The Magazine of Forschungszentrum Jülich 04|2013

RESEARCH in Jülich

:: DATA STORAGE OF THE FUTURE

Resistive Cells Could Make Computers More Powerful

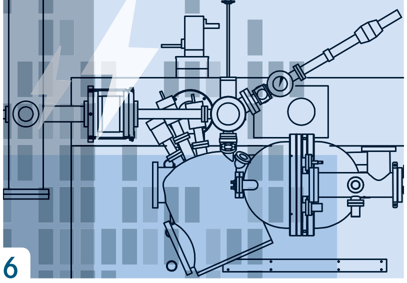
:: Kerosene from Algae: Flying with Sustainable Fuel

:: Digital Jigsaw Puzzle: Several Steps in the BigBrain Model

JÜLICH FORSCHUNGSZENTRUM

:: IN THE PICTURE

Look, but don't touch: even a hair or a flake of skin can destroy the tiny electronic components no bigger than about 100 nanometres on a wafer. Researchers at Jülich's Peter Grünberg Institute – Semiconductor Nanoelectronics (PGI-9) have access to a clean room with all of the instruments needed to fabricate such components themselves. Prototypes of novel transistors for use in future generations of laptops and smartphones are a good example. These transistors are not only more powerful than those built today; they also consume less power. Their fabrication involves several processes. After the wafer has been coated, exposed to light, and developed, it is doped using an ion implanter. In this step, ions are introduced into the base material of the wafer – usually silicon or related materials. This process allows materials properties, such as electrical conductivity, to be selectively altered.



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:: EDITORIAL

We generate data day in, day out: on computers, with digital cameras, and on our smartphones. While the volume of data is growing, storage media are expected to become smaller and faster. However, some components have almost reached the limits of what is physically possible. A new generation of storage technology – resistive RAM (ReRAM) – is already on the horizon. Jülich researchers are considered pioneers in this area. They have demonstrated that the memory cells on which ReRAMs are based have another, unexpected property: they are a type of minuscule battery. In this issue, you will discover why this is useful and what it has to do with synapses in the human brain. You will also learn how kerosene can be produced from algae and how scientists create virtual brain models.

I hope that this issue makes for interesting reading!

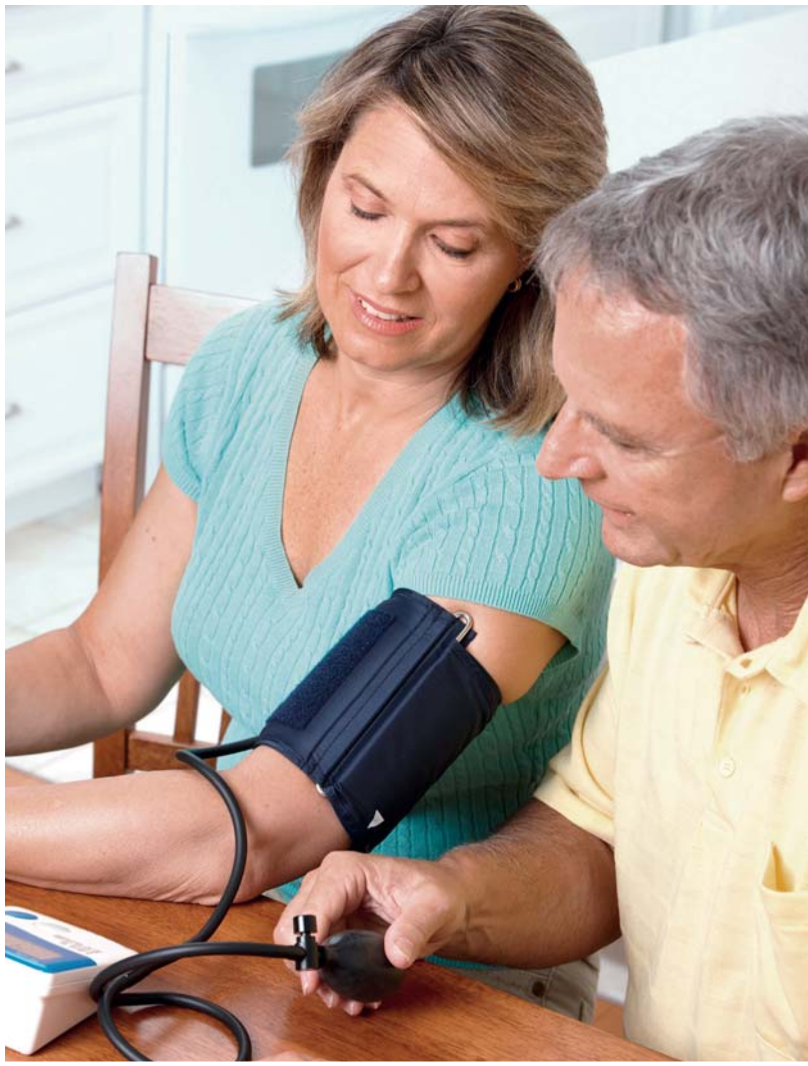
Yours sincerely,
Prof. Achim Bachem
Chairman of the Board of Directors of Forschungszentrum Jülich

