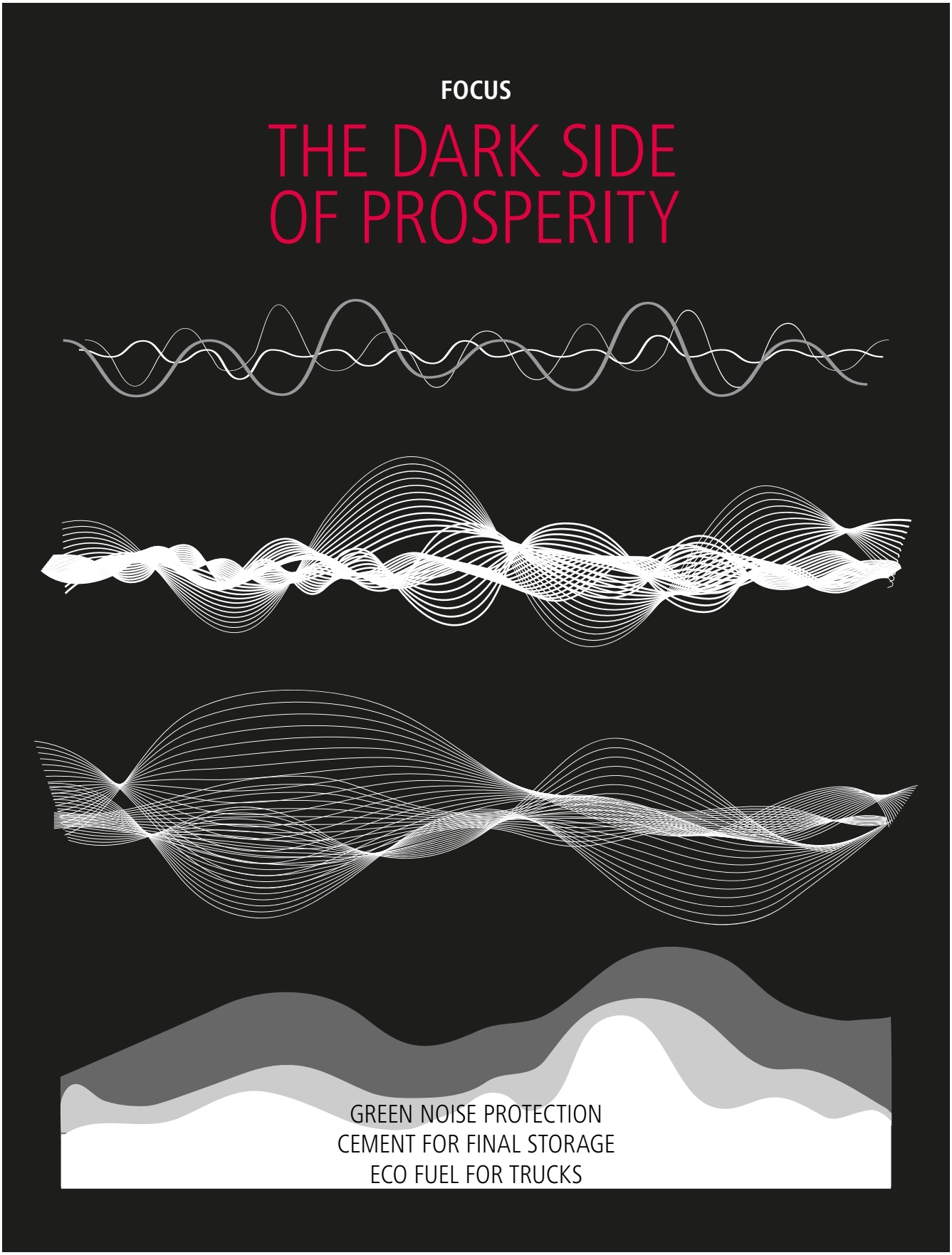
Empa Quarterly

RESEARCH & INNOVATION II #69 II OCTOBER 2020

FOCUS

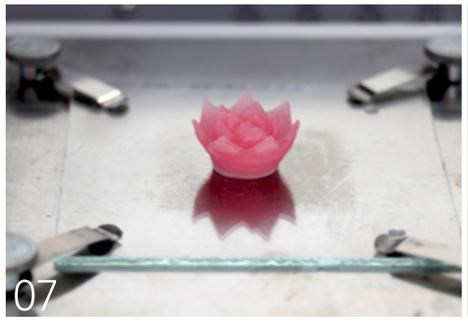
THE DARK SIDE OF PROSPERITY



GREEN NOISE PROTECTION
CEMENT FOR FINAL STORAGE
ECO FUEL FOR TRUCKS

[CONTENT]

[FOCUS: THE DARK SIDE OF PROSPERITY]



Photos: iStockphoto, Sara Keller, Empa

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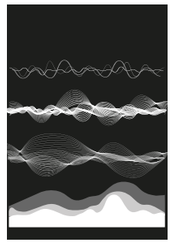

Our civilized society has side effects: we generate noise, dust, waste and greenhouse gases. Empa finds ways to detect and minimize these emissions.
Image: istockphoto

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[IMPRINT]

PUBLISHER Empa
Überlandstrasse 129
8600 Dübendorf,Schweiz
www.empa.ch
EDITORIAL Empa Kommunikation
LAYOUT PAUL AND CAT.
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PRODUCTION
rainer.klose@empa.ch

ISSN 2297-7414
Empa Quarterly (English edition)

SELF-PROCLAIMED EXPERTS EVERYWHERE

DEAR READERS

I have to admit: Slowly but surely, the virus is getting on my nerves. Matter-of-factly, though, it's not a half-dead RNA parasite that annoys me, but some of my fellow citizens. Those who believe they know – nice juxtaposition of words, BTW, which I only noticed while writing – what's going on and how to deal with the whole mess. Mind you, in a situation we never experienced in our lifetime and that sometimes leaves even experts clueless. (Well, I can already hear it in my mental ear, who needs «experts» if you've got a good intuition you can rely on, some herbs or an aluminum hat?)

None of the experts I know thinks they know it all, let alone me. But I think we would be well advised to have more trust in each other again, instead of dissing and bad-mouthing each other as soon as someone dares to disagree. Listening, pondering, asking questions and, yes, even patiently persevering once in a while is not the worst strategy (unless you suddenly find yourself face to face with a hungry lion, which, thank God, is not too common in this country).

All of this has nothing at all to do with the current Quaterly issue that focuses on the amount of «waste» we emit with our energy-hungry way of life – and of course, what we at Empa came up with to deal with it.

However, I just had to get rid of this – and as an editor, you can take this sort of freedom every now and so often. (PS: On p. 8 you can read what Empa scientists are doing to get the pandemic under control – thus closing the loop, at least thematically).
Enjoy reading!

Your MICHAEL HAGMANN

NO SANDY BEACH – A CONCRETE ROOF!
On the construction site of "HiLo", the newest unit in the NEST research and innovation building, the roof is "sprayed". No conventional formwork is used for the double-curved concrete sandwich construction, but a textile lying on a reusable cable net. The weight of the wet concrete moves the net into a predefined position and thus ultimately gives the roof its shape. For planning and calculation, researchers from the «Block Research Group» at ETH Zurich developed new design algorithms.

Further information on the topic is available at:
https://nest.empa.ch/hilo

Image: Roman Keller

HOW DANGEROUS ARE BURNING ELECTRIC CARS?

SOOT
During a fire, a battery module of an electric car develops large amounts of soot, which contains toxic metal oxides.

