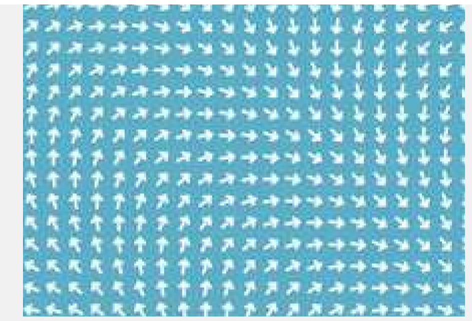
Why aren't we doing this already?
Schulz: Sequestering CO_2 in the ocean crust consumes an incredible amount of energy. Although it's true that the high temperatures in marine volcanic rock can convert liquid CO_2 into carbonate rock within just a few years, there's a major drawback: the operation would be taking place in the middle of the ocean. Travelling there in huge tankers, drilling and injecting carbon dioxide is no simple task. Right now, various agencies are calculating the carbon footprint of this procedure. In addition, we have to see whether it wouldn't be wiser to use the natural basalt deposits in Iceland, Africa and India for carbon sequestration.

Are other technologies being considered?
Haug: We should be thinking about creating a circular economy along the



At MARUM in Bremen, the team are developing remotely operated underwater vehicles to monitor and study deep-sea regions.

Researchers on the *Eugen Seibold* collect diverse samples from the Atlantic and Pacific Oceans. From their base in Panama City, the crew are also studying the weather phenomenon El Niño.



Research vessel *Eugen Seibold*

After two years spent sampling the Atlantic, the crew aboard the *Eugen Seibold* has now sailed through the Panama Canal to the Pacific Ocean. The passage was "a political tightrope act for a ship fitted with this kind of high-tech monitoring equipment," project leader Gerald Haug says. "It took having the German ambassador on board to allay the local government's fears of espionage." Later, German foreign minister Annalena Baerbock also paid a visit to the *Seibold* at the crew's new base station in Panama City. From there, the researchers are studying the weather phenomenon El Niño in transects between Panama and the Galapagos Islands. "El Niño is a major ocean-atmosphere climate event that we want to quantify in biological, physical and chemical terms," Haug says, adding that another highlight of the past year was taking biochemical samples of the large coral archipelagos in the Central Pacific, a mission privately financed by a generous oceanlover. For the first time, the researchers measured nitrogen isotopes in the corals as well as organic material, nutrients and biomarkers; their findings have now tripled the holdings of a major corals archive. The *Seibold's* crew will also contribute additional measurements, enabling quantitative comparisons to be made between current and future oceanic and atmospheric changes and those of the past decades and centuries.

Funding from the Werner Siemens Foundation
3.5 million euros (2015–2019 construction, technical installations)
3 million euros (2020–2030 operating costs)
Project duration 2015 to 2030
Project leaders Prof. Dr Gerald Haug, director of the Department of Climate Geochemistry, Max Planck Institute for Chemistry, Mainz and professor at ETH Zurich
Dr Ralf Schiebel, group leader of Micropaleontology, Max Planck Institute for Chemistry, Mainz

lines of carbon capture and utilisation, a procedure that separates CO_2 where it's emitted and then uses it in catalysis reactions to produce energy carriers like methanol. When we think in terms of larger energy cycles, I believe this could help us achieve a five to ten percent reduction in carbon dioxide over the next thirty years. But here, too, many things that are possible in the lab can't yet be done on a large enough scale.

Schulz: Another problem is that technological solutions themselves will always consume energy and we can't increase power production from renewable sources fast enough.

Haug: That's why policymakers are called on to diversify energy production as soon as possible, and—with industrial stakeholders—initiate dialogue with regions having great solar- and wind-power potential. North Africa, the Arab world, Australia and Patagonia are examples. Enough solar energy can be generated in the tropics and subtropics. At any rate, Europe will still have to import seventy percent of its energy in the future.

How hopeful are you?

Schulz: What makes me hopeful are the very serious studies showing that a less carbon-intense lifestyle doesn't mean reverting back to the Stone Age, that we would still have enough to feed the world's growing population and guarantee mobility, housing and energy consumption at a reasonable level. There are plenty of resources on earth. It's a question of how we distribute them.

Haug: We also have the necessary technology at our fingertips. For me, scientists still represent a great hope. Because, in truth, we can do it. We're motivated and willing to keep at it and work together on a multinational level. Right now, the biggest problem is the lack of political will to enter into binding international agreements and to introduce market-based steering mechanisms such as carbon pricing.

Fresh ideas for climate action

In our quest to create a more sustainable future, science-based solutions aren't enough: we also need politically and socially viable pathways. At a summer academy in the canton of Ticino, talented students were invited to learn more about climate research and to seek effective solutions for combating global warming.

Working in small groups, students in the summer academy on climate change seek viable solutions for specific climate problems.

Gabriela Blatter from the Federal Office for the Environment explains how stakeholders at international climate negotiations make deals and forge alliances.

Although seated at a table just a few dozen steps from the shimmering blue waters of Lake Lugano, the group of five young men and women are blind to the wonders of nature. They're engaged in an earnest discussion—and the clock is ticking. By evening, they need to have drawn up a plan to save the world.

Admittedly, it's not quite as dramatic as it sounds. The students are working on an assignment they received as participants in the "Climate Change: From Science to Solutions" summer academy, a week-long course in September organised by the Swiss Study Foundation, with funding from the Werner Siemens Foundation. The group's task is to come up with a concept for a global carbon tax. No mean feat, as the current system for levying CO_2 tariffs resembles a patchwork quilt: not all countries impose a carbon tax and the methods they use vary considerably.

How to go about introducing a global tax? And how to find a structure that works, is fair, and contains no loopholes? These are the questions posed to the five students from Switzerland and Austria—three women and two men, all from very different academic disciplines. What they have in common, however, is that each is an outstanding student selected by their country's study foundation—an advancement that allows them to attend continuing education courses like the summer academies in Magliaso, in Switzerland's southernmost canton.

Finding solutions is only half the battle

The Swiss Study Foundation summer academies are designed with variety in mind, but the core feature is always that participants are encouraged to develop their own creative projects or concepts. They also receive the opportunity to broaden their horizons by sparring with renowned researchers and attending lectures held by leading specialists. For example, this morning at the Climate Change summer academy, Gabriela Blatter, negotiator and expert on environmental financing at the Federal Office for the Environment, introduced the students to the world of environmental diplomacy. Drawing on her experiences in international climate negotiations, she talked about how alliances are forged, which strategies negotiating partners follow to work towards their goals, and how, after late-night discussions, last-minute agreements are reached—or not. "Climate politics revolve around interest groups," Blatter says.

These special interests are one reason why it's so difficult to get a handle on what is arguably the greatest threat to the environment and the human race of our time. "The science of climate change is actually simple," says Sonia Seneviratne, professor of land-climate dynamics at ETH Zurich, board member of the Intergovernmental Panel on Climate Change (IPCC) and co-leader of the summer academy. "The more fossil fuels we consume, the greater the warming. The solutions are there, we just have to adopt them: replacing oil heating with heat pumps and

Discussing interesting and important issues is even better outdoors on the shores of Lake Lugano.

Summer academy leaders Sonia Seneviratne and Rolf Wüstenhagen were impressed with how engaged and motivated the students were.

using wind and solar energy." But knowing the solutions isn't enough, adds summer academy co-leader Rolf Wüstenhagen, professor of management of renewable energies at the University of St. Gallen (HSG). "We mustn't underestimate the importance of emotional factors and rote behaviours. Only by taking these aspects into account can we motivate others to act."

These "soft" factors are what guided the two leaders when putting the week's programme together. "One part is devoted to questions of natural sciences, the other to finding solutions using tools from the social sciences," Sonia Seneviratne says. And because global warming causes such a wide range of problems, there are also a number of ways to tackle the issue, Rolf Wüstenhagen says. In collaboration with the think tank Foraus, he developed several such approaches, which the students are now exploring in their group projects. "The students should understand that climate policy also has a foreign policy dimension and that, for this reason, consensual solution pathways must be sought," Wüstenhagen explains.

Hashing out the details

One such pathway is a global carbon tax: polluters should bear the costs their damaging behaviour causes to the wider community. For their approach, the group of five students took the Swiss carbon tax system as a starting point: in Switzerland, a tax is levied on each metric ton of CO_2 emitted; the current rate is 120 Swiss francs. Most of the revenue is returned to the population by offsetting it against health insurance premiums as well as through subsidies for energy-efficient building renovations.

However, in many countries, 120 Swiss francs per metric ton of CO_2 far exceeds the means of broad swathes of the population. This is why a key factor in developing a global carbon tax is to factor in the different countries' purchasing power, says Sophie Halper, a law student at the University of Innsbruck. Redistribution is also a stumbling point: how do you reach people who don't have a savings account, let alone health insurance? And can authoritarian states be prevented from siphoning the money off into the wrong hands? The students ponder these and other questions—in full awareness that they won't be able to solve the riddle this afternoon.

Differences and similarities

Nevertheless, hunting for solutions during the summer academy is a fascinating exercise, says Raphael Knecht, who studies geography at the University of Zurich. "It's rather striking that we as a society are still no further, even though most of the solutions are actually on the table." For Leoni Rast, student of agricultural sciences at ETH Zurich, discussing potential courses of action is also important in view of her future profession: "Global warming will impact agriculture, which is another reason why it's a big issue for me."

The situation is serious, the topic at times depressing, but the students still find time for fun while developing their concepts and strategies.

Time's nearly up, an action plan has to be ready by nightfall: a team putting the finishing touches on their idea and sharing the results.

Maya Krell, a pharmacy student at ETH Zurich, is also concerned about climate change. She says she frequently has discussions with people who fail to understand her position and her worries, "so it's nice to be here and talk about it with people whose opinions are similar to mine".

This is all the more true, as the students learn a lot from one another. For example, business informatics student Marcel Simma from the Vienna University of Economics and Business enjoys discussing how countries differ. In contrast to Switzerland, he explains, the refund from the carbon tax in Austria depends on a person's place of residence. "If you live in the city of Vienna, you get a smaller amount than if you live in rural Montafon because public transport is less widely accessible there."

Fresh perspectives

A global carbon tax isn't the only topic on the agenda at the summer academy. Another group is looking at questions such as how improved communications could encourage more people to take part in climate-friendly projects, while a third group is writing a report on how European countries could coordinate their electricity grid planning. The group tasked with the latter topic believe that Switzerland is in an excellent position to drive this idea forward: located in the heart of Europe, its hydroelectric power plants and reservoirs could offer the flexibility needed to cope with the massive increase in solar and wind power generation in neighbouring countries. However, their conclusion is that for Switzerland to play a constructive role in the energy market—and to prevent its European neighbours from planning ahead without it—the institutional issues of cooperation with the European Union must first be resolved.

Anyone listening to the students quickly notices their expertise, creativity and enthusiasm in getting to the bottom of these questions. This has struck the two leaders too. "I see how motivated the students are," says Sonia Seneviratne. "They have lots of questions and aren't afraid to ask." She also finds it very interesting that many participants come from the humanities, and only a few from physics or climate sciences: "This leads to fresh perspectives and stimulates interdisciplinary thinking."

Rolf Wüstenhagen also enjoys his work at the academy. For a study week to be successful, he believes two basic requirements must be met: "First, the students should learn how to form a well-founded opinion." Second, he hopes they won't give up in the face of seemingly irresolvable problems. "My wish," he says, "is that they'll return home with a certain amount of optimism despite the gravity of the situation." When seeing how much interest, enthusiasm and genuine passion the students bring to their discussions, there's little doubt his wish will be granted.

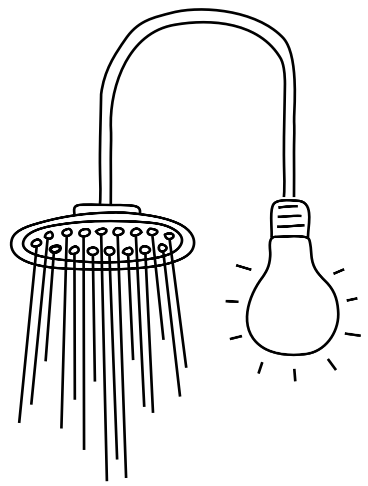
Talent funding by the Swiss Study Foundation

Studying, sitting exams, earning credit points often dominate day-to-day student life. And many students have to work to support themselves, all of which leaves precious little time for reflection. This is where the Swiss Study Foundation comes in, a body that provides gifted students with scholarships and access to programmes that complement their studies. The Werner Siemens Foundation lends its support by awarding ten annual excellence scholarships—the Werner Siemens Fellowships—to outstanding students in science, technology, engineering, mathematics, technology, medicine and pharmaceutics. In addition, WSS provides funding for three annual summer academies in which students can spend a week in interdisciplinary groups exploring topics that interest them, but for which they have no time when university is in session.

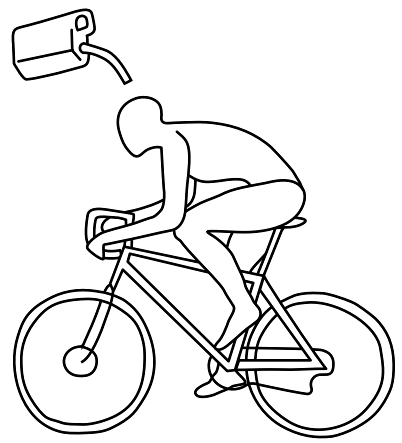
Funding from the Werner Siemens Foundation
19 800 Swiss francs per Werner Siemens Fellowship per year and person
360 000 Swiss francs annually for the summer academies
Project duration 2015 to 2025
Project leaders
Dr Klara Sekanina, director of the Swiss Study Foundation, Zurich
Dr Sarah Beyeler, academic associate at the Swiss Study Foundation, Zurich

Twelve lesser-known facts about energy

Energy is omnipresent in our lives: we use it for heating and cooling, and we need it to get from A to B. Now, as we transition to a more sustainable energy future, it's critical that we develop environmentally friendly ways of producing power—and that we become more aware of how we consume it. So, where do we generate, use and waste energy? The following presents several lesser-known facts about energy production and consumption in both humans and nature.



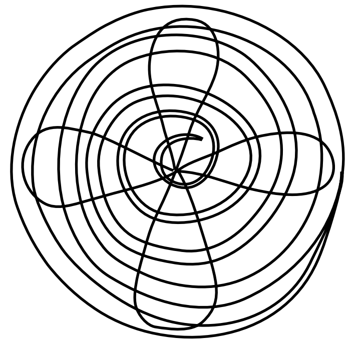
Luxuriant showers
Almost a third of all energy consumed in a household is used for heating water. One minute of soaking under the shower eats up as much energy as is needed to light a home for an entire day. And just one glorious five-minute shower burns three decilitres of petroleum.



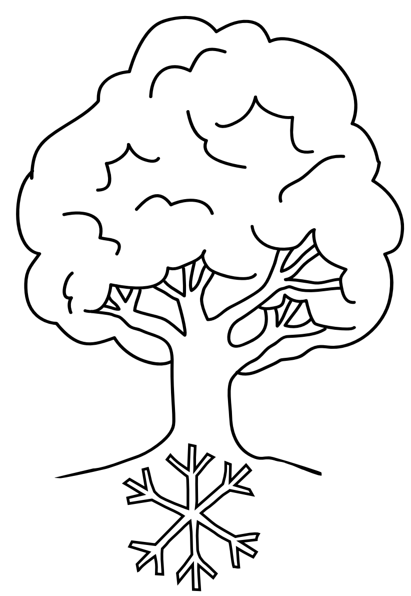
Efficient humans
Our bodies are programmed for energy efficiency. The human brain runs on roughly fifteen watts—no more than the light bulb in our refrigerators. As another example: a professional cyclist would travel 100 kilometres on just 0.7 litres of petrol if the amount of food consumed were translated into fuel.

Suggestive colour
Red is warm, blue is cold. This old saw is backed by science: studies have shown that in rooms with blue-green walls, people start to feel the cold at temperatures around fourteen degrees Celsius. By contrast, when walls are painted orange-red, the shivering commences at eleven degrees Celsius.