Champing at the Qubit

Peter Grünberg Institut/Institute for Advanced Simulations | In conventional computers, the basic unit of information – the bit – switches between the states of “zero” and “one”. This is different in a quantum computer: quantum bits, or qubits for short, can contain multiple states simultaneously and thus exist in superposition. This allows a quantum computer to perform numerous arithmetic operations simultaneously in each switching operation, enabling it to solve equations that would take today’s computers years to calculate, if at all. One idea for implementing qubits was outlined by an international research team including scientists from Jülich in the journal *Nature Nanotechnology*. The scientists produced and controlled a qubit from three “quantum dots” for the first time. They found that these triplet qubits are easier to control than qubits comprising only one or two quantum dots. Jülich researcher David DiVincenzo had predicted this back in 2000. ::

Genetic Cause of High Blood Pressure

Institute of Complex Systems | An international team of researchers including scientists from Jülich has identified a new genetic cause of one of the most important triggers of primary hyperaldosteronism, which is characterized by high blood pressure. According to estimates, some 12 % of all patients with high blood pressure are affected by this condition. Primary hyperaldosteronism is caused by the overproduction of the hormone aldosterone in the outer section of the adrenal cortex. In about a third of cases, benign tumours are responsible for this overproduction. The researchers examined such tumours in patients, and found that mutations of the gene CACNA1D accelerate cell growth and thus the formation of these tumours. This information paves the way for new approaches to treating high blood pressure. ::



Blood pressure measurements are routine. Usually, a cuff is placed around the upper arm and inflated until the blood flow is temporarily stopped. The air is then released from the cuff and the blood pressure is measured as the blood begins to flow again.

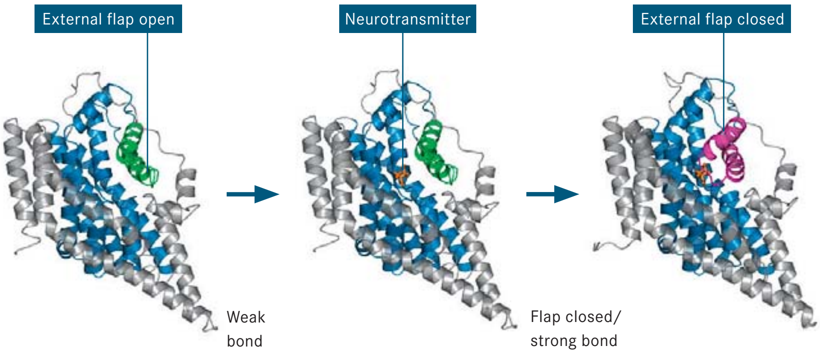
The study took place in Inner Mongolia in China; snow cover and grass height play a role in nitrous oxide emissions.