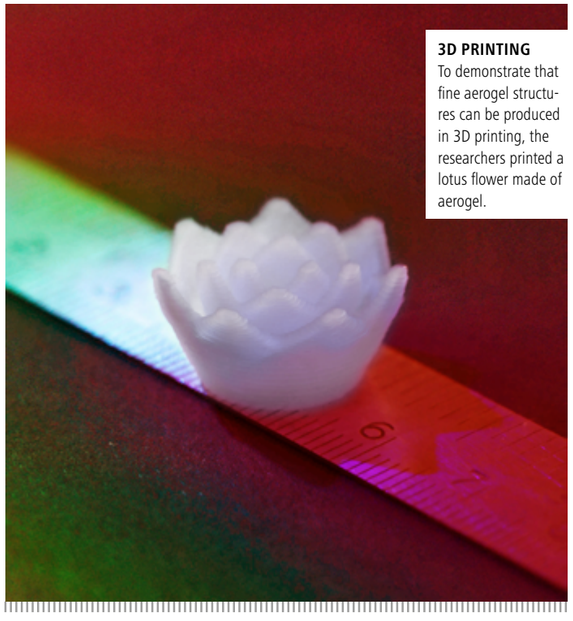
What happens if an electric car burns in a road tunnel or an underground car park? In the Hagerbach test tunnel in Switzerland, Empa researchers and tunnel safety expert Lars Derek Mellert set fire to battery cells of electric cars, analyzed the distribution of soot and smoke gases and the chemical residues in the extinguishing water.

www.empa.ch/web/s604/brandversuch-elektroauto

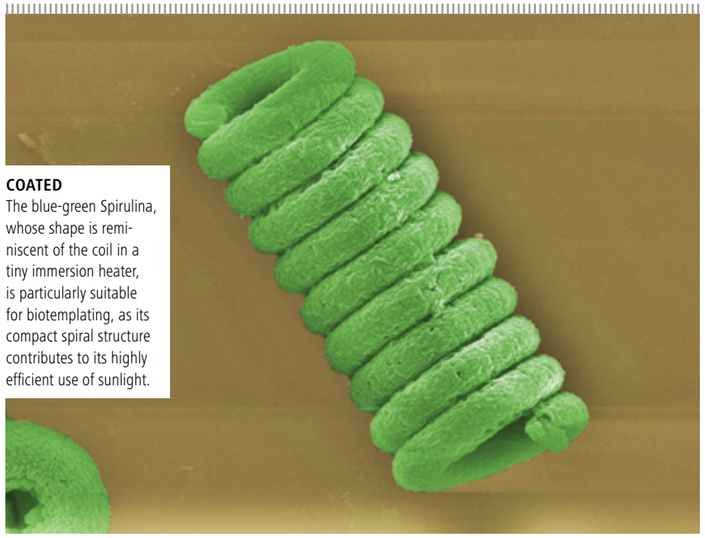
PROTECTING MICROCHIPS FROM HEAT

Aerogel is an excellent thermal insulator. So far, however, it has mainly been used on a large scale, for example in environmental technology, in physical experiments or in industrial catalysis. Empa researchers have now succeeded in making aerogels accessible to microelectronics and precision engineering. This opens up numerous new application possibilities, for example in microelectronics, robotics, biotechnology and sensor technology.

www.empa.ch/web/s604/aerogel-als-mikrobaustoff



3D PRINTING
To demonstrate that fine aerogel structures can be produced in 3D printing, the researchers printed a lotus flower made of aerogel.



COATED
The blue-green Spirulina, whose shape is reminiscent of the coil in a tiny immersion heater, is particularly suitable for biotemplating, as its compact spiral structure contributes to its highly efficient use of sunlight.

MINI POWER PLANTS FROM COATED ALGAE

Blue-green algae are among the oldest living creatures on Earth and have perfected the use of sunlight over billions of years. Empa scientists have now equipped these humble unicellular organisms with semiconductor coatings to create mini power plants, which supply biofuels and are photocatalytically active in sunlight. And what's best: The chemical reactions are circular – they form a sophisticated raw materials cycle.

www.empa.ch/web/s604/spirulina

Photos: Amstein+ Walthert Progress AG / Empa

AIR QUALITY
Pollutant expert Christoph Hüglin from Empa at the new measuring station.

NEW AIR MEASURING STATION IN DÜBENDORF

Air quality in Switzerland has improved but is still not good enough. To continue the monitoring of air pollutants which has taken place for many years in Dübendorf, canton Zurich, federal government has opened a new station as part of its National Air Pollution Monitoring Network (NABEL). As well as showing whether air pollution control measures are working, it will also be used as a platform for research activities on new measuring equipment or new air pollutants.

www.empa.ch/web/s604/nabel-station-2020

Photos: Empa

"CRUCIAL FOR THE FUTURE CORONA VACCINATION STRATEGY"

Efforts are being made worldwide to combat the new coronavirus SARS-CoV-2. Vaccines and protective masks are of prime importance. Empa researcher Peter Wick, Head of the Particles-Biology Interactions Laboratory in St. Gallen, talks to Empa Quarterly about recent antibody studies, which are crucial for the development of a COVID-19 vaccine, and the next generation of textile protective materials that inactivate or even kill corona viruses.

Interview: Andrea Six

Currently, the search for a corona vaccine is at the center of attention. An antibody study, in which your team was involved, has now provided evidence of immunity to the virus. What lessons are to be learned from your results?

Peter Wick: In the study with 160 people who had a confirmed but rather mild COVID-19 infection, we analyzed the antibody levels in the patients' serum over a period of twelve weeks in collaboration with the Center for Laboratory Medicine (ZLM) and the Cantonal Department of Health in St. Gallen. What worried us was that the antibody response to the virus already started to decline just five weeks after the infection. So if patients were receptive to the corona virus just two months after an infection, as our data suggest, we shouldn't bet on the often-cited "herd immunity". Because in this case there would be no general protection of the population based on people who have been through an infection and are thus immune.

What does this mean for a potential COVID 19 vaccination strategy?

These results are crucial for the COVID vaccination strategy. After all, a vaccine is designed to elicit an immune response in the body by simulating an infection and thereby generating long-lasting protection. Based on our data, it is

Photo: Empa

FABRIC FOR MASKS
As a member of the "Swiss National COVID-19 Science Task Force" Peter Wick is heavily involved in corona research.

ANTIVIRAL SURFACES
During the corona pandemic, computer modeling has taken a big leap forward. Now the simulations must be validated in laboratory experiments.

PETER WICK

CAREER: After studying biology and obtaining his PhD at the University of Freiburg, Wick joined Empa in 2002. The expert in cell biology and molecular biology is head of the Laboratory of Particles-Biology Interactions since 2014.
RESEARCH: Wick lectured for several years at ETH Zurich on "Air Quality and Health" and coordinated scientific projects such as the CCMX Materials Challenge "Nano Screen" and conferences such as the Swiss NanoConvention. Next year he will organize the NanoMedEurope in St.Gallen.

conceivable that a COVID vaccination only provides relatively short-term protection. However, this is of course also dependent on the type of vaccine and the interval between booster shots.

Do all infected persons react in the same way with a relatively rapidly decreasing immune response?

No, this does not seem to be the case. We have found that the trend towards a decreasing immune response is more pronounced in men than in women. Although the cohort of 160 patients over a period of 12 weeks offers a good and lengthy insight into the course of infection when compared to other studies on COVID-19, for a statistically significant characterization of subgroups, i.e. age, gender, etc., the cohort would have to be considerably larger, however.

So, do you plan a follow-up study?

The current study has shown a first trend. Now we want to take a closer look at the immune reactions together with our colleagues at ZLM. With regard to personalized medicine, the segregation of well-defined subpopulations of infected individuals is an important aspect. Thus vaccination strategies could possibly differ for distinct patients or patient groups, for example depending on age, gender or risk factors. In a follow-up of the antibody study, we now want to enlarge the cohort and collect more data over a longer period of time. In addition, another aspect of the immune response will also be monitored – the cellular immune response. There are already hints that these specialized immune cells and their chemical messengers also react differently to coronavirus in men and women.

Photos: Empa

Empa is a driving force within the ReMask consortium. What progress can be expected in mask development?

We are working – together with our industrial partners, clinicians and the ReMask network – on a new generation of protective materials. These include, for instance, masks with an antiviral coating. A whole range of options are possible here that inactivate or even destroy viruses, such as nanocoatings or surface functionalizations. But other textiles can also be equipped with protective capacities. Antiviral curtains, clothing for health personnel, or seat covers for public transport are also an issue. We are in constant exchange with our industry and research partners to identify the needs for novel efficient solutions. In this way, Swiss industry can be at the forefront of product development.

Empa has developed recommendations for textile community masks. Are such washable textile masks also ecologically beneficial?

We are currently planning to carry out comprehensive comparative analyses of textile and disposable masks and to draw up life cycle assessments. Because there are important questions which go

> "A special coating on textiles could destroy viruses."

beyond the actual effectiveness of the masks. These include health and safety aspects. Are fibers rubbed off in the washing machine, and do fiber fragments end up in the waste water? Do we inhale nanoparticles that come off coated masks? These are the questions we are investigating together with Empa's "Technology and Society" lab. We also benefit from our well-established lung model ALI, short for "Air Liquid Interface Exposure System". Thanks to ALI we can, for example, investigate how lung cells react to airborne particles, in the same way as it occurs during respiration in the human body.

Can the current pandemic also bring positive aspects for future research?