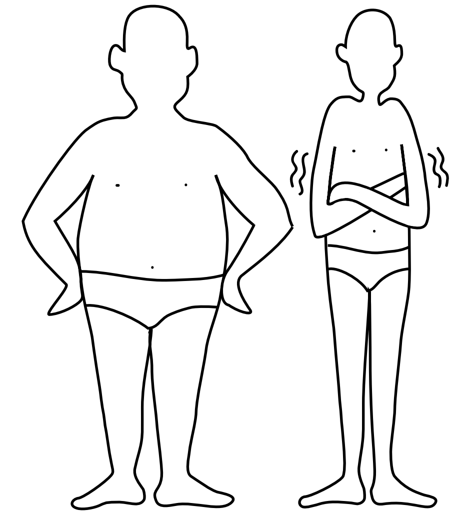
Extravagant Romans
The Baths of Caracalla were a large public bathing facility in ancient Rome. According to calculations based on models of the baths, maintaining enough hot water and air required burning between forty and fifty tonnes of wood every day. Which is merely to say that wasting energy isn't a modern invention.



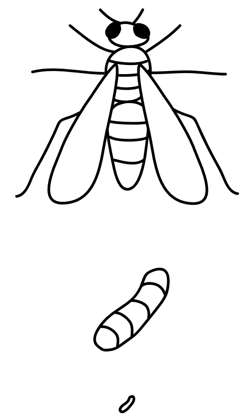
Cooling trend
Experts estimate that more energy will be needed worldwide for cooling than for heating as early as 2030. The amount of energy used for air conditioning has more than tripled in the past thirty years, and it's projected to triple again over the coming thirty. More than ninety percent of all households in the US already have air conditioning, compared to less than ten percent in Europe.



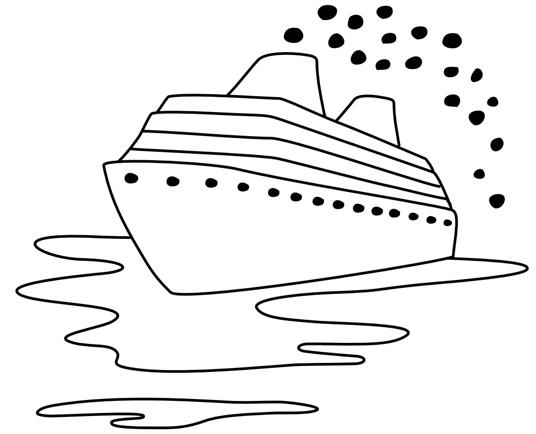
Shady trees
Trees offer excellent protection from heat, especially deciduous trees with thick foliage. In a forest, the highest temperatures in summer are up to five degrees Celsius cooler than in the surrounding areas. Put differently: one large lime tree has the same cooling effect as two hundred refrigerators.



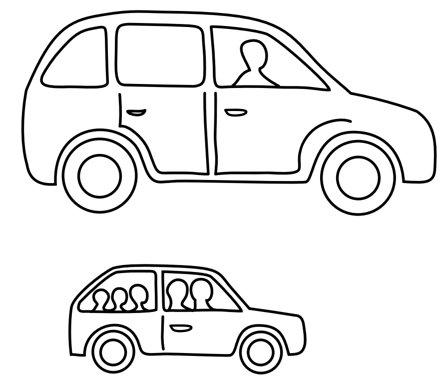
Protective plumpness
Plump people are well insulated, and when exposed to cold, they need three times less energy to generate internal heat than slender people. And whereas the body's thermoregulation soon returns to normal in the amply endowed, it's still operating at full speed an hour later in their svelte counterparts.



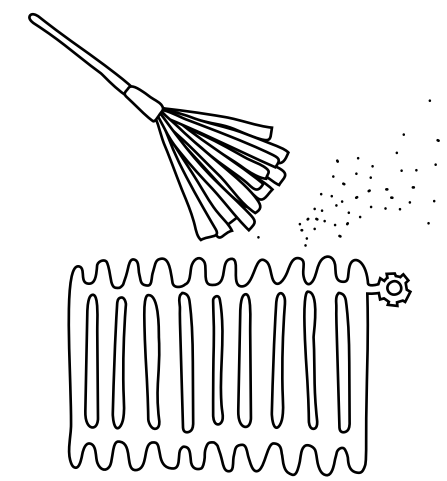
Burgeoning bees
Bees feed their young an energy-rich secretion called royal jelly. When larvae are fed copious amounts of this substance, their weight increases a thousandfold in just five days. Translated to the human scale, this would correspond to a newborn baby growing to the size of a rhinoceros in less than one week.



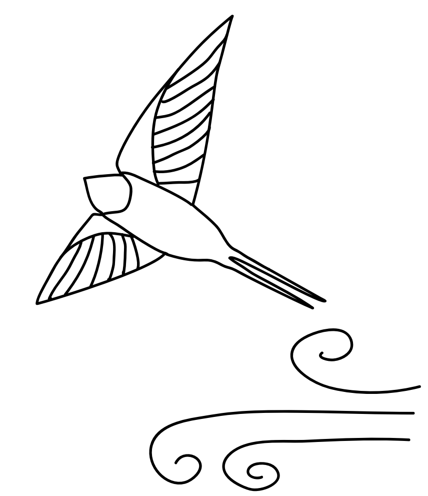
Cruise impacts
Roughly eighty-three metric tons of snow melt for every tourist aboard an Antarctic cruise ship. The cause is soot from the ship's chimneys: it settles on the snow, darkening the surface. As a consequence, less sunlight is reflected, more heat is trapped—and the snow melts.



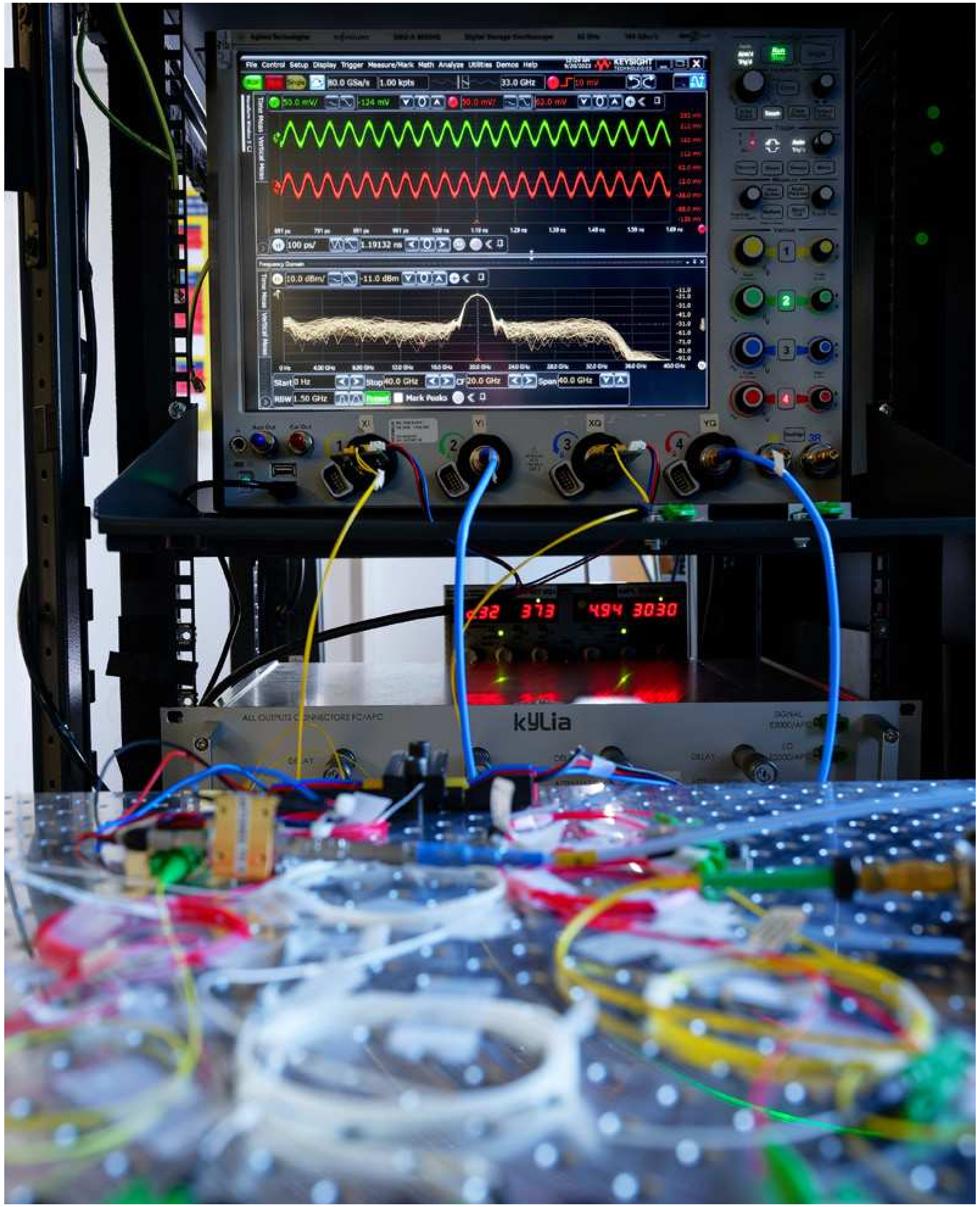
Limited headway
Over the decades, inventive engineers have boosted the energy efficiency of combustion engines. However, in 1960, cars weighed on average half as much as current models—and twice as many people sat in them. Put differently: today, four times as much car is needed to transport a single person. Any gains in efficiency have been effectively negated.



Well-tended radiators
What's possibly the simplest way to save energy is also something we very often forget to do: venting radiators, not placing objects in front of them—and cleaning them. Just one or two millimetres of dust can reduce heating efficiency by up to six percent.



Frugal nature
By strategically navigating the winds, barn swallows can fly all the way from Munich to Barcelona on just two grams of fat. And the average daily requirement of a crocodile is just sixty calories, thirty times less than what humans burn. Like all cold-blooded animals, reptiles don't need to keep their bodies warm—they let the sun do the work.



Clever concepts for exploiting energy

Tapping into renewable energy sources such as solar, wind and hydroelectric power isn't the only way to achieve sustainability. There are also many other, less well-known approaches to both generate and save energy—a point illustrated by two innovative projects that receive funding from the Werner Siemens Foundation.

In the labs at IST Austria, researchers are creating new nanomaterials in order to generate electricity from temperature gradients on their surfaces.

In lab spaces with so-called “glove boxes”, scientists can process and analyse sensitive substances with the necessary care.

Energy permeates our lives—no natural process can function without it. We need energy to move, lift, heat, light and accelerate objects. And it’s also true that wherever energy is used, there are ways of capturing, generating and saving it. Indeed, many, possibly hundreds of solutions to this end have been developed—even aside from well-known technologies like solar panels, reservoirs and wind turbines.

One such solution is harnessing powerful ocean currents on coastlines: over half a century ago, one of the world’s largest tidal power plants was built on the shores of Brittany, in western France. While tidal power converts the energy difference between low and high tide into electricity, the related technology of wave energy exploits the motion of individual waves for power generation. Aside from a few exceptions, however, wave energy systems have yet to progress beyond the experimental phase.

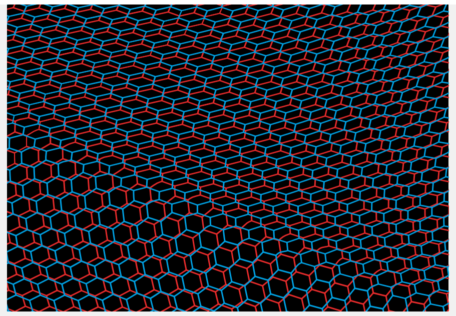
But not only natural forces are sources of energy: human beings can also function as power generators. During their four-year world tour, British rock band Coldplay are aiming to convert human energy into electricity by using kinetic dance floors whose surface consists of modules, in the form of panels, that sink slightly when fans dance on them. Part of this movement is stored in the panels as energy, which can then be used to power things like lighting. As another way to tap into “people power”, researchers are creating special fibres for knitwear or T-shirts that enable the wearer to generate electricity just by moving.

Small changes, big difference

The conversion of kinetic energy into electricity is based on the principle of piezoelectricity: when mechanical pressure is applied to certain materials, it causes the existing electric charge points to shift in such a way that an electric voltage arises. Piezoelectricity is just one example of how energy can be generated on a small scale, and how processes can be made more energy efficient.

The key to success in this area often comes down to making incremental changes to a material that nonetheless bring about significant changes in its properties. Physicist Maria Ibáñez at the Institute of Science and Technology Austria (IST Austria) in Klosterneuburg near Vienna is specialised in one such approach: developing novel nanomaterials and investigating their properties. She says: “When we work on the nanoscale, we observe entirely new phenomena that can be revolutionary in many regards.”

Today, nanomaterials are almost ubiquitous: they’re found in food, toothpaste, cosmetics and packaging. And they help in a variety of ways to make our energy future both more sustainable and more efficient. Ibáñez says that one very important area of application for nanomaterials are catalysts, substances that accelerate and enhance chemical reactions—known as “catalysis”. As one example of the use of catalysts, researchers across the globe are currently seeking ways to convert carbon



Thermoelectric materials

Whether in a computer or a refrigerator, on a windowpane or the human body: wherever temperature differences are found, they can theoretically be used to generate electricity. At present, however, the technology is still inefficient and expensive. But now, physicist Maria Ibáñez and her research group at the Werner Siemens Laboratory for Research on Thermoelectric Materials at the Institute of Science and Technology Austria (IST Austria) are working to change this: they’re seeking new materials that, thanks to precisely defined nanostructures, have the right properties.

Funding from the Werner Siemens Foundation 8 million euros
Project duration 2020 to 2028
Project leader Prof. Dr Maria Ibáñez, Institute of Science and Technology Austria (IST Austria)

dioxide into fuel—as a way of recycling the greenhouse gas rather than letting it escape into the atmosphere. Along these lines, researchers have discovered that the nanopowders of a material displaying a particularly large surface area in relation to volume are often suitable for use as catalysts because, during the catalysis process, light or electricity triggers a reaction that takes place on the surface of a catalyst.

Nanomaterials could also help make solar cells more efficient, improve battery storage capacities and save energy in building insulation. Yet another potential application is using them as components in "smart windows", where the nanomaterials would filter out those wavelengths in the electromagnetic spectrum that have heating effects. Already today, nanoparticles are found in television sets, where they increase light output and help calibrate colour.

Nanoparticles in high throughput

In her own research, Maria Ibáñez is investigating another area of application for nanoparticles: thermoelectrics. At the Werner Siemens Laboratory for Research on Thermoelectric Materials, she and her team are studying how electricity can be generated from a material's temperature gradient using materials made of novel nanoparticles. While not new knowledge, the so-called thermoelectric effect is considered inefficient, especially as, with existing materials, only very little electricity is produced. That's why a key part of Ibáñez's project is accelerating the hunt for more suitable materials. To do so, her lab is constructing a high-throughput unit capable of simultaneously analysing and further developing hundreds of samples.

The high-throughput unit is extremely complex and will be made up of three parts, one each for synthesis, material preparation and measurement. For synthesis, the researchers select a powdery material they believe has promising thermoelectric properties. This results in dozens, or even hundreds, of variants that differ only in detail at the nanoscale, but that can present different properties.

In the material preparation section, the powders are converted into a type of ink and sprayed on foils that are subsequently exposed to a heat treatment and then examined—measured—in the unit's third part. The measurement results are fed into a computer and analysed using machine learning. "Artificial intelligence helps us sift through the massive datasets and find the changes that are particularly interesting," Maria Ibáñez says. At the moment, she and her team are focusing on material preparation. They've developed a prototype that will soon be ready for use. "Our high-throughput unit really began to take off last year," Ibáñez says.

As a researcher, she's fascinated by the search for more efficient materials and new, sustainable ways of using energy. But she also believes it's important to not rely exclusively on technical advances—this, because the most effective tool for achieving energy sustainability is changing how we behave as consumers. "Finding a new technology that reduces energy consumption by twenty percent is very difficult. But saving the same amount would be easy to achieve if we adapted our behaviours."

Recycling solvents

The principle of saving energy by changing consumer behaviour applies equally to the lab. In the past, Ibáñez says, experiments were run under optimal conditions only, no matter how much energy they consumed. "But today we try to see whether an experiment or a material will still work with less energy and waste." Last year, her team focused on recycling solvents. "We fabricate our powders in special solvents and then separate them out," she explains. "We used to throw the solutions away, but now we try to reuse them several times." The team discovered they can use a solvent up to four or five times and still produce high-quality materials, which translates as up to seventy-five percent less waste.