Cattle Farming Cuts Nitrous Oxide Emissions

Institute of Bio- and Geosciences | The Jülich ecosystem researcher Prof. Nicolas Brüggemann and four members of a German-Chinese research group have been announced as this year's joint winners of the Stifterverband Science Award – the 2013 Erwin Schrödinger Prize. The award is endowed with € 50,000. In a long-term project, the team found that cattle farming in steppe and prairie regions reduces the emission of climate-damaging nitrous oxide. Researchers had previously assumed the opposite. Nicolas Brüggemann was involved in the project while still at Karlsruhe Institute of Technology. ::

Transport of Neurotransmitters Deciphered in the Brain

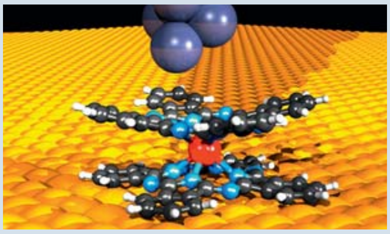
Institute of Complex Systems | Chemical messengers referred to as neurotransmitters ensure that neurons in the brain communicate with each other. An important example is the amino acid glutamate. Using fluorescence spectroscopy, Jülich researchers observed in real time how transport molecules influence glutamate-regulated signal transduction. These transport molecules prevent the neurotransmitter released by a neuron from permanently exciting another cell. They do so by binding the glutamate and only releasing it inside the cell. This mechanism only works if the bond is neither too strong nor too weak. To achieve this, the molecules have a flap that closes with a short delay to form a strong bond after the neurotransmitter has docked on. The mechanism is also of interest for medicine: in the case of a stroke, for example, some of the transporters do not function correctly, causing excessive levels of glutamate. ::



The external flap opens and a weak bond is formed with the neurotransmitter. The flap then closes the binding pocket for the transmitter, which makes the bond particularly strong.

Counting on Neodymium

Peter Grünberg Institute | Magnetic molecules are regarded as promising switching elements for future, energy-efficient information processing. An interdisciplinary team of researchers from Jülich and Aachen has successfully produced a particularly robust version that enables the direct electrical readout of magnetic information. In the journal *Nature Communications*, the scientists report that this was made possible by using the rare earth metal neodymium as the central component of the molecule. ::



Pigment and rare earth: the key component of the promising molecule comprises the rare earth metal neodymium (red) embedded between two molecules of the pigment phthalocyanine. With the tip of a scanning tunnelling microscope (top), the researchers sent electric current through the magnetic sandwich.


VITZRO TECH
VITZRO TECH

Memory Cells for Future Computers

They are the top candidates when it comes to making computers and smartphones more powerful and above all more energy efficient: resistive memory cells. New findings by Jülich researchers could help to establish these nanoelectronic components as data storage units over the next few years. In the more distant future, they may even serve as artificial synapses modelled on biological neurons.

Back in 1999, most people would immediately have thought of their personal computer's hard drive upon hearing the term "data storage". Some of them might have thought of CDs or their computer's working memory, the DRAM. USB flash drives weren't available back then: they were launched on the market a year later – with a capacity of only 8 MB and a price tag of $ 50. For young people today, USB flash drives and other flash memory devices are the quintessence of data storage. And a capacity of several gigabytes is now standard.

We have become accustomed to the fact that more and more information can be stored on increasingly smaller spaces. However, it cannot be taken for granted that this will go on forever: the miniaturization of existing data storage technologies may be approaching its natural limits. Moreover, none of the available data storage technologies is an all-rounder: ideally, they should work at breakneck speed but be energy-efficient at the same time, they should archive data permanently, and, in addition, they should be inexpensive. Information stored on the DRAM module of a computer's working memory, for example, will disappear when the power is turned off. Hard drives and flash devices don't have this problem, but they are comparatively slow.

For these reasons, researchers in science and industry worldwide are working feverishly on a new type of data storage referred to as ReRAM (resistive random access memory). "In principle, ReRAMs should be able to store data on an even smaller space than flash memories, for example, and they should also be able to do so with far less power," says Prof. Rainer Waser, director at the Peter Grünberg Institute, Forschungszentrum Jülich, and researcher and professor at RWTH Aachen University. He and his colleagues cooperate closely with companies such as Intel and Samsung Electronics and are considered pioneers in the area of resistive switching elements.

The researchers' most recent success: they showed that the resistive memory cells on which ReRAMs are based must be treated like tiny batteries. "Not only does this contradict current theory, it also has practical implications," says Dr. Ilia Valov, an electrochemist in Waser's research group and lead author of the relevant publication in the journal *Nature Communications*.