Even at the beginning of the corona pandemic, we were able to rely on our excellent research infrastructure and our huge network in order to transfer new ideas into practical clinical applications as quickly as possible, just as we do every day as a "cradle of innovation" in Switzerland. Overall, however, it must be said that such a situation is an enormous challenge for society – but also an opportunity for the research scene. Switzerland's research community has cooperated extremely intensively during the crisis and has responded swiftly and flexibly to the needs of society. For our research, this has led to an increase in digital solutions and strengthened our efforts to use big data analyses to complement experimental work and the work of our clinical partners.

In addition, we are currently establishing a method that will also be suitable for future applications. For example, manufacturers of protective materials must have their products tested for their protective effect against viruses during the development phase. Until now, this has been a complex procedure that could only be carried out in highly specialized laboratories. We want to accelerate these development steps by designing alternative methods, such as inactivated, harmless viruses that are equipped with fluorescent dyes and that light up once the pathogens have been neutralized by a functionalized surface. Once this method is established, product developers will be able to examine their materials at an early stage without having to call in a high-security lab. Efficacy tests with infectious viruses will then only be necessary for the approval of the final product. ■

Further information on the topic is available at:
www.empa.ch/web/s403

MODELING ETERNITY IN THE ROCK LABORATORY

Cement is one of the key materials for the safe storage of radioactive waste. What is needed is an almost infinite durability of the containers. Empa researchers are therefore analyzing material systems that can handle this task.

Text: Andrea Six

STORAGE IN CLAY
Exploratory tunnel in the Mont Terri international rock laboratory. Since 1996, rock formations that could help in the storage of radioactive waste have been investigated at this site.

Image: swisstopo

When Barbara Lothenbach pushes ahead with her research projects, she knows that she will not live to see the final result: What she is working on should last between 100,000 and one million years. The researcher from Empa's "Concrete & Asphalt" laboratory is investigating cement-based materials, which are suitable for the disposal of radioactive waste.

According to the Nuclear Energy Act, deep geological repositories in Switzerland are to receive low-, medium- and high-level nuclear waste in the future. For this purpose, stable rock layers must be available to enclose the waste containers. Since materials scientists know, however, that no material is unchangeable, a rock formation must be selected that is geologically as stable and dense as possible – over thousands of years. The 180 million-year-old Opalinus Clay, which extends in Switzerland between Olten and Schaffhausen at a depth of 600 meters, for example, has proven to be a suitable host rock. Since it has a low water conductivity, it has excellent insulating properties.

ROCK SOLID SEALED IN THE MOUNTAIN

But how do the crystalline structures and clay minerals of Opalinus Clay react with cement-based safety barriers when the gnawing ravages of time lead to changes? The National Cooperative for the Disposal of Radioactive Waste (Nagra) requires data on this issue so that a final repository for nuclear waste can be embedded rock-solid in the Earth with regard to environmental protection and safety.

Barbara Lothenbach and her team carry out the required analyses by conducting experiments under realistic conditions at the Mont Terri Rock Laboratory in St. Ursanne, which was constructed in an Opalinus Clay layer. Together with international partners and research groups ▶

from Switzerland, such as the University of Bern and the Paul Scherrer Institute (PSI), reactions of cement-based materials and the surrounding Opalinus Clay are simulated. The researchers are investigating and modeling the long-term development of the boundary layers between the very different material systems in experimental approaches lasting several years at different temperatures between 20 and 70 degrees Celsius.

A WELL ESTABLISHED TYPE OF CEMENT

Of particular importance here is the strongly alkaline pH of cement, which in conventional Portland cement can be as high as pH 13.5 or even higher. To ensure that the alkaline environment does not attack the clay minerals in the surrounding area, a new development, the so-called "low-alkali" cement, seemed to be a good candidate for durable, cement-based protective barriers. With a pH of 12.2 or lower, it has an alkali concentration that is more than ten times lower. Lothenbach and her team therefore compared cement types with different pH values using thermodynamic modeling and X-ray diffraction analysis. This is the first time long-term results are available that allow the cement types and their evolution in the mountain to be characterized. It turned out that low-alkali cement is indeed more gentle on the clay minerals. However, when conventional Portland cement is used, chemical compounds are formed over time that lead to similarly favorable conditions in the safety barrier. "As a result, the cheaper and well-established Portland cement has once again become the focus of interest," says Lothenbach.

INTRICATE RADIOACTIVITY

Moreover, if cement-based materials are to prevent radioactive substances from escaping into the environment, under no circumstances must the reaction between the nuclear waste and the cement impair the safety barriers of the storage facility. Empa researchers have thus investigated radioactive isotopes present in the radioactive waste, such as those of the element selenium, in adsorption studies. The results show that selenium compounds are absorbed by the cement in large quantities. "A protective barrier made of concrete delays the release of radioactivity into the biosphere, since the cement minerals bind the radioactive substances and thus stop their spread," concludes Lothenbach.

However, not all the processes taking place in the complex interplay of the materials that come into contact with each other can be evaluated so easily, the researcher points out. She was hoping that the development of new low-alkali cements would offer advantages for the durability of the safety barriers. However, the researchers discovered drawbacks in other properties: Combining thermodynamic modeling and experimental data, Lothenbach's team could see that such types of cement bind substances like radioactive iodide less well.

HAZARDOUS CORROSION

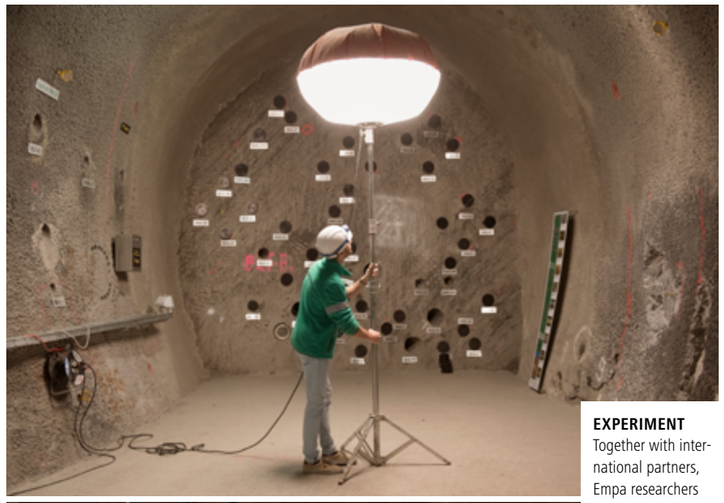
An insulation layer is desirable, which is as waterproof as possible but not gas-tight. In a deep geological repository, gases can be produced, for example, by corrosion of the enclosed steel containers, whereby iron hydroxide is formed and hydrogen is released. Such gases, which are produced in small quantities over time, must be able to escape in order to prevent excess pressure from developing. In order to trace long-term reactions in the corrosion of iron at the boundary to the cement material, the researchers carried out investigations using chemical analyses and spectroscopy. Initial results show that Portland cement with its high pH is more effective than low-alkali cement. More experiments are now planned to shed light on these still little-known corrosion processes.

In addition, Lothenbach's team has characterized the phases in the interaction zone of cement and Opalinus Clay that result from the interaction of clay minerals with the cement's constituents, such as a magnesium silicate phase. It has not yet been conclusively clarified that such intermediate layers are formed and could contribute to sealing the protective layer. Lothenbach is convinced that findings of this kind can contribute to the development of new material systems that are of interest to the entire construction industry. For despite the good material properties of Portland cement, there is an increasing search for alternatives that are more environmentally friendly and help save natural resources, which could also be used for applications other than in a deep geological repository. ■

THE MONT TERRI PROJECT

Eleven nations with various universities and research institutes are involved in the international research program at the Mont Terri Rock Laboratory, including Empa. The underground rock laboratory is located in an Opalinus Clay layer at a depth of 300 meters in Mont Terri near St. Ursanne (JU). The laboratory is operated by the Federal Office of Topography (swisstopo), and the project partners are funding the research programs. Rock formations that could play a role in the storage of radioactive waste have been investigated here since 1996.

Further information on the topic is available at:
www.empa.ch/web/s308



EXPERIMENT
Together with international partners, Empa researchers are studying the reactions of cement with the surrounding Opalinus Clay.

Photos: swisstopo

BRAKING DUST

The broad introduction of particle filters reduced the emission of combustion generated fine and ultrafine particles significantly. As a result, brake disc and tire abrasion are moving into the focus of public health experts and engineers, given their health harming potential. There is still a major challenge, though: How can the quantity and size of brake dust particles be measured correctly? Empa researchers are currently developing a sophisticated method.