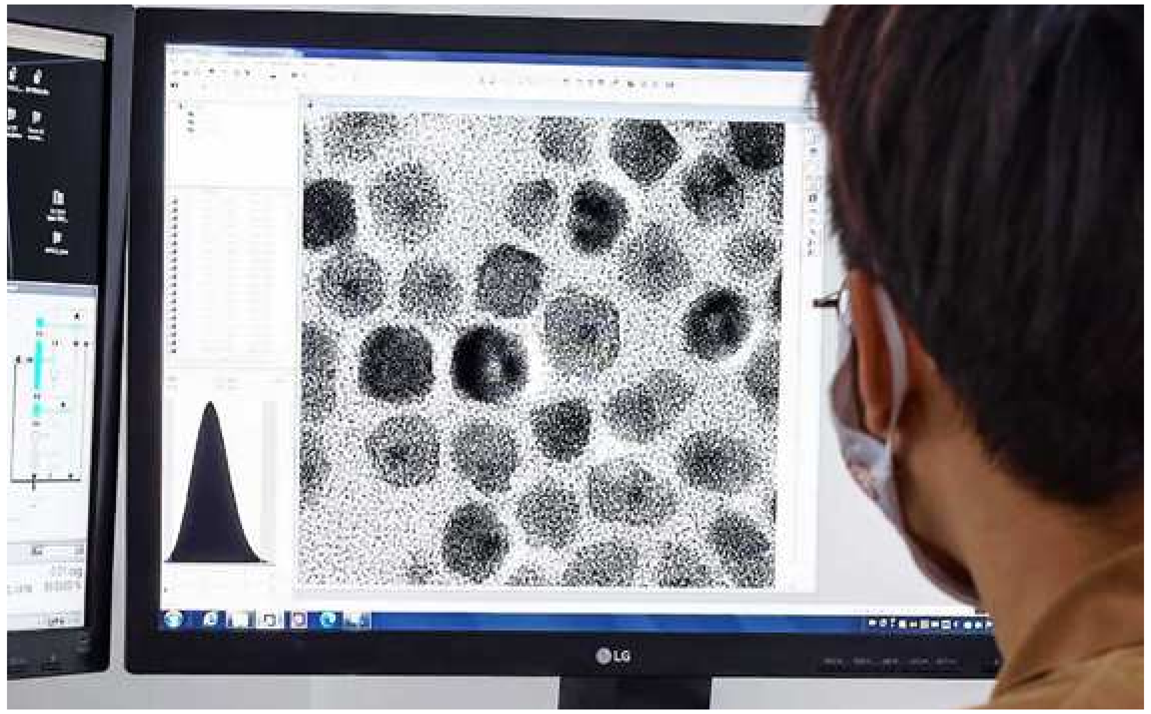
Ibáñez says that exploiting the thermoelectric effect isn't about saving huge amounts of energy all at once. But if less expensive, more efficient materials can make the technology competitive, it can still have a major impact. For instance, the thermoelectric effect could be used to supply electricity to smart sensors that, in future, will monitor temperature, lighting, air pressure and humidity in our homes or offices. Small electronic devices could also be charged using the technology. And, because the thermoelectric effect is reversible, it could also be channelled for cooling. "Transistors in electronic devices have to be cooled," Ibáñez explains. Today's cooling technology is based on ventilators. "But that doesn't work well at the smallest level. Thermoelectrics could open up new horizons," Ibáñez says.

Thrifty microchips

New horizons are also a keyword when it comes to the electronic components developed by Jürg Leuthold and his team at the Center for Single Atom Electronics and Photonics at ETH Zurich, which receives funding from the Werner Siemens Foundation. Leuthold is working on a completely novel type of microchip: one that switches on the basis of single atoms or ions rather than electrons, as is the current practice.

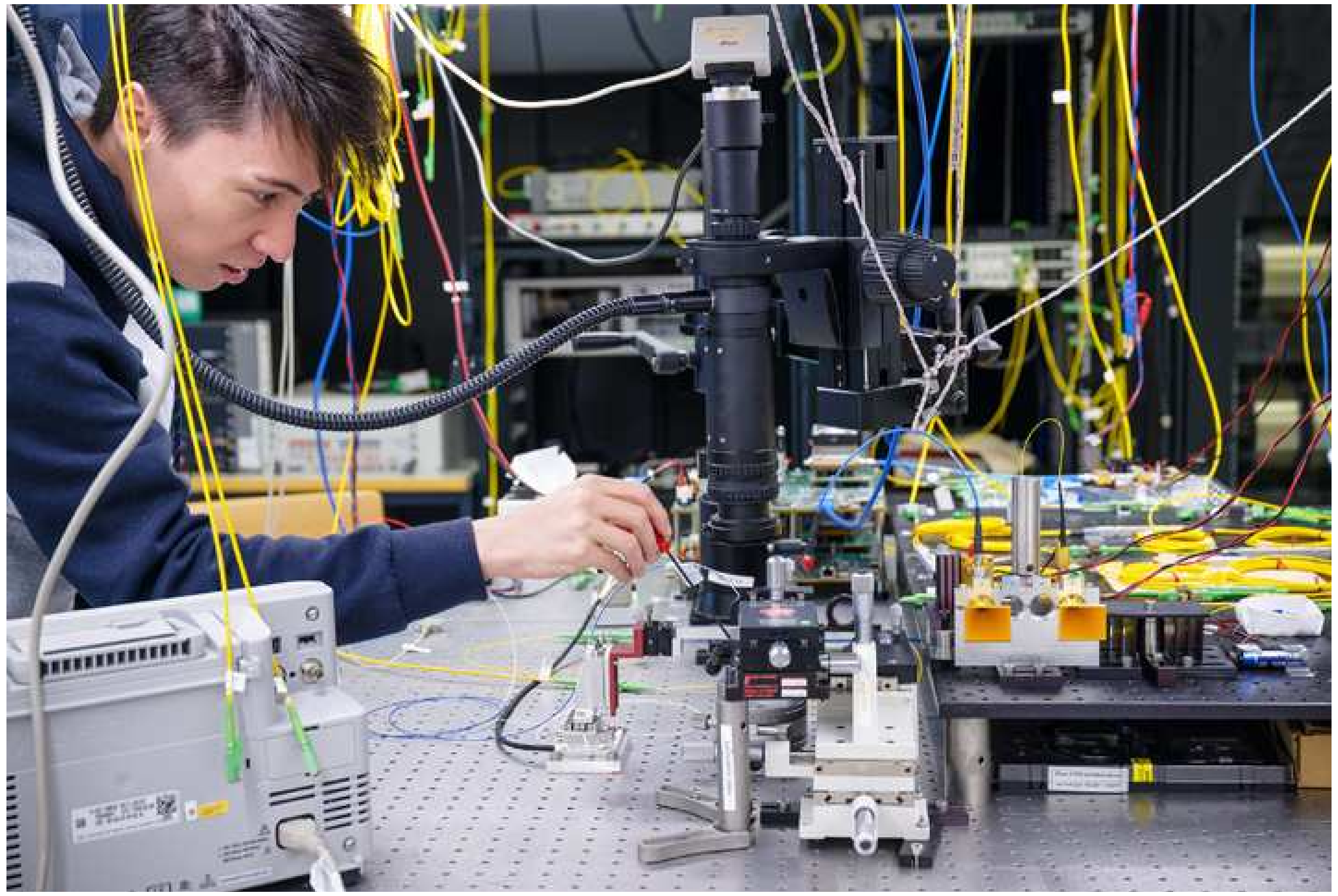
Energy consumption in digital devices in particular has spiked in the recent past; constant technical improvements and an unending supply of possible new functions are driving demand. New artificial intelligence programs are just one example, as Jürg Leuthold explains: "Technologies like ChatGPT work extremely well, but they start up their entire search engine to answer the simplest of questions. And that consumes an enormous amount of energy."

The single-atom switch project could prove especially valuable in this regard. "We're now working on next-generation microchips that could effectively boost energy efficiency by a factor of one hundred, even one thousand," Leuthold says. This doesn't mean we'll consume a



At IST Austria, the researchers also use imaging techniques to study their thermoelectric substances.

Electronics of the future: in Jürg Leuthold's lab at ETH Zurich, researchers are creating microchips that are switched on and off via a single atom.



thousand times less energy for our communication needs, he adds, although studies have shown that, for the first time, global energy consumption for communication technologies has remained stable for about two years now, something that makes Leuthold optimistic. "This levelling out isn't because demand is lower or fewer data were transmitted, but because technological innovation has brought about savings," he explains. "New technologies are being developed that can do more with less energy." In other words, the trend towards energy-saving devices and technologies is apparently able to offset our ever-growing hunger to communicate.

Leuthold's group is at the forefront of this innovative research. Among their specialisations are so-called modulators—key elements in communication infrastructures that encode electrical signals onto laser beams. Indeed, modulators that convert electrical signals into optical signals are essential components in modern IT systems: information is stored electronically in our devices, our cell phones or in data centres, but the data are also distributed via fibre-optic networks in which photons (optical signals) function as information carriers.

The researchers at ETH Zurich have now developed what are known as plasmonic phase modulators that enable extremely fast and efficient signal conversion. They've also demonstrated that these modulators can be used in various configurations for a wide range of applications, including the transition from a wireless LAN transmitter to an antenna in front of a house, as evidenced by a recently published study. "An amplifier mechanism is responsible for directly converting the signal," Leuthold explains. "And the entire process needs one hundred to one thousand times less energy than a traditional modem." PhD students in his group have now founded a start-up with the aim of commercialising these types of modulators.

Laser beams instead of deep-sea cables?

For a communication network to function properly, however, many other components besides modulators are needed. "There's new momentum and innovation in many areas," says Leuthold. As proof of this, researchers in his group have recently demonstrated how radically these innovations can change the world of communications technology. In a recent test carried out between the Jungfraujoch and the city of Bern, they demonstrated that optical data communication lasers are capable of transmitting data volumes of up to one terabyte per second through the air over long distances.

The experiment was a key step in showing that information can be transmitted via satellite through the atmosphere, even across great distances. "Already today, it's easy to communicate in space using these lasers," Leuthold says. But because air turbulence in the atmosphere interferes with transmission, he and his European partners combined various innovations to ensure that large datasets are still readable, despite the disruption. If the technology makes the leap to application, it will replace the incredibly expensive deep-sea cables that currently form the backbone of the global internet.

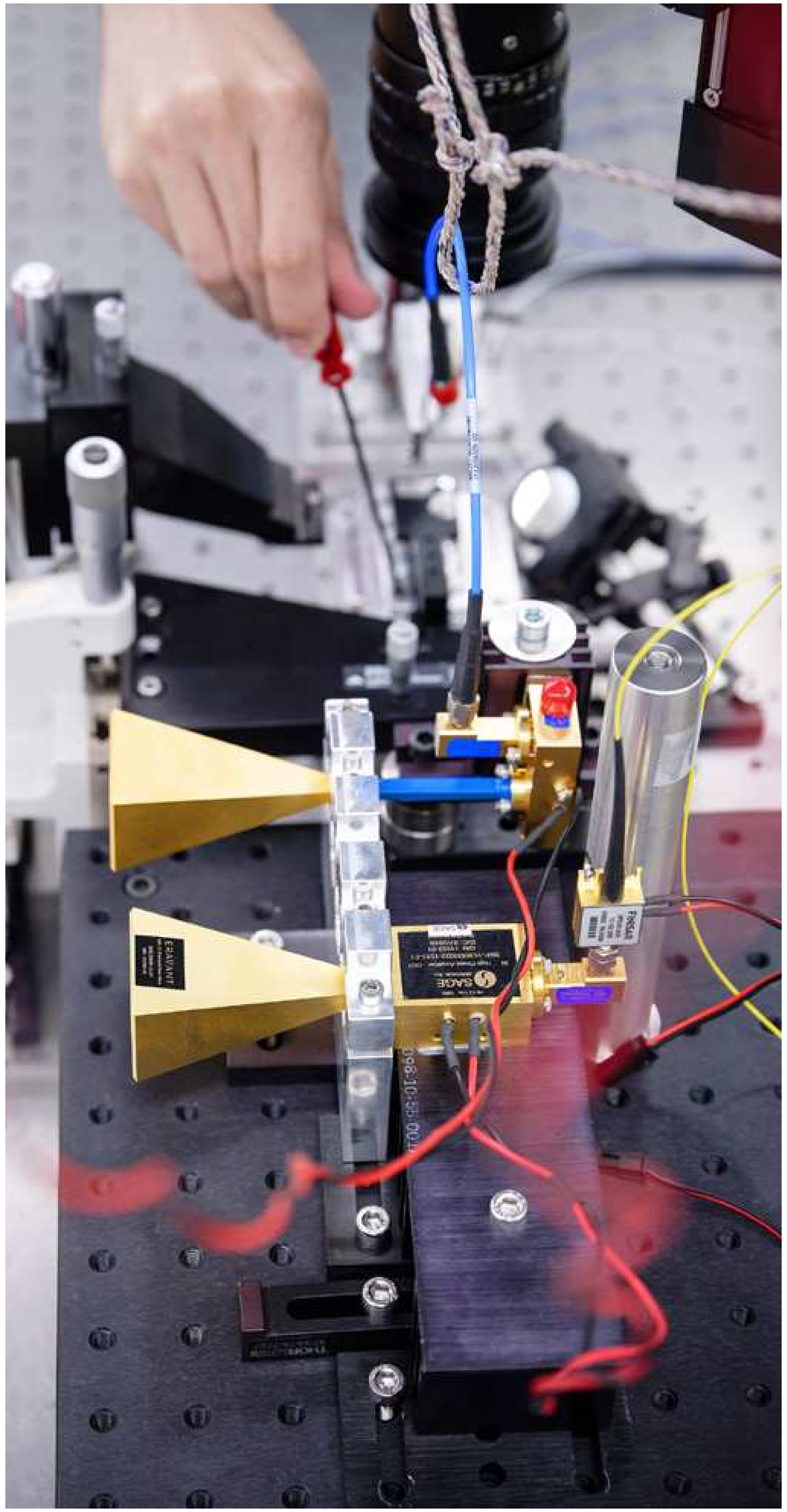
Superfast switches

In addition to these advances, there's always the chance that Leuthold's group will land yet another coup with the WSS single-atom switch project. And they're certainly well on the way: the researchers have already demonstrated that the new method significantly boosts energy efficiency, and last year they published a study proving that the novel single-atom switch can also compete with traditional switches in terms of speed. A veritable breakthrough.

Speed is critical. Even if the switches are as small as technically possible, if they react sluggishly when turned on and off, they'll never find practical application. Leuthold and his team managed to lower the switching time to less than twenty picoseconds—a picosecond being a millionth of a millionth of a second, which is more or less what today's silicon chips achieve. This means that switching speed will no longer be a reason to rule out single-atom switches.

The team scored yet another breakthrough last year in the area of switching types. In electronics, a basic distinction is made between volatile and non-volatile switches: volatile switches return to the starting position after activation, while non-volatile switches remain active until their status is changed. For the first time, Leuthold's team has succeeded in constructing both types using their single-atom switch method. "This is very important, as it enables us to expand our toolkit," Leuthold explains.

For the next few years, the researchers will be concentrating on connecting the various elements. "Up to now, we've been focusing on the single switch," Leuthold says. "But at the end of the day, we need to link several switching elements together if we're to realise a function." It's a function that promises to be a clever way to at least keep energy consumption in check.



To ensure the measurements are accurate, the settings on the complex switching components must be calibrated with the highest precision.

Revolutionary single-atom switch

From espresso machines to huge mainframe computers, microchips are found in almost every electronic device we use. In recent years, researchers have succeeded in making microchips smaller and faster, but the push to get even more minuscule has now hit a wall, and the amount of energy the chips consume is a growing problem. That's why researchers at the Center for Single Atom Electronics and Photonics at ETH Zurich and at the Karlsruhe Institute of Technology (KIT) are experimenting on a completely novel microchip—one that functions at the atomic level.

Funding from the Werner Siemens Foundation 12 million Swiss francs
Project duration 2017 to 2025
Project leader Prof. Dr Jürg Leuthold, head of the Institute of Electromagnetic Fields, ETH Zurich

“We’re in the middle of a polycrisis”

If we don’t want to jeopardise our future, we must act now, says Sandrine Dixson-Declève, co-president of the Club of Rome. And, she adds, while science is critical for achieving a sustainable future, it will take more than new technologies to manage the multiple crises that are threatening humanity.

Sandrine Dixson-Declève, does your work as co-president of the Club of Rome cause you sleepless nights? Or make you angry—or depressed?
Like many others who work in this area, I vacillate between hope and despair. Sometimes I’m optimistic. For example, when I see we have most of the tools we need to solve these problems, and that we have decision makers who listen. Unfortunately, however, those moments are rare. And now when I see yet more drilling for crude oil and gas, or how governments are moving to the right—well, it makes me very worried. We’re in the middle of a planetary emergency, and most people have the feeling they can carry on as usual.