SWITCHABLE RESISTANCE

Looking at the operating principle of resistive memory cells in more detail helps us to understand the significance of these new findings. Resistive memory cells store the two basic elements of all computer languages – "zero" and "one" – in a way that is fundamentally different to hard drives or flash devices. In a hard drive, information is stored on the magnetic layer of a rotating disk, while flash devices store bits in the form of electric charges on a special transistor. A resistive memory cell, in contrast, saves a bit using its electrical resistance which can be switched between high and low values – and it retains its state even when the external voltage is switched off.

Prof. Rainer Waser from the Jülich Aachen Research Alliance (JARA) is an internationally sought-after expert for resistive switching elements.

The resistive memory cells currently being produced and studied in laboratories all over the world have an edge length shorter than 30 nanometres, i.e. 0.00003 mm. "However, at conferences, colleagues are already reporting on even tinier cells with dimensions of only a few nanometres," says Valov.

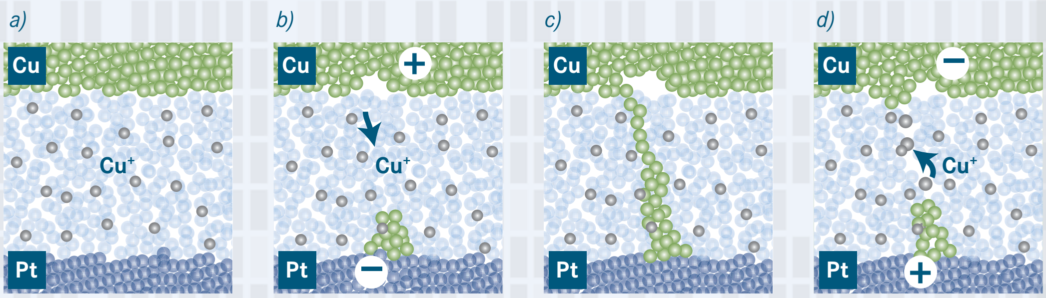
A common configuration of these cells consists of three thin layers of materials with different functions. The material in the middle, the electrolyte, is like the filling between two slices of bread in a sandwich. One of these "slices" is an active electrode made of metal, for example copper, and the other is a counter electrode made from a chemically inert material such as platinum (see graphic).

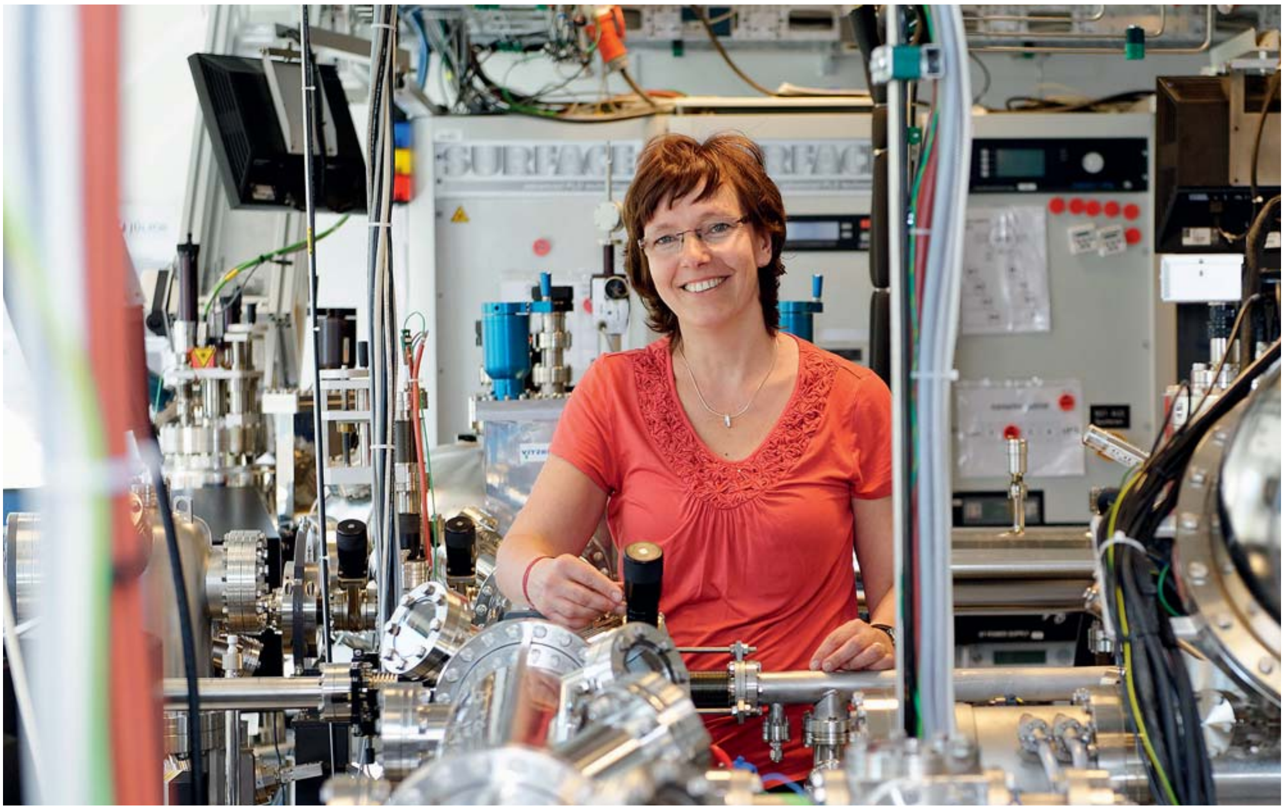
When a voltage is applied, positively charged copper ions are released from the active electrode and migrate to the counter electrode, where they gain electrons and form elementary copper atoms once again. The atoms form a narrow pathway through the electrolyte – experts refer to this as a filament. Once the filament has formed and an electrically conductive contact has been established between the two electrodes, the resistance of the entire cell is low and it is in the ON state. This corresponds to the "one" in computer language. The cell remains in this state until an appropriately high voltage of reverse polarity is applied. This causes the filament to dissolve and the cell resistance increases to a high value. The cell is now in the OFF or "zero" state.