Text: Rainer Klose

The VW Jetta Hybrid on the chassis dynamometer in Empa's Automotive Powertrains Technologies Laboratory had a couple of years of duty as a fleet vehicle. Strapped into the test chamber, it has been part of a new research purpose since July 2020: The goal is to generate brake dust, strictly following the standardized WLTP driving cycle, is the cycle that is also used to determine exhaust emissions.

The interest in brake dust measurements is fairly recent: In June 2016, a department of the UN Economic Commission for Europe (UNECE) known as the "Particle Measurement Programme Informal Working Group" (PMP IWG) decided that it was time to develop a generally applicable test procedure for brake dust that would reliably determine the mass and the number of the emitted particles. Since then, a number of research institutions, vehicle manufacturers and specialized companies for testing equipment have addressed the topic. However, there some severe challenges to tackle.

DUST GENERATOR
The brakes of a car emit particles of metal oxide.

Photos: Empa

THROWN IN ALL DIRECTIONS

Unlike an exhaust pipe, which reliably emits gases in a given direction, a rotating brake disc distributes the particles in all possible directions. So you first have to collect the particles and then introduce them in a well-defined flow towards a particle analyzer. During this process losses have to be minimized: Neither fine particles should be escape, nor should coarse particles remain in the pipes.

> "We want to measure all emissions of a vehicle simultaneously in a single test drive."

Two further complications arise: The brakes of a vehicle are attached to a rotating drive shaft, which must be carefully sealed for the measurement so that no particles are lost. In parallel a brakes have t be cooled. On the road, the airstream together with ventilation lamellas inside the brake disks provide a cooling breeze. A fully enclosed brake on a test bench, by contrast, can heat up quickly – and would then yield completely different particles than in real everyday traffic. Such an analysis would thus be of little value.

ALL EMISSIONS AT THE SAME TIME

The UNECE's PMP IWG working group solves the problem by simplification: The desired brake tests are to be carried-out in completely enclosed test stands. Such test stands exist. They resemble large cabinets, in which brake discs and brake pads rub against each other. Only one component is tested, not the entire car.

CLOSE TO REALITY
Empa measures emissions across the entire car.

"We are going to try out another way," says Panayotis Dimopoulos Eggenschwiler, who is designing the test setup at Empa. "We want to measure all emissions of a vehicle simultaneously during a test drive on the chassis dynamometer. This is much more meaningful than data from an isolated brake tester, which must then be converted to real-world conditions".

AIR FREIGHT

Together with Daniel Schreiber, an engineer by training, Dimopoulos Eggenschwiler has developed the Empa version of the test, the results of which must now stand up to comparison with other international research teams. At Empa an entire vehicle is being tested, the VW Jetta Hybrid mentioned above. The brake of the right front wheel was enclosed in a specially designed metal housing. A compressed air pipe conveys large quantities of cooling air into the metal casing from the front end of the car; at the same time the air serves as the transport medium for the emitted brake particles. These are directed into a tube about along the vehicle. After a short flight time they land in a 13-stage cascade impactor, a special instrument that sorts particles according to size. Subsequently, the particle fractions can be chemically analyzed by weight. If necessary, their morphology and composition can also be examined using an electron microscope, for instance.

"In preliminary tests, we have already determined what of consisting elements of the brake particles," says Dimopoulos Eggenschwiler. "It is mainly iron oxide, which originates from the brake disc, and a number of further oxides and species containing aluminum, magnesium, calcium, potassium and titanium, which stem from the brake pads." In addition to coarse, particles, there are also smaller particles that can be inhaled and can enter the lungs.

DO HYBRID VEHICLES BRAKE DIFFERENTLY?

Now that the measuring process is running on a stable basis, the VW Jetta will initially be operated according to the legally prescribed WLTP cycle and will supply brake particles to the cascade impactor. Further test series are planed after that. "We want to find out, for example, whether hybrid vehicles brake differently compared to cars with conventional powertrain systems and hence result in different emissions," explains the project leader. Hybrid vehicles are also capable of braking through their electric motor and, therefore, need to use their mechanical brakes much less frequently. On the other hand, hybrid vehicles have a higher mass. "With the results of our measurements, it will be possible to optimize the operating modes of future generation vehicles and keep brake dust emissions under better control than today". ■

Further information on the topic is available at:
www.empa.ch/web/s504

GREEN EARPLUGS

Cars, trains, planes: For two thirds of the European population, traffic noise is part of everyday life. However, the right environment can have a major impact on this nuisance, as Empa researchers have found out. Green spaces in urban areas help to make road and railroad noise less of a nuisance. Only in the case of aircraft noise does this seem counterproductive: the greener the surroundings, the more disturbing the aircraft noise.

Text: Cornelia Zogg

GREEN
A view into the countryside can reduce noise pollution and provide restful relaxation.

Photo: unsplash

Through the window, you hear the traffic noise from down the street, a train rumbles in the distance – that is the everyday life for many of us. Almost 75% of the European population lives in urban areas and only a quarter in rural areas. Noise pollution from cars, trains and planes poses a health problem that should not be underestimated. According to the World Health Organization (WHO), increased noise pollution leads to numerous negative effects on health, from stress and sleep disturbances to cardiovascular diseases and diabetes.

"We can escape the noise of the streets or trains by getting a little more distance. This is not possible with aircraft noise."

But how can these negative effects of noise pollution in densely populated, urban regions be reduced, and are there ways of influencing the subjective perception of noise? Empa researchers led by Beat Schäffer of the Acoustics / Noise Reduction lab, together with experts from the Swiss Federal Office for the Environment (FOEN), the Swiss Tropical and Public Health Institute and the University of Basel, have discovered that this works. A view out of the window into the countryside can significantly reduce the perceived noise pollution. Whether it's a nearby park, a pond or the mountain range on the horizon: a view into nature, and the noise will disturb us less.

GREEN LETS US RELAX

For their study, the research team used the so-called NDVI ("Normalized Difference Vegetation Index"), which is calculated on the basis of remote sensing data and documents the entire green space of a specific region – from individual groups of trees at roadsides to large parks. The research group also used data from Swisstopo. All parks and gardens are listed there, as well as other green areas such as agricultural zones and forests. The team then compared the data from Swisstopo and the NDVI with the results of the SIRENE study to find out how noise perception changes among inhabitants of urban areas. In 2019, this study with around 5600 participants provided information on noise pollution from road, rail and air traffic noise. By comparing the data on green spaces in Switzerland with the results of the survey, Schäffer and his team were able to determine how recreational areas affect the perception of noise. Conclusion of the study: Parks and green spaces help to reduce the perception of noise caused by road and train noise. The closer the recreation area to one's own home, the lower the subjectively perceived annoyance from noise emissions.

INEFFECTIVE AGAINST AIRCRAFT NOISE

It is not surprising that green spaces influence our perception of noise. But much more interesting is the result regarding aircraft noise. It's the opposite to cars and trains: The more green spaces we have, the more disturbed we feel by aircraft noise, according to a comparison of the data. According to Schäffer, there are various reasons for this. "While we can escape from road or train noise by walking a little distance, we cannot do the same with aircraft noise". We are almost helplessly at the mercy of airborne noise, because we cannot escape the noise by a few meters distance. This "being at the mercy of the noise" may lead us to perceive the noise as more disturbing. A second point is the so-called incongruity: "In a park, we expect it to be quiet. If this silence is then disturbed by something that we cannot influence, we perceive this noise as far more disturbing," says Schäffer. For example, we hardly notice an airplane in the sky when we walk around a bustling city.

GREEN FOR URBAN CLIMATE

Parks and gardens are helpful not only against noise, but also in the fight against so-called heat islands, as an Empa study has found out. The Münsterhof in Zurich served as an example. The researchers selected the site to carry out climate simulations. The calculations show that the temperatures on the Münsterhof would be significantly lower if the square were not paved but covered with earth and grass. The ground would cool down more overnight and store less heat during the day.

LIST OF CRITERIA

In a next step, the researchers want to look even further into the psychological and especially physiological aspects of noise and include other factors. A recently launched Sinergia study by the Swiss National Science Foundation (SNSF) called RESTORE is being developed in collaboration with the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and is scheduled to last four years. The team wants to analyze in more detail what effect green spaces have on physiological stress and what criteria local recreation areas must meet in order for residents to recover from stress. The aim is to apply these findings to urban planning in the future – especially in densely populated urban areas. ■

Further information on the topic is available at: www.empa.ch/web/s509

LONG DISTANCE
The energy requirements of long-distance trucks can hardly be met by batteries. Combustion engines are difficult to replace in this sector.