But you don’t seem to have succumbed to despair.
Dana Meadows, lead author of *The Limits to Growth*, the report published by the Club of Rome, once said, “There is too much bad news to justify complacency. There is too much good news to justify despair.” I think that’s

a very important point. Every day, we have to remember that there's good and bad news. And we must remain hopeful.

To this day, the Club of Rome is best known for The Limits to Growth*, published more than fifty years ago. At the time, Meadows and her co-authors warned of catastrophic consequences unless we take action against population growth, industrialisation, environmental pollution, malnutrition and the exploitation of non-renewable resources. Have the challenges changed over time?*
I think the problems have remained about the same. The world's population has continued to grow over the past fifty years, further depleting natural resources. Last autumn, the Stockholm Resilience Centre issued a new report confirming we've exceeded six of nine planetary boundaries. This is exactly what *The Limits to Growth* predicted should we continue living in an extractive economy that advocates productivity and growth at all costs.

Some observers criticise the report, saying its forecasts were inaccurate.
Yes, some people say: "But we haven't passed peak oil. We still have natural resources." And that's true. However, the report didn't say we wouldn't have any resources left. It showed that population growth would make access to resources more difficult. And that there are combined effects of social and environmental tensions.

What's the most urgent problem right now?
Today we're seeing a co-occurrence of social and environmental tipping points. If we look at the scenarios in *The Limits to Growth*, they demonstrated that a series of major tipping points—points of no return—could be reached in the 2020s. And now, here we are in the 2020s, in the middle of a polycrisis: a climate crisis, a health crisis, the Ukraine invasion, and also a biodiversity crisis. To mark the fiftieth anniversary of *The Limits to Growth*, we wrote a book—*Earth for All*—to address all these tension points and to propose possible and viable alternative scenarios.

What conclusions do you draw?
We show that the world's social crisis will be the critical tipping point and that this is probably our greatest existential threat. Inequality in the richest nations—the US or UK, for example—is on the rise. And inequality between rich and poor nations has increased exponentially. This leads to social tensions and wars, it benefits authoritarian regimes, destabilises democracies and provides a fertile breeding ground for populism.

And these developments then spill over to other problems like the climate crisis?
Exactly. But it's not really a spillover, it's an interaction. For example, we see that higher temperatures in India have a direct impact on how men treat women. There's more aggression, more domestic violence.

Why?
For one, tempers naturally run high in hotter weather. For another, fears are growing with global warming, with the rising temperatures—in this case, male aggression has increased due to poor harvests. Men are worried they won't be able to feed their families. Who would have thought that more aggression would be a consequence of climate change? But this is exactly what system-dynamic modelling and systems thinking is all about. These tools can be used to gain insights into the structures and behaviours of complex systems—and to identify a series of interrelated tension points.

"I vacillate between hope and despair."

Are there other such combined systemic effects?
We saw the same thing during the pandemic when people were forced to stay indoors. This, too, had an impact on domestic violence, especially in families living in close quarters. Or the Ukraine invasion combined with the very hot summer in France, Italy and Spain, which led to a sharp rise in food prices as well as value-chain disruptions. We often overlook these combined effects—and tend to forget they're direct consequences of a polycrisis and the interrelationship between complex systems.

In Earth for All*, you propose five pathways to change the trajectory. They concern poverty, inequality, empowerment, energy and nutrition. Do you see progress in any of these areas?*
It's critical to understand that solutions must go beyond improving any one individual area. The five pathways must work together as a whole. For example, some people believe we can solve everything through technology. Technological innovations are hyped, they're "sexy". But we'll never solve problems of inequality and poverty through technology alone. We need more: we need the right governance to rewire the economic and financial systems—and to enable new technical solutions at the right pace and scale. But we humans tend to resist political and economic change.

One of your proposals is to introduce a universal basic dividend: businesses would be taxed for consuming resources that actually belong to the larger community. This includes water, land, minerals, fossil fuels, data. Do you see movement in this direction?
Norway and Alaska have systems that are very similar to our proposal. Every year, the governments there give their population a cheque or tax refund. This way, people experience first-hand how the global commons, our natural resources, are shared. That said, the population's share isn't very large compared to company profits.

In general, one of the Club of Rome's key demands is reorienting the economy towards sustainability and away from growth that's measured by a country's gross domestic product. How do you want to achieve this?
Well, it won't be the economy that takes action. We need governments to step in and create new indicators that weaken the significance of the GDP and productivity in these metrics. They can do this by lending more weight to other economic indicators like access to housing, healthcare, education and other social services. Another way would be by taxing externalities of energy or food. And by giving real value to the factors that are most important for people's lives and livelihoods. Yet none of this is happening. That's why we developed our "well-being index". It shows that general well-being did indeed increase up to the start of this decade, mainly in high-income countries. But, especially in the past few years, we've registered a dramatic decline in people's well-being—due to the pandemic, the invasion in Ukraine and the effects of inflation.

"The social crisis is our greatest existential threat."

What's behind this development?
We've seen a complete decoupling of the financial markets from the real economy. Most of the profit winds up in the pockets of shareholders or interest groups rather than being directed into the producing economy. We have no binding social contract. When a business lays off employees, its shares go up. That's good for the company and the shareholders, but the layoffs create costs for the social system, society at large and individual livelihoods.

So inequality is again the problem.
Yes.

In Earth for All*, you write that humanity is at a crossroads. How much time do we have to get moving in the right direction?*
We're running out of time. Now is the time to act. We've already seen 1.2 degrees Celsius of warming and we'll most likely reach 1.5 degrees by 2030. We're already seeing devastating effects, even in Europe: floods, droughts, forest fires. And the impacts will be even greater once we reach between 1.5 and 2 degrees of warming. We also have grave social tipping points that are linked to the climate tipping points. That's the main message in the book: society is at a crossroads due to the combination of social and environmental emergencies.

What role does science play in enabling or accelerating change?
Science is fundamental in these processes, and our models are based on scientific findings. But we also need to integrate scientific knowledge into the ongoing political discourse on issues like climate action. Unfortunately, we're seeing a divergence here. The science is becoming more and more robust in terms of its predictions, but this new knowledge isn't being channelled into negotiations. In addition, there are people in parts of governments, parts of the economy, who want to know absolutely nothing about the crisis. Because that would mean they, as leaders, would have to foster deep change. But their chief concern is retaining power and profit. This is where things are becoming increasingly tense: between people in power and people like myself, scientists or young people who say: this is no longer the time to just cling to power. We must do things differently—and not only work to protect our own individual interests but ensure that we thrive collectively.

How can funding organisations like the Werner Siemens Foundation contribute to a more sustainable future?
I think such bodies need to understand the role of science today. Science and research should have only one focus: enabling society to thrive within planetary boundaries. In our times of planetary crisis, we need to invest all our research funding into what really matters. And science, for its part, mustn't stay in the confines of the ivory tower. It must focus on the most pressing challenges of the 21st century. And results must be implemented and scaled up quickly, especially because, in many cases, research and innovation are much too slow. I'm also chair of the European Commission's Expert Group on the

Sandrine Dixson-Declève
Sandrine Dixson-Declève is co-president of the Club of Rome, an office she shares with South African doctor and politician Mamphela Ramphele. A Belgian citizen who grew up in the US, she studied environmental sciences, economics and international relations. Sandrine Dixson-Declève has advised the UN, EU and governments across the globe as well as companies, academic institutions and NGOs on issues surrounding sustainability and new economic models as well as climate and energy policies. The media company GreenBiz ranks her as one of the world's thirty most influential women who are driving change towards a low-carbon economy and promoting green business. To mark the 50th anniversary of the Club of Rome, she and renowned co-authors published *Earth for All* to show how humanity can still get a grip on the world's most pressing problems.

Sandrine Dixson-Declève, Owen Gaffney, Jayati Ghosh, Jørgen Randers, Johan Rockström, Per Espen Stoknes: *Earth for All – A Survival Guide for Humanity,* New Society Publishers, 2022

Economic and Societal Impacts of Research and Innovation, where we're working on making science relevant for politicians who are responsible for taking policy decisions. We often see that policymakers don't get research findings on time—namely when they have to take decisions.

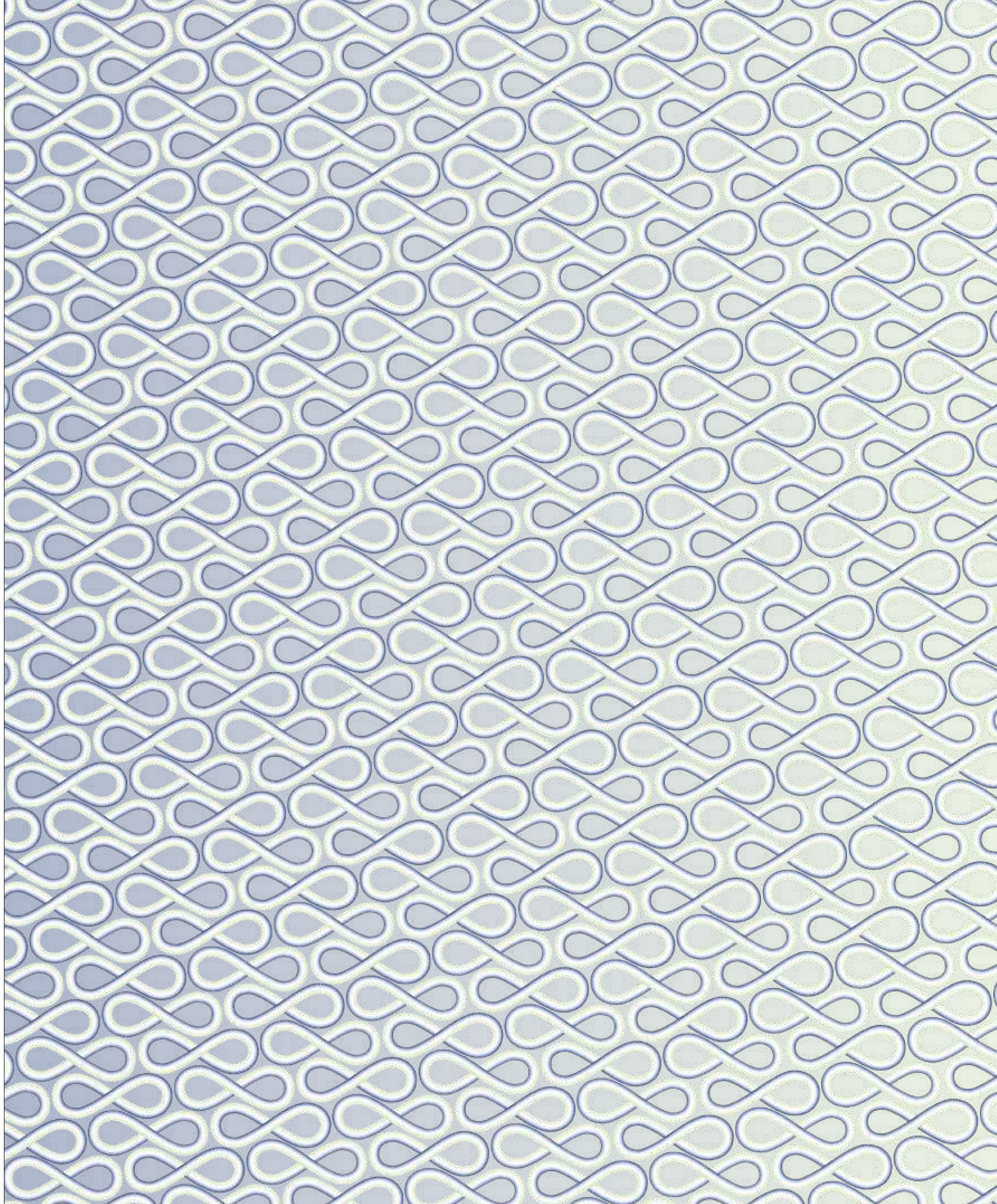
"We're seeing a dramatic decline in people's well-being."

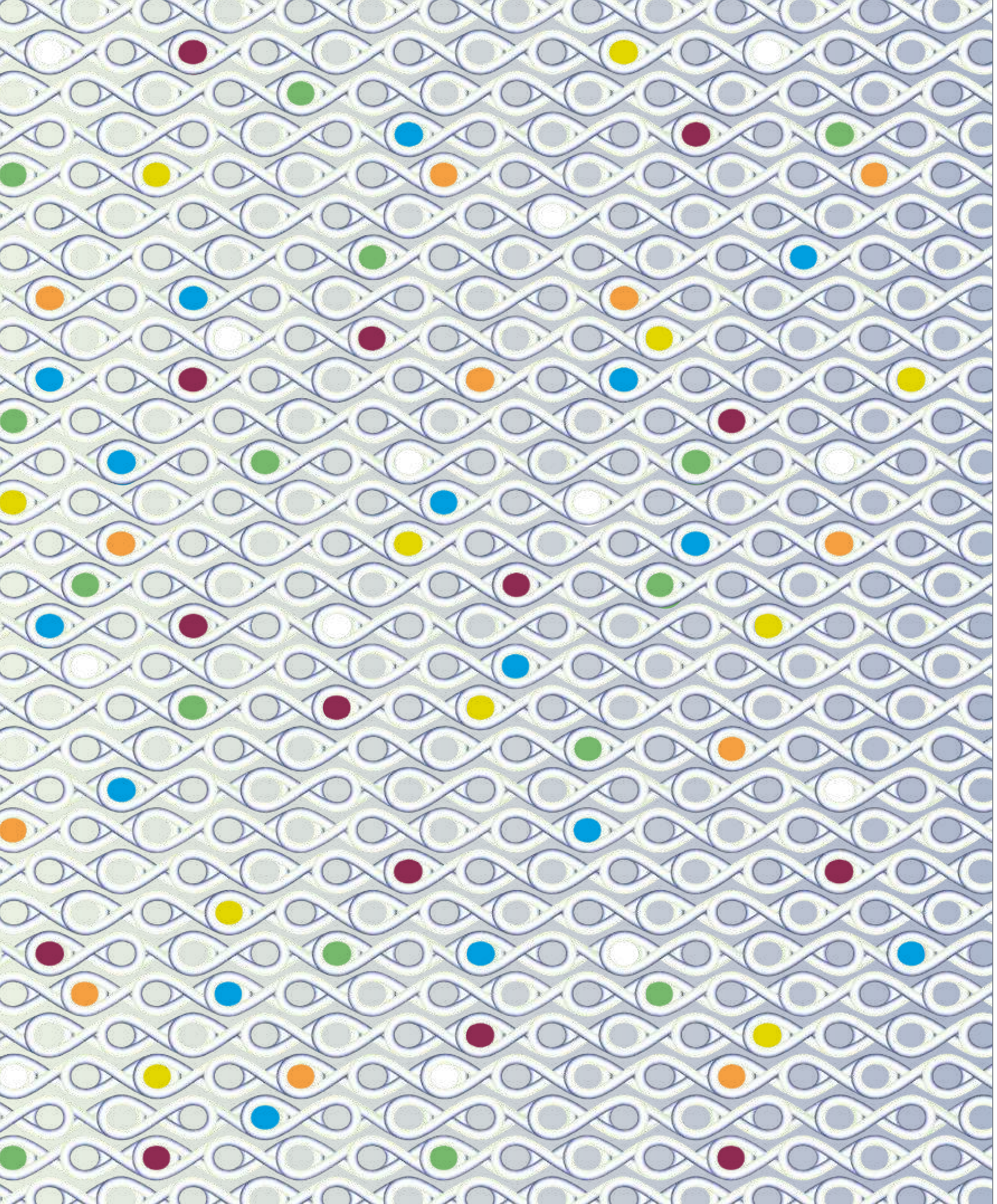
But it's not only politicians who have to take decisions. We all do. And we all know that climate change is a threat and that we can't consume resources indefinitely. And still, many people—not just those in power—are doing nothing. How do you explain this disconnect between knowledge and action?
I think human beings suffer from the ostrich syndrome: we'd rather stick our heads in the sand than look at the problem, and we're only willing to change when something hits us right in the face. However, there are also many people who are worried and anxious, some have even given up. They've grown cynical about their political leaders and governments. But I believe that if you give people a hopeful vision, an alternative and positive future, then they're ready for change.