"The ions are primarily responsible for forming and dissolving the filament, the switching processes, and therefore the information storage," says Valov. This gives the technology a significant advantage over flash memory devices

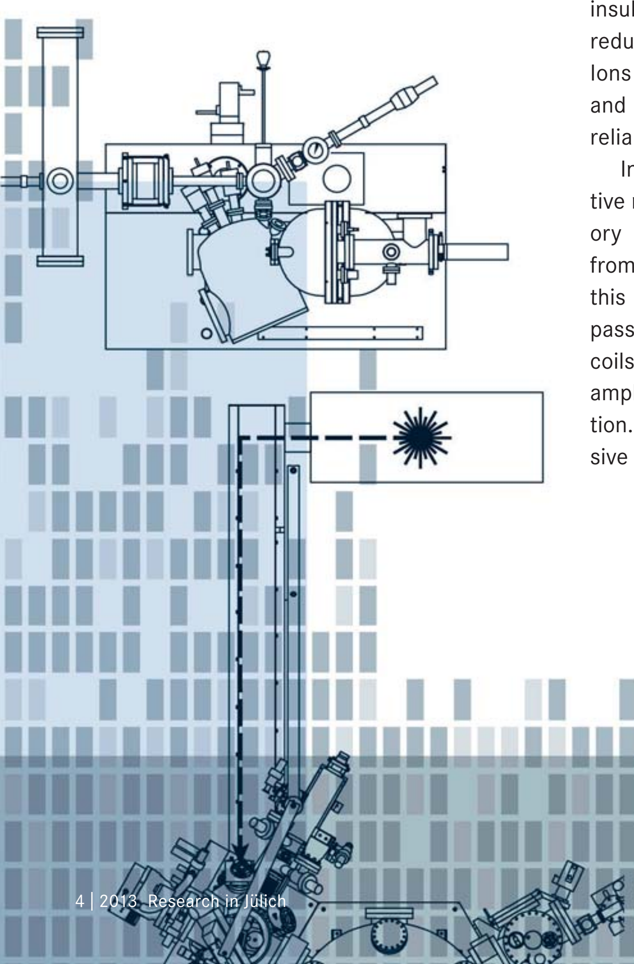
How resistive memory cells work

In the OFF state (a), a resistive memory cell has a high electrical resistance. When a voltage (b) is applied, positively charged ions (grey) are released by the copper electrode and migrate to the platinum electrode, where they gain electrons and form atoms again (green). An electrically conductive filament (c) is created between the two electrodes. The cell therefore has a low resistance (ON state). When a sufficiently strong voltage with reverse polarity is applied (d), the filament dissolves.