VOLATILE STUFF FOR TRUCKS

In future, commercial vehicles will not only have to emit less CO_2 but also meet stricter exhaust emission limits. Many experts expect that this could herald the end for fossil diesel. One possible alternative is dimethyl ether: The highly volatile substance burns very cleanly and can be produced from renewable energy. Empa is investigating this new powertrain concept using a special test engine.

Text: Rainer Klose

Operating a fleet of trucks is a tough business. Forget trucker romance; strong competition and high price pressure is the name of the game. Increasingly strict environmental regulations aiming at lower CO_2 emissions and strict exhaust gas values, especially with regard to nitrogen oxides (NO_x), will further intensify pressure on the industry in the years ahead. If truck operators do not rely on the latest technology, they will have to fear increased tolls or tax disadvantages in numerous countries.

Many commercial vehicle manufacturers and operators are now considering alternative powertrain systems to improve the environmental performance of their fleets. However, electric drives are hardly suitable for commercial vehicles in long-distance operation: The batteries would be too heavy, the charging times too long and the required charging power too high for competitive use. Hydrogen could solve this problem: As of September 2020, the first Hyundai fuel cell trucks are in commercial test operation in Switzerland. Synthetic natural gas from surplus green electricity is also under investigation: From 2021 the first natural gas trucks will be refuelled at Empa's mobility demonstrator, move. But there is another alternative that would be suitable for long-distance transport and that deserves closer examination: dimethyl ether or DME, in short.

VERY CLEAN COMBUSTION

DME is produced on a scale of several tens of thousand tons annually. The chemical is used as a propellant in spray cans and serves as a component of refrigerants in cooling systems. DME is also widely used as an intermediate product in the chemical industry. Its advantage is that it can be produced at low costs and almost loss-free from methanol, which in turn can be cheaply produced using electricity from solar and wind energy. DME thus offers the opportunity to make trucks CO_2-neutral.

Photo: istockphoto

Another advantage: DME has similar properties to liquefied petroleum gas (LPG). Unlike hydrogen, it can be transported and stored in standard tanks under low pressure in liquid form. The technology for LPG refueling stations, and thereby also for DME, is inexpensive, it is known worldwide and has already been in use for decades. What's more, since DME contains chemically bound oxygen, the substance burns particularly clean and with little soot formation.

TESTING IN A MODIFIED TRUCK ENGINE

There have already been trials with DME as a fuel in the past: Volvo Trucks has been conducting field trials with experimental trucks powered by DME in Sweden and the US since 2013. In Germany, a research project coordinated by the Ford Research and Innovation Center Aachen has been running since 2016. The engine has been fitted and tested in a Ford Mondeo.

Empa, together with FPT Motorenforschung AG Arbon, Politechnico di Milano, lubricant manufacturer Motorex and other partners, will now extend the knowledge gained thus far. Since early July 2020, the test engine ▶

SUSTAINABLE LONG-DISTANCE TRANSPORT – THESE ARE THE OPTIONS:

In the passenger car sector, the electric drive is considered to be the way of the future, the plug-in hybrid is seen as an interim solution. The future is less clear for commercial vehicles. An overview of the powertrain variants under discussion, with their advantages and disadvantages.

FUEL	SHORT DISTANCE	LONG DISTANCE	FILLING STATIONS	TECHNOLOGY	ENGINE TYPE
BATTERY	FINE	POOR	EXPENSIVE	STILL EXPENSIVE	ELECTRIC
Note: heavy batteries reduce the payload, low range.					
OVERHEAD LINE	POOR	FINE	EXPENSIVE	EXPENSIVE	ELECTRIC
Note: for the last mile off the highway a second drive system is required.					
HYDROGEN	FINE	FINE	EXPENSIVE	EXPENSIVE	ELECTRIC
Note: in case of gaseous refuelling the range is smaller compared to diesel. Liquid refuelling is not yet tested.					
POWER TO GAS	FINE	FINE	ALREADY AVAILABLE	AFFORDABLE	PETROL / GAS
Note: efficient methanation of hydrogen is still being researched.					
POWER TO LIQUID	FINE	FINE	ALREADY AVAILABLE	AFFORDABLE	DIESEL
Note: high losses in the production of syndiesel using the Fischer-Tropsch process.					
DIMETHYLETHER	FINE	FINE	AFFORDABLE (LIKE LPG)	AFFORDABLE	DIESEL
Note: Engine technology is still being researched.					

has been in operation on a dynamometer in Empa's Automotive Powertrains Technologies Laboratory. The scientists intend to provide sound data on the combustion process, efficiency and environmental impact of DME in the commercial vehicle sector.

"We already know this engine very well," says project leader Patrik Soltic. "The engine block is derived from a Cursor 11 commercial vehicle engine manufactured by FPT Industrial and has already served us for five years in various research projects. Over the past few months, we have converted it to DME together with our partner FPT." This wasn't easy: In contrast to diesel, the highly volatile DME has almost no lubricating qualities, which would have quickly destroyed the high-pressure pump of the common rail injection system.

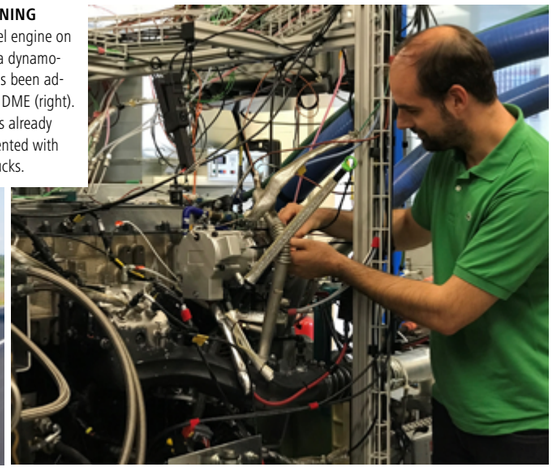
OPERATION WITHOUT FUEL ADDITIVES

The researchers want to run their test engine with pure DME, without using lubricating additives, as has been done in previous projects. In cooperation with a major European supplier, a new oil-lubricated common-rail pump had therefore been developed. In addition, the valves and valve seat inserts were converted to materials suitable for DME. An electrically driven compressor for precise exhaust gas recirculation is also used. Finally, the combustion chambers and compression ratio of the former diesel engine have also been modified. The new shape of the combustion chambers was developed with the help of mathematical simulations at the Politechnico di Milano. The research project is co-financed by the Swiss Federal Office of Energy (FOEN).

SIMULATED HIGHWAY OPERATION

"Now we want to get to know the engine with the new fuel," says Soltic. The researchers are start-ing with a medium-load driving style that is common in highway operation, where the engine must deliver 100 kW of power. "Then we modify the timing and pressure of the injection, among other things, and look at exhaust emission values and fuel consumption." The first results are very prom-ising. The experimental engine runs stable in all engine load ranges, produces practically no soot particles and significantly lower NO_x values than a diesel. This leads to a significantly more compact and cost efficient exhaust gas aftertreatment system, even for future extremely strict pollutant emission limits.

The big advantage of DME operation, says Soltic, is the opportunity to transfer a very high proportion of exhaust gas to the next charge in the cylinder. This is done through so-called exhaust gas recirculation (EGR). This technology makes it possible to save a great deal of NO_x, which eases the burden on the exhaust gas purification system behind the engine and allows future, stricter limits to be met easily. With fossil diesel, high exhaust gas recirculation rates lead to higher particle emissions, which is not the case with DME.



ECO-TUNING
The diesel engine on the Empa dynamometer has been adapted to DME (right). Volvo has already experimented with entire trucks.

Images: Volvo, Empa

During the test phase, Empa researchers repeatedly take samples of the engine oil to trace chemical reactions The results are forwarded to project partner Motorex who uses the data to develop a new engine oil specially adapted for DME operation.

JOINT RESEARCH AMONG COMPETITORS

"We are currently still in the pre-competitive phase of our research," Soltic explains. The results of the project are partly public and are discussed jointly among competitors in the vehicle industry. The platform for these discussions is the "International DME Association" founded in 2001, which currently has 50 members from science and industry." But at some future stage everyone will want to keep their results to themselves," the Empa researcher says. "At that point, it is crucial for us to have a good understanding of the technology in order to be able to continue providing valuable input as a research partner for industry". ■

FUEL FROM THE ECO-FACTORY

Dimethyl ether (DME), the eco-fuel for compression ignition engines, can be produced from hydrogen and CO_2. If hydrogen is produced with renewable energy and CO_2 is captured from the atmosphere, trucks could be driven with virtually no greenhouse gas emissions.