And how do you give them that vision?
We conducted a survey in all G20 countries in which seventy-four percent of the respondents declared they wanted a transformation to an economy that ensures greater well-being for all, not just a few. This is the key message in our book and the one I'm bringing to governments and other audiences. I don't think it's smart to stir up fears. Activists in the environmental and climate movement are often criticised for just that. I prefer to look at things as a challenge, maybe because I grew up in the US. When you run a race, you know it's going to be tough. What motivates you is how you'll feel when you achieve your goal, the sense of achievement at the end. The race we're facing is a marathon, and we have to find a way to show people what reward is awaiting them at the finish line: the opportunity to lead a holistic, fulfilling life.

THE CLUB OF ROME

Club of Rome
The Club of Rome is an association of leaders and experts from various disciplines and more than thirty countries. Founded in 1968, the non-profit organisation strives to ensure a sustainable future for humanity as a whole. Its landmark study, *The Limits to Growth*, was published in 1972 and warned of economic repercussions in the 21st century unless society changes how it consumes the planet's natural resources.



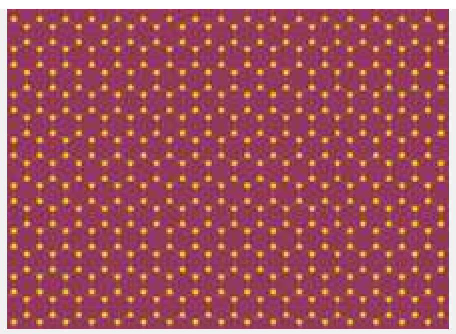


Projects

In addition to pioneering projects in energy and sustainability, the Werner Siemens Foundation finances other research endeavours in the natural sciences and technology—from fields as diverse as medical technology, quantum physics and computer science. On the following pages, readers can learn how the ongoing WSS-funded projects have progressed over the past year.

Stabilising nanomagnets

Researchers in the CarboQuant project embed quantised magnetic moments—so-called “spins”—in their graphene nanoribbons and then link them together. Now, the next step is enabling the use of these nanomagnets as switching elements for quantum applications in sensory technology, communications systems and data processing. To achieve this aim, the project leaders have recruited one of the world’s leading experts in the field of quantum magnetism.



CarboQuant

The CarboQuant team at the Swiss Federal Laboratories for Materials Science and Technology (Empa) in Dübendorf is aiming to develop ultra-tiny quantum electronic components that will ideally function at room temperature, making them suitable for use in everyday devices.

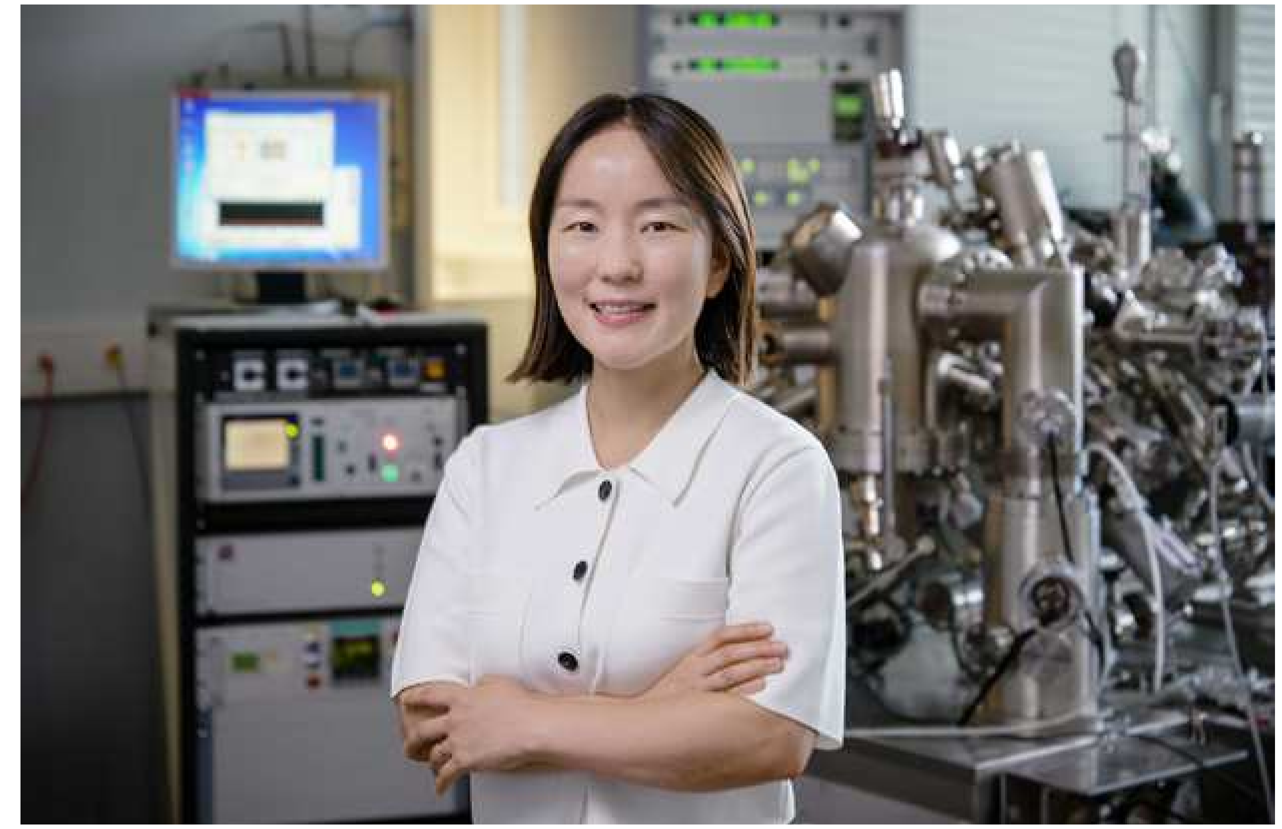
Funding from the Werner Siemens Foundation 15 million Swiss francs
Project duration 2022 to 2032
Project leaders
Prof. Dr Roman Fasel, head of the nanotech@surfaces Laboratory at the Swiss Federal Laboratories for Materials Science and Technology (Empa), Dübendorf
Dr Oliver Gröning, co-project leader of CarboQuant and deputy head of the nanotech@surfaces Laboratory at the Swiss Federal Laboratories for Materials Science and Technology (Empa), Dübendorf

“CarboQuant is the glue that connects all our research activities,” says Oliver Gröning, co-project leader. Last year, he and his colleague Roman Fasel, head of the nanotech@surfaces Laboratory at the Swiss Federal Laboratories for Materials Science and Technology (Empa) in Dübendorf near Zurich, reorganised the research groups working in their division. The new areas are carbon nanomaterials; atomistic simulations; local optical spectroscopy; molecular quantum magnetism; and material integration in circuits. The PhD students and postdocs employed in these groups now mainly work on the CarboQuant project. “Strong interconnections between the research groups are extremely important in our project,” Gröning says. “The new structure of our interdisciplinary collaboration is essential for making the leap from basic research to quantum applications.”

The ball is rolling

Funding from the Werner Siemens Foundation (WSS) has acted as a major catalyst in the project. “Once the ball is set in motion, it starts other balls rolling,” says Gröning with satisfaction. Thanks to the WSS grant of fifteen million Swiss francs over ten years (2022 to 2032), the project leaders are able to better link specialised subfields funded by institutions such as the Swiss National Science Foundation and the European Research Council and integrate them into CarboQuant’s long-term objective.

“CarboQuant is really branching out,” Gröning says, “also in terms of staff.” One new team member is quantum physicist Dr Yujeong Bae from South Korea, one of the world’s leading experts in quantum control of electron and nuclear spins on surfaces. Before moving to Switzerland in January 2024, Bae led her own research group at the renowned Center for Quantum Nanoscience in Seoul. Thanks to the WSS grant, the CarboQuant project leaders were able to offer her excellent employment conditions.



Quantum physicist Dr Yujeong Bae is joining the recently reorganised interdisciplinary CarboQuant team at Empa.

One of the world’s best

“Yujeong Bae was our first choice,” Gröning explains. “Her expertise is exactly what we need to achieve our goal of controlling quantum magnetism with atomic precision.” Worldwide, only a handful of people have the necessary qualifications, he says, adding that a strong motivation behind Bae’s decision to choose the CarboQuant project is likely that young scientists at Empa have a great deal of freedom in their work. “Our role as experienced project leaders is to set the general agenda, remove obstacles and open doors. But then we expect junior researchers to find their own solutions,” Gröning says. The flexibility to investigate unexpected findings and break new ground is explicitly given and encouraged: “This freedom is extremely appealing, and it opens up a creative research field that very few institutions can offer.”

Indeed, a good portion of creativity will be needed to achieve the next steps. The goal is clear: developing nanomaterials in which electron spins can be embedded and controlled in such a way that quantum operations and functionalities are viable under normal ambient conditions. This means more than connecting the spins: the researchers must also realise the controlled production of what’s known as “quantum entanglement”, a phenomenon that exponentially increases the number of possible combinations, and by extension boosts potential computing power.

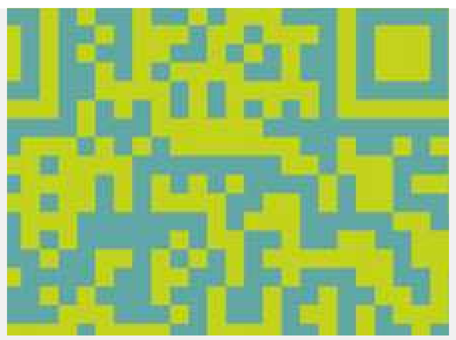
Coupled, but wobbly

“We’ve already had great success in coupling the spins in our CarboQuant carbon nanomaterials,” Gröning says. Now, the biggest challenge lies in attaining the extremely transient state of quantum entanglement and then maintaining it for as long as possible. “This is what Yujeong Bae will be concentrating on.”

This is no easy task, as the spins used in the CarboQuant project are rather ambiguous creatures. It’s very possible to arrange them at specific places along the nanostructures, a process that enables controlled coupling. However, the spins are also chemically reactive, hence potentially unstable. “To stabilise them, we have to encase them,” Gröning explains. The researchers have chosen hexagonal boron nitride—white graphene—for this task. With this compound, the spins on the carbon nanoribbons can be encapsulated and protected from chemical reactions caused by factors such as humidity. This insulation, which has yet to be mastered, is the basic requirement for the next project phase: using these novel molecular nanomagnets in next-generation quantum applications such as switching elements or sensors.

Tightened security

We regularly exchange confidential, highly sensitive data on the internet. To make these transactions one hundred percent secure, computer scientists working in the Centre for Cyber Trust project at ETH Zurich and the University of Bonn are developing innovative, trustworthy security systems—and have now scored a breakthrough in verification procedures.



Centre for Cyber Trust

The actions of cybercriminals and hackers undermine the faith society has in online data exchange. To remedy this, computer scientists in the Centre for Cyber Trust project at ETH Zurich and the University of Bonn are developing a fundamentally new security architecture for the internet. Their aim is to transfer traditional relationships of trust from the physical world to the digital realm.

Funding from the Werner Siemens Foundation 9.83 million Swiss francs
Project duration 2019 to 2027
Project leaders Prof. Dr David Basin, Department of Computer Science, Information Security, ETH Zurich
Prof. Dr Peter Müller, Department of Computer Science, Programming Methodology, ETH Zurich
Prof. Dr Adrian Perrig, Department of Computer Science, System and Network Security, ETH Zurich
Prof. Dr Matthew Smith, Institute of Computer Science, Usable Security and Privacy, University of Bonn

Digital technologies have become an integral part of our lives. We search the internet for information, communicate by email, and interact on social media and messaging platforms. We use smartphones to do our banking and credit cards to shop online. But how do we really know who we're dealing with in these digital spaces? This question is at the heart of the Centre for Cyber Trust project conducted at ETH Zurich and the University of Bonn.

"In the real world, we see who we're speaking to and, when in doubt, can ask to see someone's ID," says David Basin, who leads the WSS-funded project with two ETH colleagues, Peter Müller and Adrian Perrig, as well as Matthew Smith from the University of Bonn. By contrast, authenticating someone's identity is more difficult online, where information is exchanged in the form of bits, or binary digits.

To guarantee the authenticity of a sender or a website, computer scientists work with so-called protocols, which are sets of rules that govern the interactions between computers, networks or processes. "For example, e-banking systems use a cryptographic protocol known as TLS to ensure that clients can safely communicate with their bank and that data can't be read or manipulated during transmission," David Basin explains.

Eliminating weak links

Nevertheless, hackers are still capable of compromising these protocols to steal data. That's why researchers in the Centre for Cyber Trust project are working on techniques to ensure that protocols are fully secure. In addition to writing these protocols, it's also necessary to rule out any weaknesses that cybercriminals could take advantage of. "There are two main causes for vulnerabilities in these systems: technical and human error," Peter Müller explains.

While Matthew Smith in Bonn is focusing on the human side of the equation, David Basin and Peter Müller are working on excluding technical flaws. To do so, they use verification techniques: they run programs that automatically construct mathematical proofs verifying that a software program has the security properties its developers intended—protection against cyberattacks, for example. "We define the set of all the ways that two parties can run a protocol and that a third party—a cybercriminal or hacker—can intervene," David Basin says. These formalised definitions, known as semantics in programming language theory, can then be analysed mathematically.

Vulnerable interfaces

These verification processes are time-consuming, and the security protocol itself isn't the only thing that can cause problems: errors also occur in the code used for protocol implementation—when a protocol is integrated in a software program. "In the implementation step, things can be accidentally omitted, or problems arise that are not reflected in the protocol description itself," Peter Müller explains. "That's why we want to verify both the protocol and its implementation."

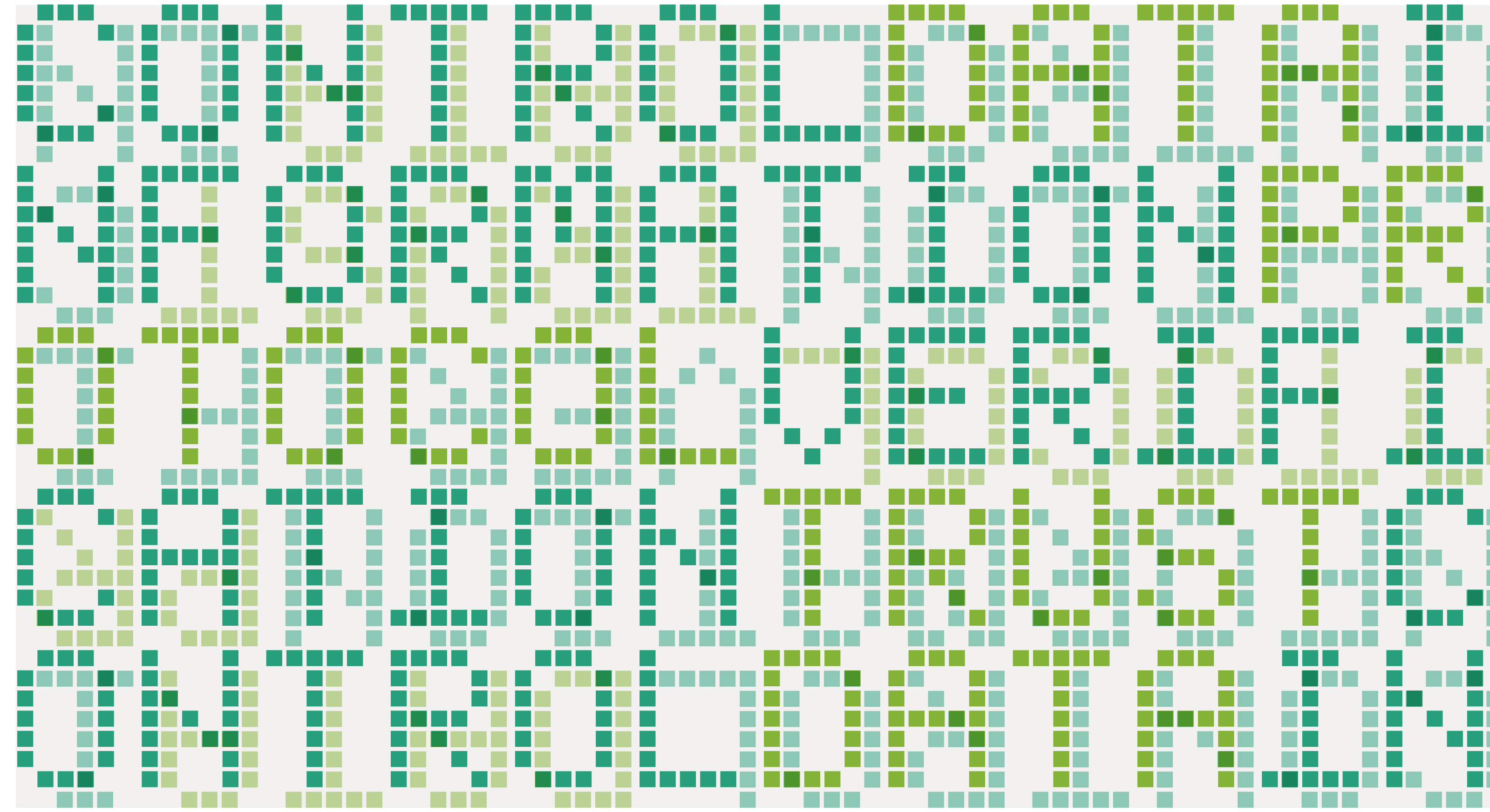
The interface between these two steps has always been a weak point in proofs for whether a protocol is running exactly as it should, Müller continues. "At the interface, there were previously no tools to control that the two proofs—the proof that a protocol design is secure and the proof that the implementation is correct—fit together properly. Instead, it's people who decide whether the protocol and implementation levels are working together error-free—which is error-prone in practice."