Prof. Regina Dittmann coordinated the construction of the Oxide Cluster – a laboratory that cost € 3.7 million in which layers of materials and resistive memory cells are produced and examined in an ultrahigh vacuum.



which store electrons. "Electrons are highly mobile and small, which means that they can easily find a way to break free, causing the information to be lost," says Valov. This can be prevented using insulation layers, for example, but these reduce both storage density and speed. Ions are easier to manage in comparison and they are generally more suitable for reliable information storage.

In the past, scientists described resistive memory cells using "memristor" theory (memristor is a portmanteau word from memory and resistor). According to this theory, resistive memory cells are passive components just like capacitors, coils, and resistors, all of which neither amplify a signal nor have a control function. An important characteristic of passive components is that no current flows through them unless a voltage is applied. Conversely, no voltage can be measured without current flowing.

The team of researchers headed by Valov theoretically deduced that this is intrinsically different in resistive cells. The cells produce a voltage like a tiny battery. The researchers even underpinned their theory with the results of measurements on different versions of such cells. To do this, they fabricated and characterized numerous cells similar to those being examined by groups all over the world in a complex procedure.

The scientists immediately realized that their discovery of a battery voltage in ReRAMs could be used to optimize the reading out of information from these cells. Experts previously assumed that electric current is needed to determine whether resistive cells are in the ON or OFF state. However, this current could potentially alter the state of sensitive cells. The battery voltage, in contrast, can be measured without current in a nondestructive process. The researchers have already filed patent applications for the relevant methods. "Furthermore, the existence of a battery voltage must also be taken into consideration when connecting resistive memory cells or developing reliable ReRAMs," says Valov.

Other scientists working with Rainer Waser in the Jülich Aachen Research Alliance are already building larger units from resistive memory cells and using computers to simulate the integration of ReRAMs into existing semiconductor technology. Over the last few weeks, Panasonic has even begun integrating ReRAMs into their microcontrollers. Despite this, Valov's colleague Prof. Regina Dittmann is also convinced that further basic research into resistive memory cells is necessary to improve characteristics such as the durability and switching speed of ReRAMs. "Industry is continuously confronted with challenges in this respect that can only be overcome by improving our understanding of the basic principles," says Dittmann.

Dr. Ilia Valov and his colleagues discovered that resistive memory cells produce a voltage – like a tiny battery.

Dr. Susanne Hoffmann-Eifert points out parallels between biological synapses in the brain and resistive components.