Empa researcher Andreas Borgschulte and his team are investigating chemical processes that produce DME as efficiently as possible. The method of sorption-assisted catalysis is considered to be very promising: The two gaseous starting materials, hydrogen and CO_2, need to get in contact with active copper particles in order to start the chemical reaction to form methanol or DME. Water is formed as a by-product. If water is removed from the reaction mixture, the chemical equilibrium shifts towards the desired large quantities of methanol and DME be produced. To remove water, Empa researchers use zeolite, a water-absorbing mineral.

In lab experiments Borgschulte's team found that, at a certain temperature, CO_2 and hydrogen mainly produce DME, with only a rather small amount of methanol. "DME production using this method is therefore theoretically feasible," says Borgschulte, adding: "Unfortunately, at present the process is not yet very efficient.» The next step would thus be to refine the chemical process and develop suitable production facilities. Only then can we assess whether DME production using sorption-assisted catalysis is economically competitive.

The research was carried out in collaboration with the University of Zurich as part of the LightChEC project.

Further information on the topic is available at:
www.empa.ch/web/s504

HANGING BY A COLORED THREAD

High-performance fibres that have been exposed to high temperatures usually lose their mechanical properties undetected and, in the worst case, can tear precisely when lives depend on them. For example, safety ropes used by fire brigades or suspension ropes for heavy loads on construction sites. Empa researchers have now developed a coating that changes color when exposed to high temperatures through friction or fire.

Text: Cornelia Zogg

IS IT STILL HOLDING? Ropes are used for safety in various areas, in fire brigade and rescue operations as well as on construction sites and in mountaineering.

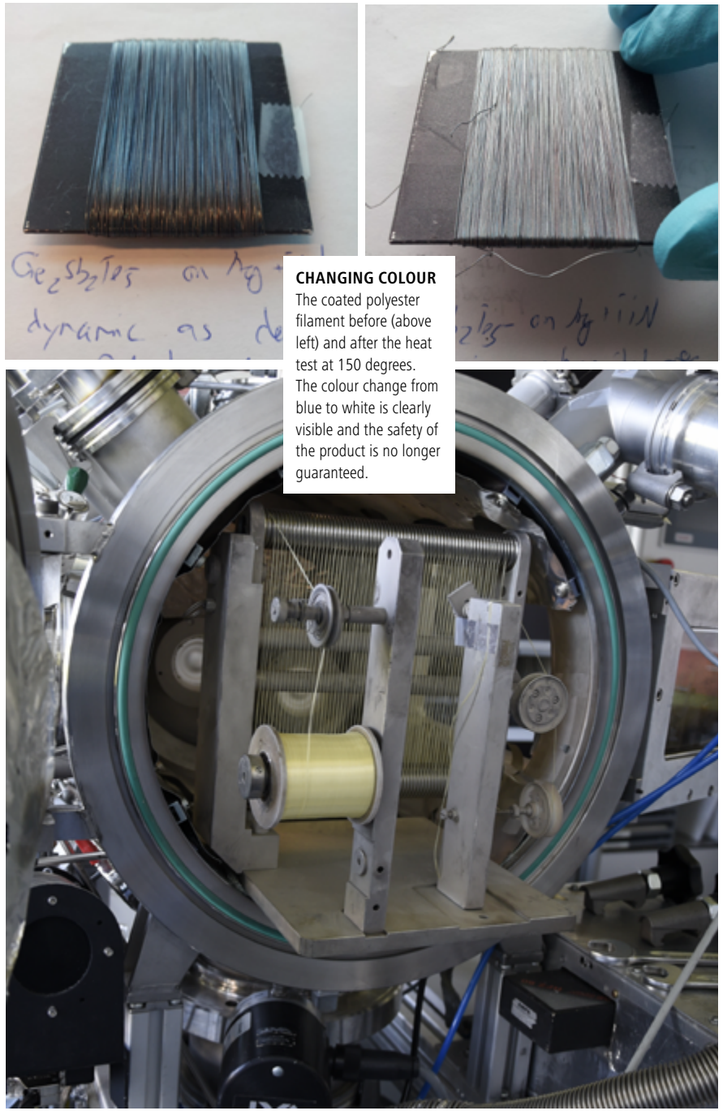
Photo: istockphoto

The firefighter runs into the burning building and systematically searches room by room for people in need of rescue. Attached to him is a safety rope at the other end of which his colleagues are waiting outside in front of the building. In an emergency – should he lose consciousness for any reason – they can pull him out of the building or follow him into the building for rescue. However, if this rope has been exposed to excessive heat during previous operations, it may tear apart. This means danger to life! And up to now there has been no way of noticing this damage to the rope. A team of researchers from Empa and ETH Zurich has now developed a coating which changes color due to the physical reaction with heat, thus clearly indicating whether a rope will continue to provide the safety it promises in the future.

Researchers from ETH Zurich and Empa developed a coating system in 2018 as part of a Master's thesis, which the Empa team was now able to apply to fibers. "It was a process involving several steps," says Dirk Hegemann from Empa's Advances Fibers lab. The first coatings only worked on smooth surfaces, so the method first had to be adapted so that it would also work on curved surfaces. Empa has extensive know-how in the coating of fibers – Hegemann and his team have already developed electrically conductive fibers in the past. The so-called sputtering process has now also been successfully applied to the latest coating.

WAFER-THIN LAYERS WITH GREAT EFFECT

Three layers are required to ensure that the fiber actually changes color when heated. The researchers apply silver to the fibre itself, in this case PET (i.e. polyester) and VectranTM, a hightech fibre. This serves as a reflector – in other words, as a metallic base layer. This is followed by an intermediate layer of titanium nitrogen oxide, which ensures that the silver remains stable. And only then follows the amorphous layer that causes the color change: Germanium-antimony tellurium (GST), which is just 20 nanometers thick. When this layer is exposed to elevated temperatures, it crystallizes, changing the color from blue to white. The colour change is based on a physical phenomenon known as interference. Two different waves (e.g. light) meet and amplify or weaken each other. Depending on the chemical composition of the temperature-sensitive layer, this color change can be adjusted to a temperature range between 100 and 400 degrees and thus adapted to the mechanical properties of the fiber type. ▶



CHANGING COLOUR
The coated polyester filament before (above left) and after the heat test at 150 degrees. The colour change from blue to white is clearly visible and the safety of the product is no longer guaranteed.

"The color change can be adjusted to a temperature range between 100 and 400 degrees Celsius."

TAILOR-MADE SOLUTIONS

The possible areas of application for the colour-changing fibres are still open, and Hegemann is currently looking for possible project partners. In addition to safety equipment for firefighters or mountaineers, the fibres can also be used for load ropes in production facilities, on construction sites, etc. In any case, research on the subject is far from complete. At present, it is not yet possible to store the fibers for long periods of time without losing their functionality. "Unfortunately, the phase-change materials oxidize over the course of a few months," says Hegemann. This means that the corresponding phase change – crystallization – no longer takes place, even with heat, and the rope thus loses its "warning signal". In any case, it has been proven that the principle works, and durability is a topic for future research, says Hegemann. "As soon as the first partners from industry register their interest in our own products, the fibers can be further optimized according to their needs". ■

Further information on the topic is available at:
www.empa.ch/web/s402

Images: Empa

PLAYER ON A ROUGH FIELD

Pietro Lura has bold plans. As head of the new "Concrete & Asphalt" lab at Empa, he is committed to durable materials that are subject to ever-changing external conditions. Climate change and the scarcity of resources require a fundamental rethink in the field of building materials – and Lura is keen on laying the foundation for this massive transformation.

Text: Andrea Six

Once conceived for eternity, building materials such as concrete and asphalt must now keep up with the times. Both products face similar challenges, such as an environmentally friendly, resource-efficient production and significantly lower CO_2 emissions. Pietro Lura, who heads the new "Concrete & Asphalt" lab at Empa, has made this transformation his mission. The research activities of his team – cement chemistry, concrete technology, asphalt and road construction – thus fit perfectly with the objectives of Empa's research focus area, "Sustainable Built Environment". After all, the quality of our built environment is an essential factor for a sustainable society. This includes high-quality and at the same time affordable buildings as living and working space, modern transportation networks and a reliable supply of energy, water and information.

Not an easy task when you consider that concrete and asphalt, with an annual demand of over 4.5 billion tonnes, represent the lion's share of all materials used worldwide. Admittedly, this enormous quantity accounts for a large proportion of global CO_2 emissions. "But that's precisely why optimized material properties directly translate into an enormous reduction in the CO_2 pollution caused by these building materials," explains civil engineer Lura.