Now, however, in painstaking work, the two researchers and their groups have succeeded in using mathematical descriptions to link the two layers together so closely that the interface weakness in the verification proof has been completely eliminated. "It's a breakthrough," David Basin says with evident satisfaction. And Peter Müller adds: "Researchers have been working on code verification for sixty years, and on protocol verification for thirty. Before us, however, no one had ever managed to link protocol verification and high-performance protocol implementation this closely."

Error-free not good enough

In effect, linking the two levels means end-to-end verification: during the entire process, from protocol to code, each and every step has been verified by a tool. Nevertheless, there remains much to do. For one, the researchers want to automate the verification further and adapt them for more complex implementations, Peter Müller explains.

And another important issue is under investigation: although the new verification methods for ruling out errors in the protocol and code are essential for secure websites, error-free isn't good enough, as David Basin says. "Users also need to understand and trust these security architectures." That's why ways of gaining this trust is the other key question the researchers are exploring.



At the Center for Artificial Muscles, researchers have begun developing artificial facial muscles. Their aim is to help people with facial paralysis smile again.

A workout for artificial muscles

Steady progress and new projects: researchers at the Center for Artificial Muscles in Neuchâtel can look back on a successful year. In collaboration with surgeons, they made significant progress in developing their innovative solutions for patients suffering from cardiovascular diseases, facial paralysis and incontinence.

Our muscles grow when we work them, a phenomenon that also applies at the Center for Artificial Muscles (CAM), located on the Neuchâtel campus of the École polytechnique fédérale de Lausanne. There, the team led by director Yves Perriard and managing director Yoan Civet work with such persistence and dedication that their projects are thriving in all regards.

First, there's the flagship project: developing a battery-powered electroactive polymer ring to boost the aorta's pumping capacity in cases of cardiac insufficiency. In autumn 2022, the researchers tested the system on pigs, and Yoan Civet reports that it increased cardiac functioning by up to fifteen percent—which is a threefold increase over earlier results.

More power or minimally invasive

Despite the advance, however, it's still not powerful enough, as Yves Perriard explains: "At first, surgeons affiliated with the project wanted to improve the heart's pumping capacity by twenty percent, but now they'd like to have thirty to forty percent." One of the reasons for needing higher capacity is related to the method they've been using: an invasive surgical intervention in which the muscular ring replaces a section of the aorta, making an incision through the artery wall necessary.

To meet the new specifications, the researchers are working to make their artificial muscle more powerful by using a slightly thicker membrane and extending the ring's length to measure twelve centimetres. "In lab tests, we attain a pumping capacity of twenty percent," Civet says. This is very good news, especially as earlier tests have shown that the pressure change in the static lab unit is doubled when later used in a living organism.

But the researchers are also pursuing another avenue and seeking ways to place the ring around—and not in—the aorta. "This way, surgery would be much less invasive, and an improvement of 20 percent would be enough for an exterior placement," Yves Perriard says. The initial results are promising in this project, too: in lab experiments, the researchers fitted the muscle around an artificial aorta, lending pumping capacity a significant boost. "We now want to test both of the systems in a pig," Perriard says.

Helping children with univentricular hearts

The CAM team are also working on a second heart project, this time with the aim of helping children whose hearts have just one, rather than two, chambers. In these young patients, the body's pulmonary and circulatory systems—containing both oxygen-rich and oxygen-poor blood—converge at the same place in the heart. Surgeons separate the two systems by implanting tubes that channel oxygen-poor blood returning from circulating through the body and organs into the lungs' pulmonary system.

"Our idea is to replace this passive blood flow with an active process," Yoan Civet explains. The researchers are now aiming to combine their soft, pliable polymer with blood vessels. "When we contract the softer tube and then open it again in a regular rhythm, we generate a flow—without using a valve." Here, too, the initial results are very encouraging.

Growing bladder cell cultures

Another potential area of application for the artificial muscle is in the field of urology. The researchers are working to develop an artificial sphincter for the urethra to help patients suffering from urinary incontinence. Currently, they're building an artificial urethra to test their idea in the lab. In a second part of the project, their aim is to create a platform for urologists at Inselspital Bern, enabling them to grow and study bladder cells. Yoan Civet explains that "it's impossible to grow bladder cells in a Petri dish", because our bladders expand when full of urine, and then shrink after we've emptied them. Bladder cells need this constant expansion and contraction to grow and later function properly.

Because the researchers at CAM believe the high elasticity of the material used in their artificial muscles could prove ideal for simulating this process, they're now working on the development of a two-sided elastic membrane for growing the cell types in the bladder on either side.

The gift of a smile

The third area of work at CAM is facial reconstruction. Here, the researchers hope their artificial muscles will one day replace complex surgeries to transplant leg muscles into the cheeks of patients with partial facial paralysis. The Neuchâtel researchers recently published their first study on this endeavour, demonstrating that, when fitted near the mouth, their artificial muscle system is capable of quickly translating nerve signals into movement. They hope this application could one day help affected persons smile again, and more studies are currently being conducted on a skull model. All in all, there's a lot to keep the team at CAM busy.

Artificial muscles

Cardiac insufficiency is a common disease, affecting one in every fifty adults. At the Center for Artificial Muscles, located at the Neuchâtel campus of the École polytechnique fédérale de Lausanne (EPFL), researchers are working on a state-of-the-art solution—they're creating an artificial muscle designed to give weak hearts a boost. Their idea is to place a ring-shaped electroactive polymer inside or around a patient's aorta; the polymer is powered via an external battery worn by the patient. The artificial muscles could also be adapted for other areas in medical care, and the Neuchâtel team are now working on applications for the urinary tract and facial reconstruction, too.

Funding from the Werner Siemens Foundation 12 million Swiss francs
Project duration 2018 to 2029
Project leader Prof. Dr Yves Perriard, director of the Center for Artificial Muscles and the Integrated Actuators Laboratory (LAI), EPFL

Automated brain-wave analysis

Medical engineer Jelena Skorucak has developed an automated software platform for detecting indicators of epilepsy in the brain activity of children. Thanks to a MedTechEntrepreneur Fellowship from the University of Zurich, she can now prepare the platform for market entry.

Up to one percent of the population suffers from a form of epilepsy, and children are more commonly affected than adults. Epilepsy patients who experience severe seizures are generally diagnosed very soon, but others have seizures that often—or almost exclusively—occur during sleep. When their brainwaves are measured in an electroencephalogram (EEG) scan, these episodes register as marked aberrations, or "spikes".

Although neurologists can detect epilepsy by observing these spikes on an EEG, "analysing an EEG for an entire night is extremely demanding", says Jelena Skorucak, a medical engineer and postdoc at the University Children's Hospital Zurich. To simplify the procedure, she came upon the idea to automate EEG analyses.

Her solution was developing a software tool that detects the spikes; she and her colleagues first validated the software platform by comparing their results to the analyses of experienced neurologists. They then conducted a study using a dataset of more than 400 sleep EEGs carried out at the University Children's Hospital Zurich over the last twenty-five years.

Promising results

The software also traces a marker for sleep quality, as it's believed that seizures disrupt sleep patterns and the regeneration of synapses in the brain, which is why people with epilepsy often experience fatigue as well as problems with concentration and memory. And in fact, a study the team published in the journal *Scientific Reports* showed that the software reliably detected both spikes and sleep quality. Moreover, it confirmed that spikes and poor sleep do indeed co-occur frequently in epilepsy patients, and that the two are correlated. This correlation is especially high in children with Lennox-Gastaut syndrome, a particularly severe form of epilepsy.

Jelena Skorucak is now aiming to prepare her analysis platform for market entry, and the first steps have been made possible by the MedTechEntrepreneur Fellowship she received in the spring of 2023. The University of Zurich programme is financed by the Werner Siemens Foundation and endowed with a scholarship of 150 000 Swiss francs. The fellows are also mentored by experienced coaches who help them overcome the myriad obstacles on the rocky road to establishing a firm; in addition, they have access to the UZH Incubator Lab and are invited to join a network of current and former fellowship holders.

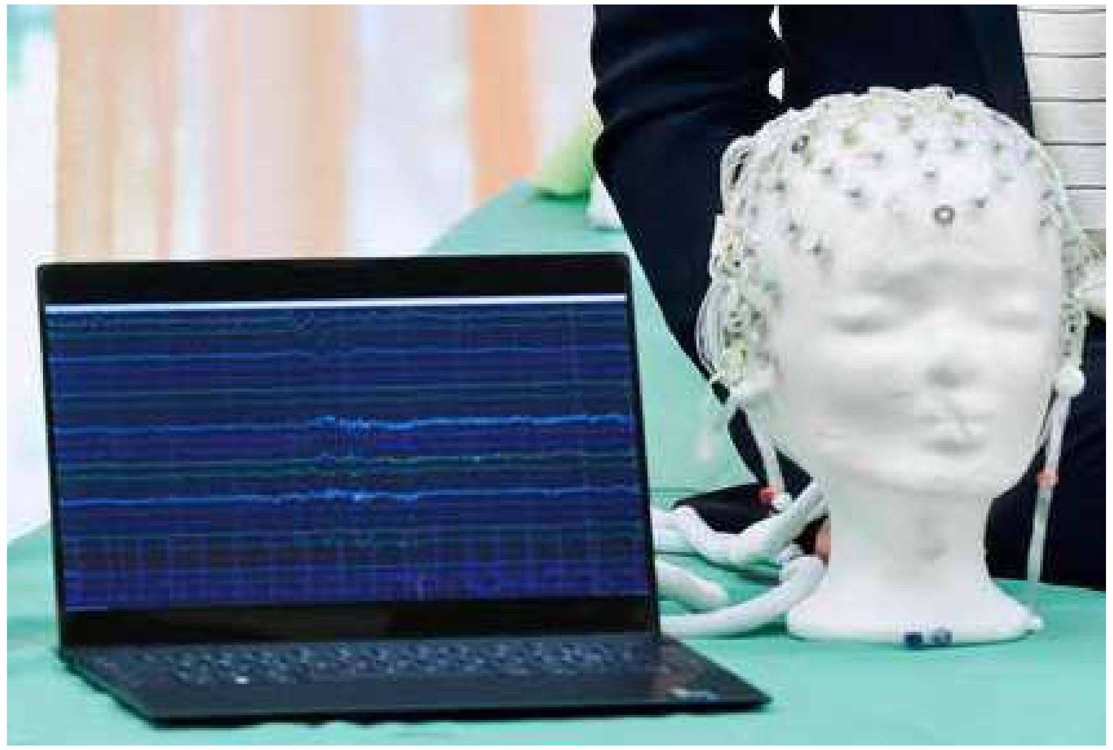
Complex approval process

Jelena Skorucak says she has already benefitted greatly from the programme and that she's particularly grateful for aid in addressing regulatory matters, "as the greatest challenge will probably be organising all the necessary certificates for the platform", she says. Her software belongs to the category of medical products, and completing all steps of the approval process can take considerable time.

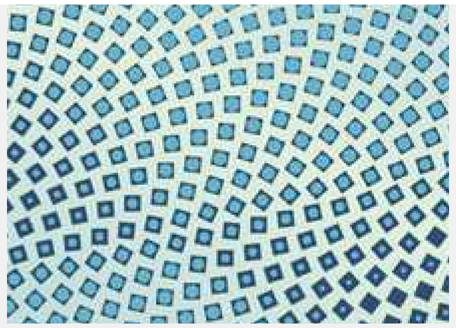
Another challenge is ensuring that the product design appeals to potential buyers. "It has to be easy to operate," says Skorucak. And, of course, it must provide added value. On that score, the researcher has confidence in her product, not least because the analysis platform harbours potential for further development. For instance, it could be adapted for adult epilepsy patients or used to analyse different regions of the brain, which could aid in the diagnosis of various types of epilepsy.

But there are possibilities beyond the field of epilepsy, too, and Jelena Skorucak says she's also developing the platform for use in sleep apnoea screening. In addition, there are indicators that some Alzheimer's or ADHD patients experience epileptic spikes during sleep. All in all, it would be possible to create a platform that detects various sleep-associated diseases in EEG data.

But, as Skorucak says, humans will always be needed to make a diagnosis, and to control and interpret results. "It's a semi-automated system: our idea isn't to replace doctors, but to spare them the tedious analysis work."



Jelena Skorucak has developed a software program that identifies major spikes in the brain activity of children—making it easier to detect and diagnose epilepsy.



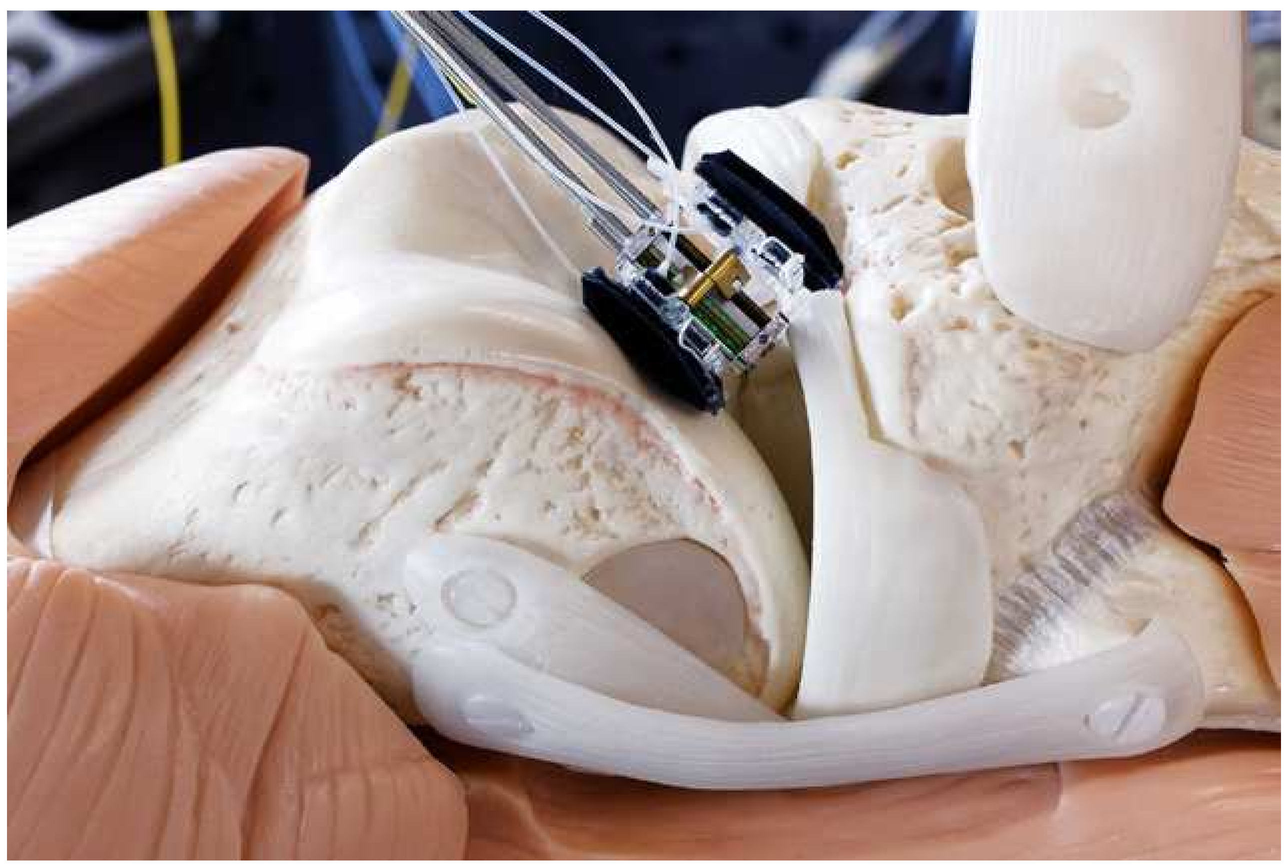
From idea to company

The University of Zurich Entrepreneur Fellowships were created to support talented junior researchers who want to establish a firm on the basis of their research findings. Thanks to funding from the Werner Siemens Foundation, fellowships in the field of medical technology were added to the programme in 2018. Since then, a total of twenty-two junior researchers have received a MedTechEntrepreneur Fellowship and six new companies have been founded.