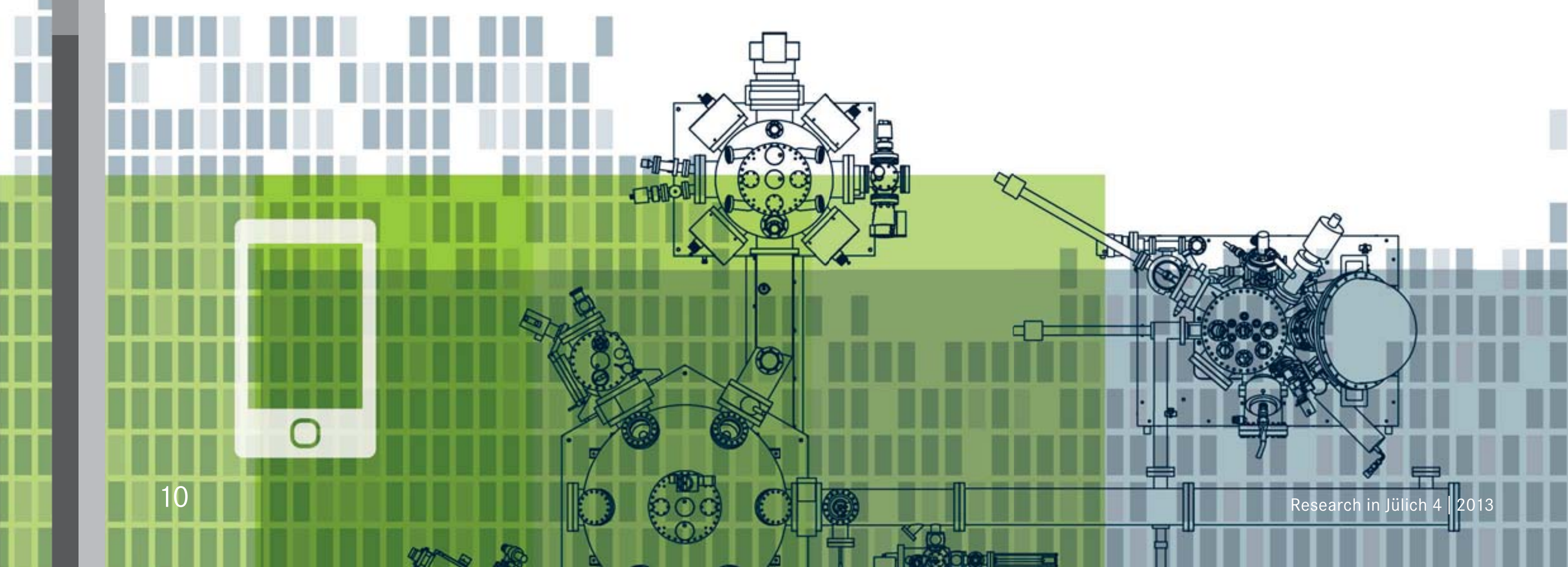
NO AIR CONTACT

The scientists now have access to a new laboratory at Jülich's Peter Grünberg Institute – the Oxide Cluster – for their fundamental experiments. "The facility allows us to produce layers of materials and resistive memory cells and to use the latest methods in microscopy and spectroscopy, for example to observe the atoms and electrons during switching processes and therefore "at work" without the materials leaving the ultrahigh vacuum," says Dittmann. This is important because contact with air would influence the processes that occur at the surface of these materials.

In principle, resistive memory cells do not just switch between two resistance values but rather between several. In other words, they can also assume intermediate states between "zero" and "one". This provides a good basis for creating computer systems capable of learning using synapses as a model (the interfaces between cells in the biological nervous system).

"There are also a number of parallels between how biological synapses and resistive components function," says Dr. Susanne Hoffmann-Eifert from Waser's research group. For example, the functioning of both synapses and resistive cells is based on the movement of ions. Another similarity is that a connection between human neurons becomes stronger and more efficient the more frequently and intensively it is used. "The more current that is transmitted through the conductive filaments in resistive memory cells, the stronger they become," says Hoffmann-Eifert. One day, this effect could help us to create computers capable of deviating from their programs independently if a connection is unexpectedly intensively used. ::

Dr. Frank Frick



The IT of Tomorrow

Overview of activities at Jülich

From an MP3 player not much bigger than a postage stamp to Jülich's supercomputers with their enormous mathematical prowess – today's information technology is based on the selective displacement of electrons or controlling these carriers of electric charge in another way. In the past, the semiconductor industry very successfully sent electrons through tinier and tinier components. But Gordon Moore's law from 1965, which states that the number of transistors on a microchip doubles every two years or so at no additional cost, will soon no longer apply. Jülich scientists are working to ensure that miniaturization will nevertheless continue. And most importantly, they are developing energy-efficient components. Today, information technology accounts for around 12 % of the electricity consumed in Germany – and this figure is on the rise.

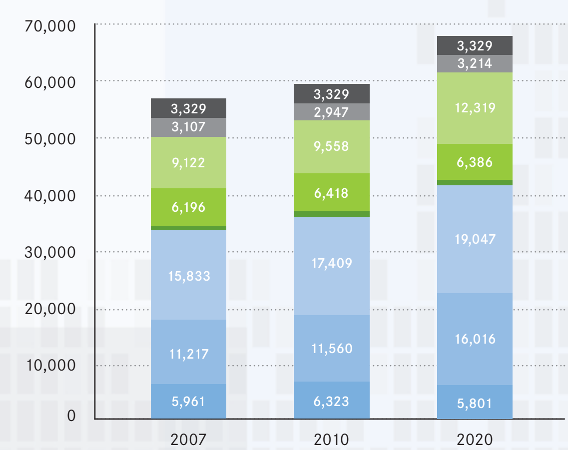
Other scientists at Jülich aim to exploit an additional property of electrons instead of their charge. Electrons rotate around their own axis, and therefore have an angular momentum, which is referred to as their spin. This field is known as spintronics and it could succeed semiconductor technology if one day semiconductor components cannot be made any smaller. It promises to process information in a particularly fast and energy-efficient manner.