IT'S ALL ABOUT THE TEAM

In any case, no task is too big for the researcher, who has been working at Empa for twelve years and holds a titular professorship at the Institute for Building Materials at ETH Zurich since 2011. And this was already apparent long before he decided on a career: Basketball, of all things, is something the not exactly above-average sized Lura enjoys playing passionately in his free time. And after a humanistic school education, he was drawn to engineering where he distinguished himself at universities in Italy, the Netherlands, Denmark and the US.

And this is exactly how Lura sees his task at Empa: In the small country of Switzerland he works in a large field of research with enormous international competition. "It's all a team effort," says Lura. As in team sports, the synergies within the team are important. With its research expertise, its approximately 40-member lab has a USP within the Swiss research landscape and is therefore highly relevant to decision-makers such as the Federal Roads Office (FEDRO). Cooperation with industrial partners and research institutions on an international level is also already well established.

"BIG DATA" FOR BUILDING MATERIALS

Thematically, there are plenty of synergies within concrete and asphalt research because both building materials are confronted with similar challenges. Central topics include the use of alternative ingredients and previously unused secondary raw materials from industrial processes as well as the implementation of efficient recycling processes.

Cement and bitumen, the binding agents on which concrete and asphalt are based, have indeed been used since ancient times. Today, however, research is breaking completely new ground in order to analyze the chemical properties of these highly complex materials, to optimize construction materials or even to equip them with completely new properties. Both fields rely on the latest methods, for example from digitalization (artificial intelligence, machine learning, big data and computer simulations), manufacturing technology (additive manufacturing) ▶

CLOSE TO THE MATERIAL
For Pietro Lura, Head of Empa's "Concrete & Asphalt" lab, sustainability in his research projects is also a matter close to his heart.

Photo: Sara Keller

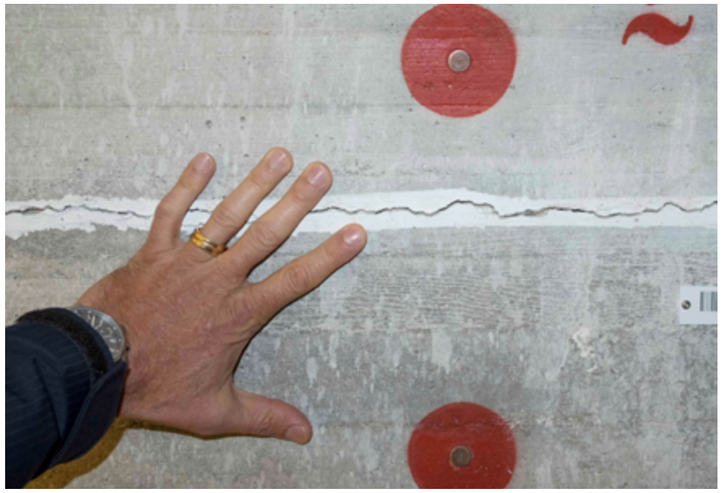
and the field of material characterization. "Our goal is to implement the principles of recycling management by developing new composite materials, enabling the cross-recycling of asphalt and concrete, and analyzing alternative binders," says Lura, adding: "An exciting task in a globally ever-growing market."

CONCRETE AS SOCIAL IDENTITY

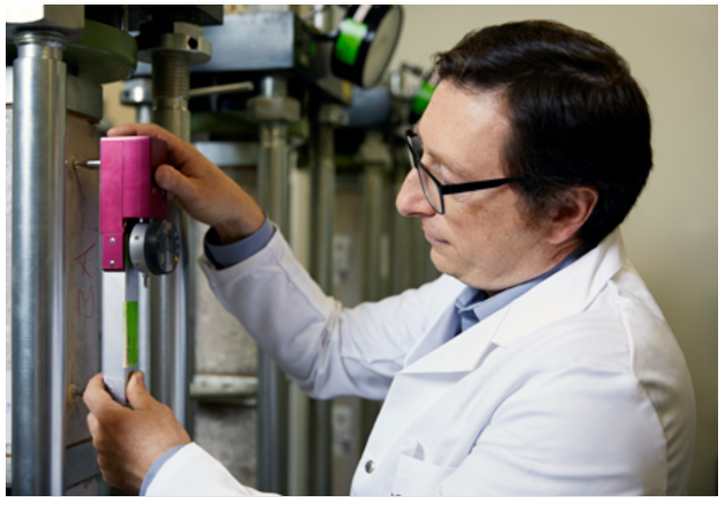
For some, concrete and asphalt may be coarse, shapeless building materials whose fascination is not apparent at first glance. For Pietro Lura, on the other hand, this fascination is obvious: Concrete and asphalt are much more than inexpensive, robust materials. They act as "binders" in our society by bringing people together on roads. They create the entire infrastructure of the world on a large scale – and on a small scale, if privacy is given space with a home or a hospital room. In a world with rapidly increasing mobility and a widely felt globalization, building materials also form the physical basis, with which civil engineers and architects create a social identity and cultural localization of people.

INVENTIVE SPIRIT FOR NEW MATERIALS

As the father of three sons, the sustainability of his research is also a matter close to Lura's heart, which at the same time meets the requirements of the United Nations Environment Program (UNEP): New cement-based materials that are more climate-friendly and cheaper are to be developed and used immediately. The cement industry currently accounts for around seven percent of global CO_2 emissions. However, this is likely to increase in future, as demand in Asia and increasingly also in Africa is growing, while production in Europe is stable. When Empa researchers work on the development of new cement- and bitumen-based materials, their aim is to produce less of the harmful climate gas – or even to banish CO_2 from the atmosphere. Currently, around 700 kilograms of CO_2 are released during the production of every ton of cement.



SUSTAINABLE
Due to the climate debate, Lura sees crucial global changes coming to the construction industry.



Photos: Sara Keller, Empa

> "In a globalized world, building materials form the physical basis for creating a social identity and cultural localization."

For Lura, driving innovation is a familiar concept, given his experience with inventions from the perspective of a patent examiner from his time at the European Patent Office in Munich. "This is a long-term strategy that will have a strong positive impact on the sustainability of the construction industry," he says. For instance, his team is investigating reduced burning temperatures and modified raw material recipes for building materials. Alternative ingredients such as blast furnace slags or waste products from the electronics industry are being screened for their availability and material properties. And for concrete and asphalt, the recycling process for demolished buildings and road surfaces can still be significantly optimized. To ensure that such approaches do not end up as niche products, new eco-building materials must ultimately meet the same requirements as conventional products, for example in terms of durability and strength.

And in yet another area, Lura sees its activity as a "binder": connecting research with the public. For example, he was editor-in-chief of the renowned technical journal "Materials and Structures" for many years. But Lura goes one step further, because he has always advocated the principle of "open access", i.e. free access to the results of publicly funded research. Researchers should be connected to the world, and the world should have insight into their research. Lura: "It's important to make advances in the scientific community available to the public."

As head of a rather large lab, the researcher certainly misses doing research himself; this is usually his team's task. Nevertheless, Lura stays on the ball when he contributes his ideas and sees them grow into new experiments, technologies or material compositions. It is an exciting time for him to see how globally important decisions for the future of the construction industry are about to be made. ■

Further information on the topic is available at:
www.empa.ch/web/s308/research

DRYING FRUIT WITH IONIC WIND

If fruit or vegetables are dried with heat, nutrients can be destroyed and flavors can be reduced. This is why non-thermal drying of food – i.e. without heating – is preferred by the industry. Among other things, fans are used for this purpose. A new drying process developed at Empa using ionic wind promises to make the non-thermal drying of food much more energy-efficient, faster and even gentler.

Text: Mara Hausammann

When the blades of a fan rotate, a steady wind is blowing as a result. This phenomenon is well known from everyday life, and so we use the fan on hot summer days to cool us down. An unwanted side effect is the unpleasant feeling in the eyes, which become drier and drier due to the artificial wind. The food industry has been taking advantage of this effect for a long time: Fruit and veggies are preferably dried without heat, because heat deteriorates nutrients and flavor.