Funding from the Werner Siemens Foundation 10.67 million Swiss francs
Project duration 2018 to 2027
Project leader Prof. Dr Elisabeth Stark, Vice President Research, University of Zurich

Interlocked and interlinked

The goal of the MIRACLE II project at the University of Basel is a laser robot that will make minimally invasive, patient-friendly bone surgery a reality. Now, the many, highly complex aspects of the endeavour are beginning to come together, and the researchers are integrating the technologies and systems designed and developed over the past several years.



Using a device that resembles an air cushion, the surgical robot can be affixed in the gap of the knee joint, stabilising the laser so that it can cut without moving.

Last year, one of the highlights for the team in the MIRACLE II project at the University of Basel was their move to new, state-of-the-art facilities. The physical relocation is also an apt metaphor for the project's next phase: in addition to offering more space, the new labs and meeting rooms are designed to ensure that researchers have plenty of opportunities to come together and share ideas.

Indeed, collaboration between the different research groups is taking on ever greater importance, as project leader Philippe Cattin explains: "We're focusing more on integrating the various systems and sensors we developed in the earlier MIRACLE I project." All these advances are serving the larger goal of the current MIRACLE II project—constructing a robot-guided laser system capable of performing minimally invasive bone surgery and inserting made-to-measure implants in the body.

From VR to 3D

An integral part of the project is the virtual and augmented reality system designed by Cattin and his team. Used for planning and monitoring surgical interventions, the VR tool can analyse a defective bone, or the part of a bone damaged by a tumour. "We've also trained the system to calculate the dimensions of the replacement part so that it fits nicely into the affected bone's shape, be it a skull or another bone," Cattin explains.

To this end, the researchers first had to develop an artificial intelligence system capable of understanding human anatomy. The innovative system's task is to assess where tissue is missing and calculate how this section would look in a healthy bone of the same size. "Today, highly paid specialists use CAD to draw the shapes for these kinds of implants," Cattin says.

His group has now already linked their automated planning system with the manufacture of implants, the part of the project conducted by the research team led by Florian Thieringer, senior physician for oral and cranio-maxillofacial surgery at the University Hospital Basel and head of the hospital's in-house 3D printing lab. Once the artificial intelligence has calculated an implant's size, the result is sent to the 3D printer in Thieringer's lab, which then fabricates a made-to-measure implant.

Right now, the file created in the planning tool must first be saved and then restarted in the printer tool. "But our goal is starting the 3D printer by just pressing a button in the VR system," Cattin says. And although the system works perfectly from a technical point of view, the automation is currently not in use at the hospital, as regulatory issues are yet to be settled.

Coordinated lasers

Advances in other areas are also slowly but surely being integrated into the overall project, including the most important feature: a tiny laser beam capable of making clean and precise incisions in a damaged bone. To avoid causing inadvertent harm to the surrounding area, the laser must also have access to information about where exactly in the body it's operating and what kind of tissue it will be cutting.

To realise the intricate tool, the researchers first developed three different laser systems: one to measure how deep an incision should be, one to characterise tissue, and one to cut. "At the beginning, every PhD student was working separately on their piece of the puzzle," Cattin explains. "Only after the individual parts worked could we concentrate on integrating them." Which they now have done: in a published study, the MIRACLE team demonstrated how the laser types interact. They made ultra-precise incisions and, at the same time, minimised damage to the bone marrow thanks to the tool's measuring and characterising capacities.

An air bed for the robot

However, more specifications must still be met before the robot laser can safely make its precise incisions. For instance, the tiny, robot-guided endoscope where the laser is situated must remain immobile throughout the entire intervention, steadying itself inside the body. "That may sound trivial but in fact it's a major technical challenge," Cattin says.

A PhD student in the group led by co-project leader Georg Rauter has now found a solution for the problem: taking the knee joint as an example, she created a prototype for a fastening system that works using a type of balloon or air cushion. When these devices are put in place, they inflate and fill the space between the laser robot and the tissue, affixing the robot to the spot. "After the laser has made an incision, surgeons can let the air out of the cushions and the robot will move to the next incision site," Cattin explains.

Step by step and piece by piece, the MIRACLE team are revolutionising bone surgery.

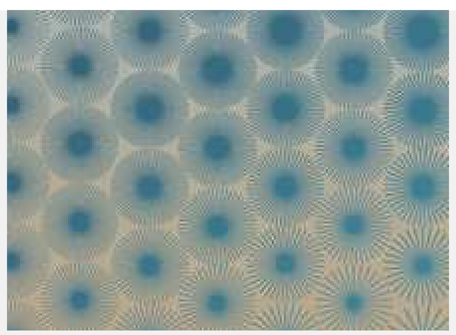
MIRACLE II

Gentle, minimally invasive, robot-guided and highly precise bone surgery—this is the aim of researchers in the MIRACLE II project at the University of Basel. The team are developing an endoscopic laser robot capable of making ultra-exact incisions in bones, while miniature sensors and a 3D software program are used to promote patient safety during surgery. In the hospital's in house 3D-printing lab, made-to-measure implants will be fabricated to fit into the precut bones. All of which helps bones heal faster after an intervention.

Funding from the Werner Siemens Foundation 12 million Swiss francs
Project duration 2022 to 2027
Project leaders
Prof. Dr Philippe Cattin, head of the Department of Biomedical Engineering (DBE) at the University of Basel
Prof. Dr Florian M. Thieringer, senior physician for oral and cranio-maxillofacial surgery and head of the Swiss MAM research group at DBE and the University Hospital Basel
Prof. Dr Georg Rauter, head of Bio-Inspired RObots for MEDicine-Lab (BIROMED-Lab) at DBE at the University of Basel

Harvests from the Stone Age

Last year, researchers in the palaeobiotechnology project achieved a major milestone: they found and "resurrected" ancient microbial compounds—some of which date back 100 000 years. This is clear proof that their bold idea works.



Palaeobiotechnology

Is the future of medicine a journey to the past? In their palaeobiotechnology project, chemist Pierre Stallforth and molecular archaeologist Christina Warinner are taking an unusual approach to solving the problem of antibiotic resistance: they're analysing the dental calculus of early humans to find ancient substances effective against today's resistant bacteria—and then reproducing them in the lab.

Funding from the Werner Siemens Foundation 10 million euros
Project duration 2020 to 2029
Project leaders
Prof. Dr Pierre Stallforth, Leibniz Institute for Natural Product Research and Infection Biology – Hans Knöll Institute, Jena
Prof. Dr Christina Warinner, Max Planck Institute for Evolutionary Anthropology, Leipzig, and Harvard University, Cambridge

Conducting research is a little like gardening. It takes a great deal of patience—the harvest comes well after the sowing. In the labs of the palaeobiotechnology project in Jena, the metaphorical act of sowing lasted three years. Now, however, researchers in the team of chemist Pierre Stallforth and molecular archaeologist Christina Warinner can look forward to reaping the fruits of their labour. Last year, they demonstrated their project will indeed deliver the desired results: for the first time, they recreated natural products found in the dental plaque of early humans—natural products produced by bacteria up to 100 000 years ago.

For their study, which was published in the top-tier journal *Science*, the team examined dental calculus found in Neanderthals who lived between 40 000 and 100 000 years ago, as well as the dental calculus of humans who lived between 150 years and 30 000 years ago. The researchers applied specialized methods to sequence billions of ancient DNA fragments and then assemble them—much like puzzle pieces—into the reconstructed genomes of numerous bacterial species.

New—and relevant—research field

The team worked with one particularly well-preserved genome of a green sulphur bacterium to recreate a so-called biosynthetic gene cluster—a genetic blueprint for enzymes that produce natural products or small molecules. Using state-of-the-art biotechnological methods, they inserted these genes into living bacteria. Et voilà! The bacteria formed functioning enzymes that produced two previously unknown microbial natural products. Tens of thousands of years ago, a living bacterium most likely used these substances for regulating photosynthesis.

The publication represents a major milestone for Warinner and Stallforth. "We've demonstrated that our idea is feasible: we can indeed find ancient microbial substances and reproduce them," Christina Warinner explains, adding that the response from the research community was extremely positive. "Not only did our colleagues rate our publication highly," Warinner says, "they also believe that our approach is very relevant."

In order for this type of interdisciplinary project to work, many different pieces must fit together. For Pierre Stallforth, the collaboration between the research groups was a personal highlight. He says it was fascinating, yet also challenging, to find a common language among archaeologists, chemists and bioinformaticians.

High-speed analyses

Now the team can move to the next phase and, so to speak, harvest their DNA crop. Stallforth names two developments in particular that are making this possible. First, bioinformaticians working in the project have developed a screening tool called nf-core/funcscan that enables the rapid screening of millions of reconstructed gene sequences to identify those capable of producing natural products. And second, the Leibniz Institute for Natural Product Research and Infection Biology in Jena has built a one-of-a-kind automation platform for standardised, high-throughput testing of newly discovered molecules—to determine a molecule's antibiotic or antifungal effect, for example.

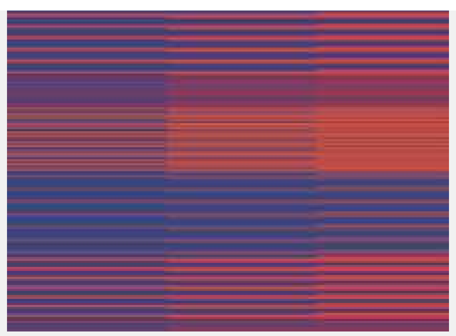
The devices on the robotic platform have several advantages: in addition to working round the clock, they can also fill and read microtiter plates with between 96 and 384 miniature "wells" in just a single step. "This means we can test 100 to 1000 times more samples than previously," says Stallforth. In addition, errors and irregularities during pipetting are excluded when robots—and not humans—do the job. "In future, we can draw from all these resources," Stallforth sums up.

The project's next goal is examining as many samples as possible—but also understanding what purpose an ancient natural product had in its natural environment. For Christina Warinner, this aspect is key: "The more we know about an compound's function, the more new applications we'll find." It will be very interesting to see what new products the palaeobiotechnology team will, in future, retrieve from the past.

With their new automation platform, researchers in Jena can now conduct high-speed tests on molecules found in the dental plaque of early humans.

Analysing gaits and simulating fractures

The smart implants project is entering its second phase: after gaining a good overall understanding of how broken bones heal, the researchers are now seeking ways to consolidate this knowledge—and build a novel implant.



Smart implants

In future, intelligent implants fitted in a bone will be able to directly monitor how well a lower-leg fracture is healing. In addition to stabilising the broken bone, they will provide information on healing and detect incorrect weight-bearing. If a bone isn't healing well, the implant will react and, if necessary, trigger targeted micro-movements to actively stimulate healing at the site of the fracture. The smart implants project is conducted by a research team at Saarland University Medical Center.

Funding from the Werner Siemens Foundation 8 million euros
Project duration 2019 to 2025
Project leaders Prof. Dr Tim Pohlemann and Prof. Dr Bergita Ganse, Saarland University Medical Center

Three years of preparatory research were needed before the team could really begin making inroads, says Tim Pohlemann, head of the Department for Trauma, Hand and Reconstructive Surgery at the Saarland University Medical Center. He and his colleague Bergita Ganse lead the smart implants project, which has received funding from the Werner Siemens Foundation since 2019. In the project, the Saarland researchers apply novel technologies from the fields of materials science and engineering to design intelligent implants that promote healing in complex bone fractures. The devices will be able to carry out three different tasks, virtually at the same time: monitor the fracture site, detect incorrect weight-bearing—and stimulate healing through targeted, autonomous movements at the site of a break.

Pohlemann explains that all the groups involved in the project—the surgery unit, the simulation and computer technology teams as well as the technical developers—first had to make advances in their fields. "But now we're ready to consolidate our new knowledge and to integrate it into a functioning implant," he says.

Was it the patient or a bus?

Gait analysis is one area where the researchers made particularly good progress last year. "We've now been able to gather data on how bone fractures healed in a total of ninety patients—in studies conducted here in the lab and at the patients' homes," says Bergita Ganse, Werner Siemens Foundation Endowed Chair for innovative implant development at Saarland University. For this, the patients had so-called wearables installed in their shoes: thin insoles equipped with sensors that measure pressure, acceleration and weight-bearing factors.

"Using the insoles, we generated the first long-term data as well as many other findings that have now been published," Ganse says. Understanding which parameters change during healing—and how they change—is of particular importance in the project, as is using this information to identify those values that quickly indicate suboptimal healing. "Many patients recover very well," Ganse explains, "but unfortunately there are still too many cases that don't progress as they should." She adds that the difference in strength between a person's right and left foot could be an indicator of poor healing. Another might be the movement of the centre of gravity on the sole of the foot. "The data also show us how often a patient puts up their leg to rest," Ganse says. "Now, the next step is analysing each individual pattern of motion and its distribution in connection with the healing prognosis."

Another critical aspect in the project is understanding why pressure and acceleration measurements change. "When the insoles deliver data saying there was an uptake in speed, we need to know whether the patient was running or sitting on a bus," Pohlemann says. The researchers have also studied the type of surface (asphalt, sand, grass, gravel) as well as topography (walking uphill or downhill, climbing stairs) to ascertain what effects they have on the force curves. Patient safety is the reason for needing this information, as Bergita Ganse explains: if a problem arises, the smart implant embedded in the leg of a patient should emit a warning and, if necessary, counteract incorrect weight-bearing. In order to do this, the implant must be capable of recognising the myriad factors involved in these types of changes, but standard statistical methods are often not able to make the necessary calculations. For this reason, the researchers have developed targeted AI algorithms to detect correlations that are otherwise difficult to identify.

How much movement is enough?

The researchers have also attained excellent results in their computer simulations. "We used data from computer tomography scans of patients to simulate fractures at different places and angles," Ganse says. Here, the goal is to find out how much the implant should move—depending on the type of fracture—to best steer healing.

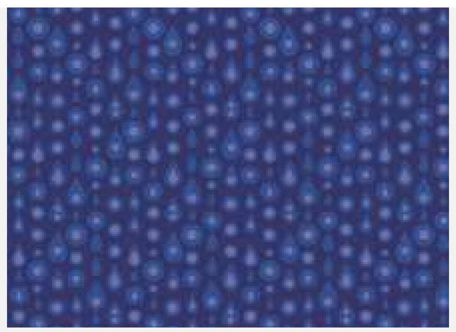
It's no easy task. One problem arises in the case of complex fractures such as wedge-shaped breaks that make pressure and weight-bearing distribution difficult to calculate. Another challenge lies in considering changes that occur over time. "Because tissues become stiffer as they heal, we need other forces to act on the fracture site," Bergita Ganse explains.

The team's computer simulations are a key step towards understanding what an implant must be able to do, Tim Pohlemann adds: "This is at the very heart of our project: we want to build the implant so that, in the end, it's capable of triggering movements and changes in weight-bearing that support healing effectively."

Through gait analysis, researchers in the team led by Bergita Ganse (left) gather important data on which parameters best depict healing in a bone fracture.

Progress on many fronts

The TriggerINK team at DWI – Leibniz Institute for Interactive Materials in Aachen are working to develop an innovative method to promote cartilage regeneration in damaged joints. To realise their vision, they must first break new ground in various research areas—and last year saw them make several important advances.



TriggerINK

Regrowing damaged cartilage using a scaffold made of bio-ink: this is the aim of researchers in the TriggerINK project at DWI – Leibniz Institute for Interactive Materials in Aachen. Their innovative approach is built on pioneering 4D printing technology. First, a 3D printer injects the bio-ink into a wound, where it is infused with light and aligned via a magnetic field. Then, ultrasound is applied to activate or release the agents and growth factors contained in the bio-ink at set times. If their method works, it promises to revolutionise cartilage regeneration therapies—and could also be further developed to help repair other kinds of damaged tissue.

Funding from the Werner Siemens Foundation 10 million euros
Project duration 2022 to 2026
Project leaders Prof. Dr-Ing. Laura De Laporte, DWI – Leibniz Institute for Interactive Materials and RWTH Aachen University
Prof. Dr Stefan Hecht, Humboldt-Universität zu Berlin; associated researcher at DWI Aachen
Prof. Dr Andreas Hermann, DWI and RWTH Aachen University
Prof. Dr-Ing. Matthias Wessling, DWI and RWTH Aachen

In their work to enable regeneration in damaged cartilage, researchers in the TriggerINK project have chosen an innovative, highly sophisticated strategy. Described in simple terms, the team from Aachen are first fabricating a supportive scaffold made of their gelatinous bio-ink that will be injected into the damaged joint. In a second step, a range of techniques and other materials will be applied to stimulate cells into growing cartilage tissue inside the scaffold—and thus trigger healing.

Nanomagnets point the way

Although many questions must be answered and new techniques developed before their method finds application in medical care, the team made good progress in the second year of their project. One particularly important advance was in cell alignment, as project leader Laura De Laporte explains. Because the cartilage in our joints is made up of diverse zones in which the cells align themselves differently, one prerequisite to regrowing cartilage is the ability to steer cell growth in several directions. To this end, the TriggerINK team enriches their bio-ink with microscopic gel rods that contain magnetic nanoparticles and align via an external magnetic field. This allows the researchers to arrange the gel rods in a specific direction—and ultimately steer which way the cells grow. In principle, the cells sense the resistance stemming from the rods and then grow parallel to how the rods are aligned. Now, researchers in the group led by co-project leader Matthias Wessling have found a way to mass-produce these gel rods. They chose a method called stop-flow lithography, in which a polymer solution flows through a confined space and, by means of ultraviolet light and a custom-made mask, is then gelled in localised places only. The team then added spindle-shaped magnetic nanoparticles made of the rare mineral maghemite to the gel rods and, already during gel rod production, they succeeded in prealigning the maghemite particles

Researchers in Aachen use stop-flow lithography to align maghemite nanoparticles inside the gel rods via a magnetic field during the gel rod production phase itself.

via a magnetic field in various, predefined directions. This enables the gel rods to align at predefined angles in one and the same magnetic field.

Size matters

Although alignment of the microgel rods is important, it's just one factor of many that must be considered when constructing the scaffold. For example, the researchers wanted to understand how composition of the bio-ink affects the alignment of cartilage tissue cells. Through testing, they discovered the best scaffold conditions, in which mesenchymal stem cells (MSCs)—progenitor cells that can differentiate into specific cell types—stimulate cartilage regeneration. After being introduced into the scaffold, the MSCs turned into so-called chondrocytes, a major component in cartilage. "We also found out that the MSCs align themselves particularly well inside the scaffold when our microgel rods measure 10 x 10 x 100 micrometres," Laura De Laporte says.

Once the researchers manage to stimulate cartilage cells into growing, layer by layer, in the correct directions, the focus will shift to their method for speeding up patient recovery: the "in vivo gym". The approach works as follows: the hydrogel used to build the scaffold also contains soft spherical microgels that can be modified via an external light signal. Depending on the signal, the microgels shrink and swell rapidly, thereby setting the surrounding cell-containing scaffold in motion. Previous research indicates that such actuation movements may accelerate the healing process.

Last year, the researchers scored two successes on this front. First, they used microfluidic chips fitted with up to 100 parallel-connected channels to increase the production rate of the in vivo gym's microgels by several orders of magnitude. Second, they demonstrated that a frequency of one Hertz transmits the shrinking and swelling of the microgels to the surrounding scaffold, setting it in motion over long distances. "To be most beneficial, the in vivo gym's microgels should be linked to the scaffold at the right bond strength," as De Laporte explains. "If the bond is too strong or too weak, the effect is minimal."

In-house robotic printer

Another key advance concerns the 4D printing robot the researchers constructed for injecting the bio-ink and all its ingredients directly into a damaged joint. The robotic arm is now installed and can carry out its precise movements thanks to a software program written for this purpose. In addition, the researchers built a printhead capable of printing several components at the same time.

Although much work remains before the team realises their goal of speedy and patient-friendly cartilage regeneration, many of the individual components and techniques for their endeavour are already taking shape.

Simple application: the antiviral drug envisioned by Francesco Stellacci's group at EPFL is effective at combatting numerous viruses and can be administered via an inhaler.

A spray to neutralise viruses

Last year, Francesco Stellacci and his team at École polytechnique fédérale de Lausanne (EPFL) continued working on their novel antiviral agents that could one day be used to treat a wide range of viral infections. The researchers have now transformed their agents into an inhalable powder form—meaning the future antiviral drug will be easy to administer as a nose spray.

At the EPFL Supramolecular Nano-Materials and Interfaces Laboratory, a team led by Francesco Stellacci are currently focusing their efforts on developing a drug to treat viruses that cause respiratory tract infections. This includes the common respiratory syncytial virus (RSV) that, while relatively harmless for most people, can cause serious infections in infants and the elderly. However, the innovative antiviral drug designed by Stellacci and his team can do more than combat RSV—and now the drug's potency has been confirmed in two animal experiments conducted in 2023: a SARS-CoV-2 study with hamsters and an influenza study with ferrets.

The new antiviral belongs to the class of so-called entry inhibitors, which are drugs that prevent viruses from entering a host cell, thus robbing them of the ability to reproduce and spread. In the case of RSV, it also ensures that a virus can't make its way through the nose or mouth to the respiratory track—and damage the lungs. The antiviral created by Stellacci's research group is a broad-spectrum entry inhibitor whose "backbone" has been combined with the chemical compound mercapto-undecane sulfonic acid (MUS). MUS is capable of neutralising a wide range of viruses: it irreversibly inactivates them by occupying protein parts in a virus via a sophisticated binding mechanism.

Powerful powder

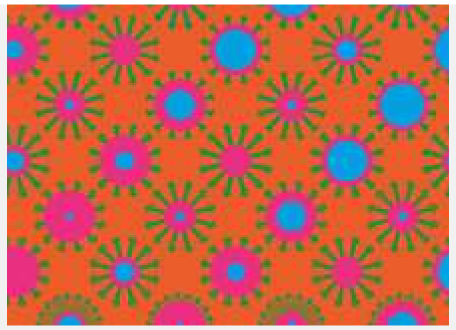
On the basis of the positive results in the preclinical trials, the researchers dried the agent to attain a substance that can be used in a conventional dry-powder inhaler. The substance was found to be both effective and well tolerated by the test animals. The researchers' long-term aim is to make an antiviral that can be easily administered as a nose spray.

Francesco Stellacci says it takes years to develop new drugs. The antiviral substance is subjected to strict controls not only in terms of efficacy but also regarding its toxicity. Currently, a Dutch contract research organisation is testing to see how many viruses are still living in the lungs of the lab animals after administering the drug—the fewer, the better, of course—and whether the chemical compound harms the animals' lungs. "The viruses already damage lung tissue. We can't have our medication causing even more problems," Stellacci explains, adding that "no observable side effects" were evident in the first preclinical trial with mice. He's confident that his innovative antiviral drug will also prove to be well tolerated in future preclinical studies: "So far, the trial data are very good."

Only perfect is good enough

To conduct in vivo studies on toxicity levels in the MUS compound, the molecules need to be produced in large (industrial-size) quantities, and current global good manufacturing practices (GMP) must be upheld. At present, experts at EPFL are working with Francesco Stellacci to prepare the necessary documents and contracts for the trials.

Last year, Stellacci was also busy drafting a proposal for an international centre for viral research at EPFL. The idea is to create a space that promotes dialogue and enables international research groups to consolidate their efforts in combating viruses of all kinds. "Basically, it would be about finding which agents are effective at combatting viruses," is how Francesco Stellacci describes the centre's mission. As soon as he submits the detailed proposal, the Werner Siemens Foundation will carefully review it and consider funding the centre.



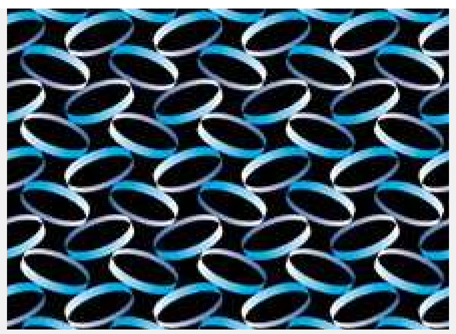
Antiviral drugs

Materials scientist Francesco Stellacci and his team have developed artificial molecules that use hydrophobic pressure to destroy viruses before they can enter a human cell. Their aim is to develop a broad-spectrum antiviral drug to treat various kinds of viral infections as well as medications designed to be effective against specific viruses that evade the general "antivirotic". The first preclinical trials revealed both very good efficacy and tolerability of the novel antiviral agent, also when administered as a spray.

Funding from the Werner Siemens Foundation
5 million Swiss francs (2020–2021: development of a broad-spectrum antiviral)
4.5 million Swiss francs (2021–2023: proposal for a Werner Siemens Foundation Centre for Antiviral Research WSS-CaRe)
Project duration 2020 to 2023
Project leader Prof. Dr Francesco Stellacci, Supramolecular Nano-Materials and Interfaces Laboratory (SuNMiL), Institute of Materials, École polytechnique fédérale de Lausanne (EPFL)

The future of cancer therapies

Researchers at the Werner Siemens Imaging Center are leading the way in the development of medical imaging techniques for cancer diagnostics. In a current project, they're creating an AI-trained software program to analyse the massive amount of data generated by MRI and PET scanners—thus enabling groundbreaking insights into tumorous tissues.



Werner Siemens Imaging Center

The Werner Siemens Imaging Center (WSIC) in Tübingen plays in the premier league of research on medical imaging techniques, and the Center's work on personalised tumour therapies forms part of Germany's national Excellence Strategy. Thanks to the new, combined medical imaging techniques developed at WSIC, tissues and molecules can be studied in greater detail. The innovative technologies also reveal which patients will benefit most from which therapies.

Funding from the Werner Siemens Foundation
18.4 million euros (2024–2033)
15.6 million euros (2016–2023)
12.3 million euros (2007–2016)
Project duration 2007 to 2033
Project leader Prof. Dr Bernd Pichler, Werner Siemens Foundation Endowed Chair and director of the Werner Siemens Imaging Center at the University of Tübingen

Malignant tumours are complex: rather than consisting of uniform tissue, they're often made up of very different tumorous areas and cell structures, which are themselves undergoing constant change. What's more, each metastasis formed by these tumours is unique. This heterogeneity poses a challenge in treating many kinds of cancers, and the result is all too often a treatment that is ineffective—or a tumour that becomes resistant because it can't be completely eradicated.

Fully characterising the diverse aspects of cancerous tumours is nearly impossible using today's methods, in which doctors or researchers generally take a biopsy and then examine the tissue. "However," says Bernd Pichler, head of the Werner Siemens Imaging Center (WSIC) in Tübingen, "a biopsy represents only a very small part of the tumour." And because biopsy procedures are invasive, and sometimes dangerous, they can't be conducted on a daily or weekly basis.

Smart data analysis

To better capture the heterogeneous nature of tumours, Pichler and his research team at WSIC are working to develop new, non-invasive diagnostic tools. They've made steady progress towards this aim, and last year saw the publication of several well-received papers on their projects, one of which applied an innovative approach to differentiating living, dead, necrotic and fibrotic tissues in a type of colon cancer.

For that study, the researchers examined tumours using a combined PET-MRI scanner. These techniques generate a massive amount of data, and to process all this information, the team created a machine learning software tool. In a first step, they fed the tool data from scans of some fifty mice with a colon cancer modelled on the kind that grows in humans; by processing the mouse data, the program learned how to distinguish between different tissue types.

In a second step, the team tested the software's recognition capability on

At the Werner Siemens Imaging Center in Tübingen, researchers are using machine learning to process and analyse massive datasets generated by PET and MRI scans, opening up new possibilities in tumour diagnostics.

liver metastases in six colon cancer patients. "We were able to demonstrate that the algorithm translates very well to humans," Bernd Pichler says. "And this is just a first example." Indeed, the technology opens up previously unthinkable possibilities in tumour diagnostics: "It can also be used to examine and differentiate many other tumour properties."

Now, the Tübingen researchers are aiming to distinguish aspects such as the various different stages in a cell cycle. Many tumour cells exist in what is known as a senescent state: although they no longer divide, they're still alive and can "wake up" and trigger the growth of other tumour cells. Tracing them and finding the right moment to administer drugs that destroy them is of critical importance.

Personalised cancer treatments

The researchers believe that medical imaging techniques based on machine learning could be used to characterise the immune properties of various types of cancer cells as well as the traits of intercellular spaces—the extracellular matrix. First, however, special tracers (radio-labelled molecules) must be developed. After being introduced into a living organism, the tracers are absorbed by specific cells or used for targeted metabolic processes, depending on the type of molecule used. The tracers in the tissue are then rendered visible on scans generated by medical imaging techniques. As Bernd Pichler explains, "This helps us to better understand the microenvironment of tumours."

It will also pave the way for new patient-specific therapeutic options. Last year, Bernd Pichler and his team published their vision for one such approach in a review article in *Nature Reviews Cancer*, a top-tier journal. In future, they write, advanced medical imaging techniques will help researchers identify a wide range of molecules, processes and properties in tumour tissues—thus laying the basis for personalised cancer therapies. "As just one example, we could study a tumour to find out how much the pH value should be adjusted to ensure that the chosen immunotherapy is effective," says Pichler, who received the 2023 Gold Medal Award, the highest honour bestowed by the World Molecular Imaging Society.

Although it will still be many years before these visions become reality, the research groups at the WSIC are hard at work on their detection methods that are destined to revolutionise cancer treatment.

Who we are

Governing bodies

Siemens Family Advisory Board

Descendants of Werner von Siemens and his brother Carl von Siemens sit on the Siemens Family Advisory Board. The Siemens Family Advisory Board supports the work of the Foundation Board and holds important veto rights.

Oliver von Seidel
Chair
Düsseldorf, Germany

Dr Christina Ezrahi
Member
Tel Aviv, Israel

Alexander von Brandenstein
Member
Hamburg, Germany

Foundation Board

The Foundation Board manages the ongoing activities of the Werner Siemens Foundation.

Dr Hubert Keiber
Chair
Lucerne, Switzerland

Prof. Dr Peter Athanas
Member
Baden, Switzerland

Beat Voegeli
Member
Rotkreuz, Switzerland

Scientific Advisory Board

The Scientific Advisory Board is an independent body that supports the Foundation Board in identifying suitable projects. Board members are responsible for reviewing and assessing the quality of proposals submitted to the Foundation.

Gianni Operto, Chair
Ebmatingen, Switzerland

Prof. Dr Gerald Haug, Member
Max Planck Institute for Chemistry
Mainz, Germany, and
ETH Zurich, Switzerland

Prof. Dr-Ing. Dr h. c. Matthias Kleiner, Member, former President of the Leibniz Association, Berlin, Germany

Prof. Dr Bernd Pichler, Member
University of Tübingen, Germany

Prof. Dr Peter Seitz, Member
EPFL, Switzerland

Selection process

Selection criteria

Every year, the Werner Siemens Foundation finances up to three new groundbreaking projects in the fields of technology and the natural sciences. The projects are generally conducted at higher education institutions in Germany, Austria and Switzerland. Requirements include upholding the highest standards and contributing to solving key problems of our time.

As a rule, each project is awarded generous funding of five to fifteen million euros or Swiss francs. Projects are selected in a multistep procedure by the Scientific Advisory Board, the Foundation Board and the Family Advisory Board of the Werner Siemens Foundation.

In addition to projects, the Werner Siemens Foundation funds exceptional programmes in education and in the promotion of young talent in STEM subjects.

The Foundation does not support activities in the arts, culture, sports, leisure, politics, disaster relief, nor does it support permanent projects, commercially oriented projects, project co-sponsoring with other foundations, individual scholarships, costs of studying or doctoral theses.

Project application

Project proposals must be submitted in writing to the Werner Siemens Foundation. The selection process is as follows:

1 Project proposal is appraised for compliance with the Foundation's funding criteria
2 The Scientific Advisory Board evaluates the project
3 The Scientific Advisory Board presents its recommendation to the Foundation Board and the Siemens Family Advisory Board
4 The Foundation Board and the Siemens Family Advisory Board consider the project for approval
5 Final decision
6 Contract

The selection process takes approximately six months.

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