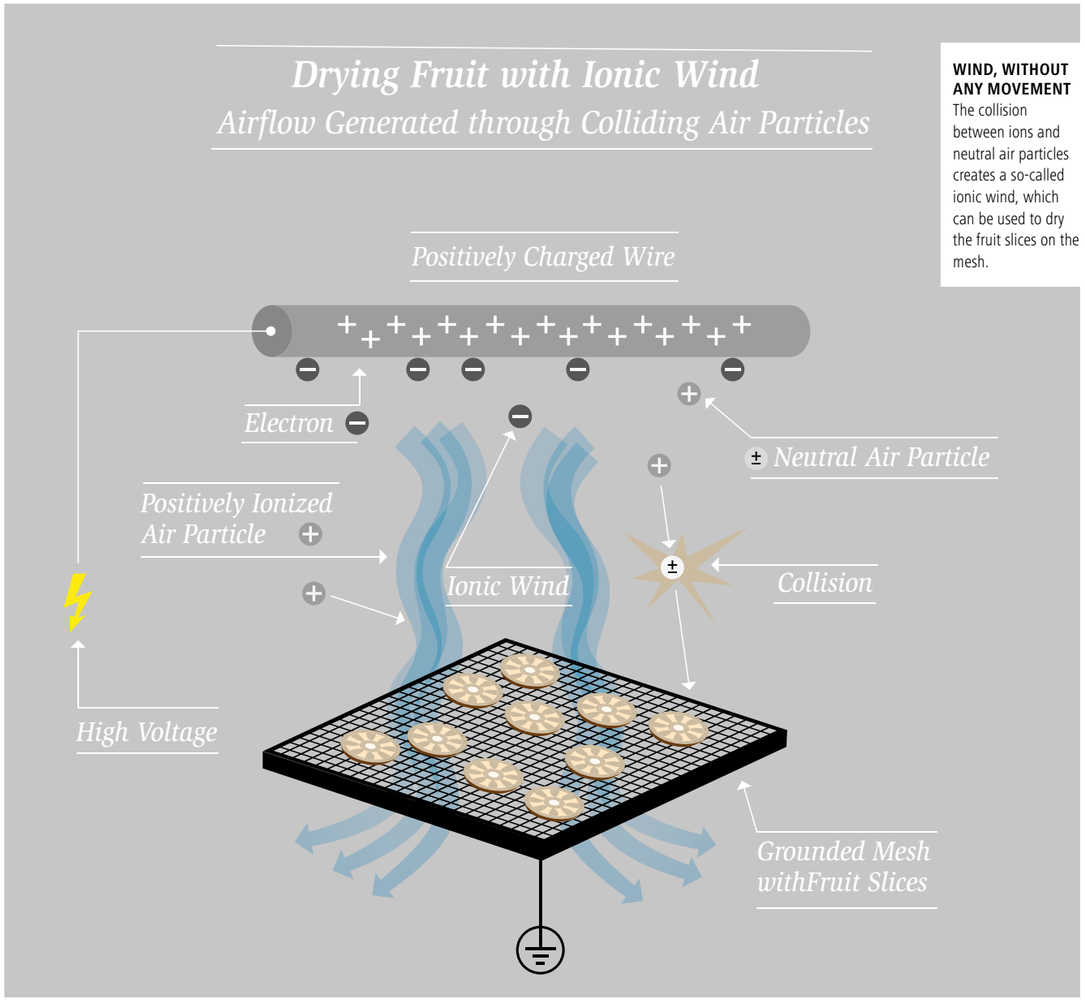
The so-called non-thermal convective drying of food with the help of large fans has a drawback, however: The drying process is time-consuming and requires a lot of energy. This is why industry has been looking to find a more energy-efficient method for a long time. One alternative technology is based on the so-called ionic wind. Although this already works on a small scale, attempts to upscale the concept for industry have failed so far. Empa researchers have now developed a more energy-efficient drying system based on ionic wind, which is perfectly suitable for industrial applications.

MAKING WIND WITHOUT FANS

Ionic wind is not generated by the rotating blades of a fan; it is created by connecting, for instance, a metal wire to a high-voltage source with a positive voltage of 10,000 to 30,000 volts. This charges the wire positively and ionizes the surrounding air. Air consists of various gases such as oxygen (O_2), nitrogen (N_2) or carbon dioxide (CO_2). Each of these molecules consists of atoms, which in turn consist of positively charged elementary particles – the protons – and negatively charged particles – the electrons. The electrons are attracted by the positively charged wire, while the much heavier protons are repelled by the wire. These electrostatic forces ultimately cause electrons to "split off" from the (electrically neutral) gas molecules, the remaining molecules are now positively charged – or "ionized". The positive ions collide with other air molecules on their way away from the wire towards the grounded collector located below the wire and set them in motion. This impulse, or rather the particle movement triggered by it, then creates the ionic wind, which is also known as electrohydrodynamic airflow.

POWER DRYING
If the fruit slices are placed on a mesh, they are dried faster and more evenly.

Researchers tried to make use of ionic wind with different approaches for the industrial drying of food – but so far without remarkable success, because an upscaling was not possible. Empa researcher Thijs Defraeye from the "Biomimetic Membranes and Textiles" lab and his team pursued the idea further and varied various process parameters. First, the researchers did not place the food to be dried on a tray as it was done previously, but used a mesh instead. "Now this isn't exactly rocket science, but so far no one has considered this adaptation for the drying with ionic wind," says the Empa researcher. What sounds like a small change makes a huge difference, though: The water can now evaporate from all sides of the fruits or vegetables. As a result, the ionic wind dries the food twice as fast as on an impermeable tray, which was used by researchers over the world so far. But above all, the ionic wind dries fruit and vegetables more uniformly on the mesh. In contrast to the previous approaches of electrohydrodynamic drying, the new design is also easier to scale up – and thus extremely interesting for industry.



WIND, WITHOUT ANY MOVEMENT
The collision between ions and neutral air particles creates a so-called ionic wind, which can be used to dry the fruit slices on the mesh.

Photo: Empa, Graphic: Empa

REFINED BY COMPUTER MODELING

In refining their new concept further, Empa researchers relied on complex computer simulations. This allows various dryer device adjustments and their influence on the drying process to be simulated virtually. Hence, the system can be optimized "in silico" without having to physically build new drying equipment each time.

But can the results of the computer calculation be successfully transferred into the real world? Is it really possible to optimize the process in this way? In cooperation with researchers from Dalhousie University in Canada, a first prototype of the new drying system was built in their lab. Initial tests did indeed show considerable improvements: Drying by means of ionic wind is much faster and consumes less than half the energy required by conventional processes. In addition, the food is dried more evenly and the nutrients are preserved much better. Last but not least, the process can be scaled up to industrial scale rather easily. Defraeye and his team are currently working with a Swiss retailer to develop the concept further. ■

Further information on the topic is available at:
www.empa.ch/web/s401

AVENIR SUISSE RELIES ON EMPA EXPERTISE

SUSTAINABLE
At full throttle towards "net zero".

The think tank Avenir Suisse presented its latest publication entitled "Sustainable Powertrain Technologies" on July 16. The key message is clear: an openness towards different technologies is needed to achieve the climate goal of "net zero" – meaning CO_2 emissions – by the year 2050. Among the authors are Peter Richner and Christian Bach from Empa.

www.empa.ch/web/s604/avenir

RECYCLING LITHIUM-ION BATTERIES

On September 4, 2020, the Swiss electric vehicle manufacturer Kyburz commissioned an in-house lithium-ion battery recycling plant – the first of its kind in Switzerland. The plant was designed in close collaboration with Empa experts and has succeeded in recovering up to 91 percent of the metals.

www.empa.ch/web/s604/kyburz-batterierecycling

CIRCULAR ECONOMY
The new recycling plant for lithium-ion batteries at Kyburz AG.

Photos: David Becker / Unsplash, Kyburz Switzerland AG

HIGH-TECH WOOD AS CLIMATE SAVER

On September 1, 2020 Ingo Burgert representing the wood research teams at Empa and ETH, was given the SDG Award 2020 for sustainability. "Burgert and his team are contributing substantially to the fact that in the future solutions and applications will find their way into our lives which will contribute to saving the climate", was the jury's conclusion.

www.empa.ch/web/s604/nachhaltigkeitsaward_sdg

AWARD WINNERS
Empa researchers have refined wood into a lightweight, malleable material of the new generation.

STEERING NOISE PROTECTION

OVERVIEW
Empa researcher Jean Marc Wunderli is the new President of the Swiss Federal Noise Abatement Commission.

The Federal Council has appointed Empa researcher Jean Marc Wunderli as President of the Swiss Federal Noise Abatement Commission (EKLB). Since 2019 Wunderli heads the lab for Acoustics/Noise Control at Empa. The FNAC works as an interdisciplinary and independent extra-parliamentary expert commission in the fields of noise and vibration abatement.

www.empa.ch/web/s604/wunderli-prasident-eklb

Photos: Empa

EVENTS

(IN GERMAN AND ENGLISH)

11. NOVEMBER 2020
Techbriefing: Smart Energy Applied Solutions
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Empa, Dübendorf

16. DEZEMBER 2020
Workshop: Simulation and Sensing@Empa
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26. MÄRZ 2021
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