NEW COMPONENTS FOR COMPUTERS

However, information is also contained in the arrangement or configuration of atoms, ions, and molecules. In addition to Prof. Rainer Waser's team (see main article), other research groups at Jülich are also exploring the fundamental chemical and physical processes that are triggered by changes in the configuration of certain material systems. The scientists aim to regulate changes in the configuration on the smallest scale possible and develop new components for computers on this basis.

Last but not least, scientists at Jülich are pursuing another line of research: quantum computing projects. In contrast to conventional processors, quantum computers can basically perform multiple operations simultaneously in one switching process. Conventional computers work with bits as the smallest information units, which can only have the values of "zero" or "one". Quantum computers, in contrast, operate with quantum bits, or qubits for short, which consist of several states in superposition. ::

Dr. Frank Frick



Growing appetite for energy

Development of electricity consumed by information and communications technology in Germany (gigawatt hours per year)

Core networks
Mobile communications
Computing centres
Businesses PC+
Businesses rest
Households TV+
Households PC+
Households rest

"+" incl. peripherals

Source: FhG-IZM and FHG-ISI

Fine Structures Improve Climate Models

Researchers from Jülich and Karlsruhe discovered that thin, elongated filaments of extremely dry air from the stratosphere extend right down into the troposphere. Current climate models do not take such phenomena into account.

The devil is in the detail. State-of-the-art climate research is no exception. When the International Panel on Climate Change (IPCC) presented its Fifth Assessment Report in late September 2013, it was met with criticism. In the report, the IPCC warns of rising sea levels, extreme weather conditions, and the shifting of entire climate zones on planet Earth. However, it does not explain why over the last 15 years the average temperature of the Earth's surface has not risen quite as much as predicted by models. It would appear that current climate models do not consider all of the details of climate processes. Dr. Jörn Ungermann from the Institute of Energy and Climate Research (IEK) at Forschungszentrum Jülich confirms this: "Climate change itself is beyond question. However, existing models have certain deficiencies. More precise data on the exchange processes between the troposphere and the overlying stratosphere, for example, are still not available."

Relief in the control centre: GLORIA works reliably even during the 3D flight. From left to right: Dr. Guido Maucher (KIT), Tobias Guggenmoser (FZJ), Hermann Oelhaf (KIT, standing), Thomas Gulde (KIT), Axel Schönfeld (FZJ, background), Felix Friedl-Vallon (KIT), and Dr. Peter Preusse (FZJ: Forschungszentrum Jülich, KIT: Karlsruhe Institute of Technology)

GLORIA PROVIDES INSIGHTS

Yet it is precisely in this layer between the dry, cold stratosphere and the warm, humid troposphere below it where the fate of our climate is decided. On the one hand, greenhouse gases such as CO_2, methane, and water vapour contribute to rising temperatures on Earth. On the other hand, atmospheric aerosols function like a parasol and have a cooling effect. But what happens when polluted, humid air from the troposphere enters the dry stratosphere? What chemical processes occur then and how strong is the interaction? Researchers and technicians from Jülich and Karlsruhe have designed a unique instrument to improve our understanding of the dynamics and chemical processes in this region: GLORIA.

GLORIA is a novel infrared camera that breaks down the thermal radiation of gases and aerosols into spectral colours. This allows air flows to be mapped in more detail than before. "Vertically, we can achieve an excellent resolution of about 200 metres," says Dr. Peter Preusse from IEK. "At the moment, GLORIA is the only instrument capable of this," he adds. During the summer and autumn of 2012, the instrument travelled some 88,000 kilometres on board the German research aircraft HALO and collected almost 30 terabytes of data.

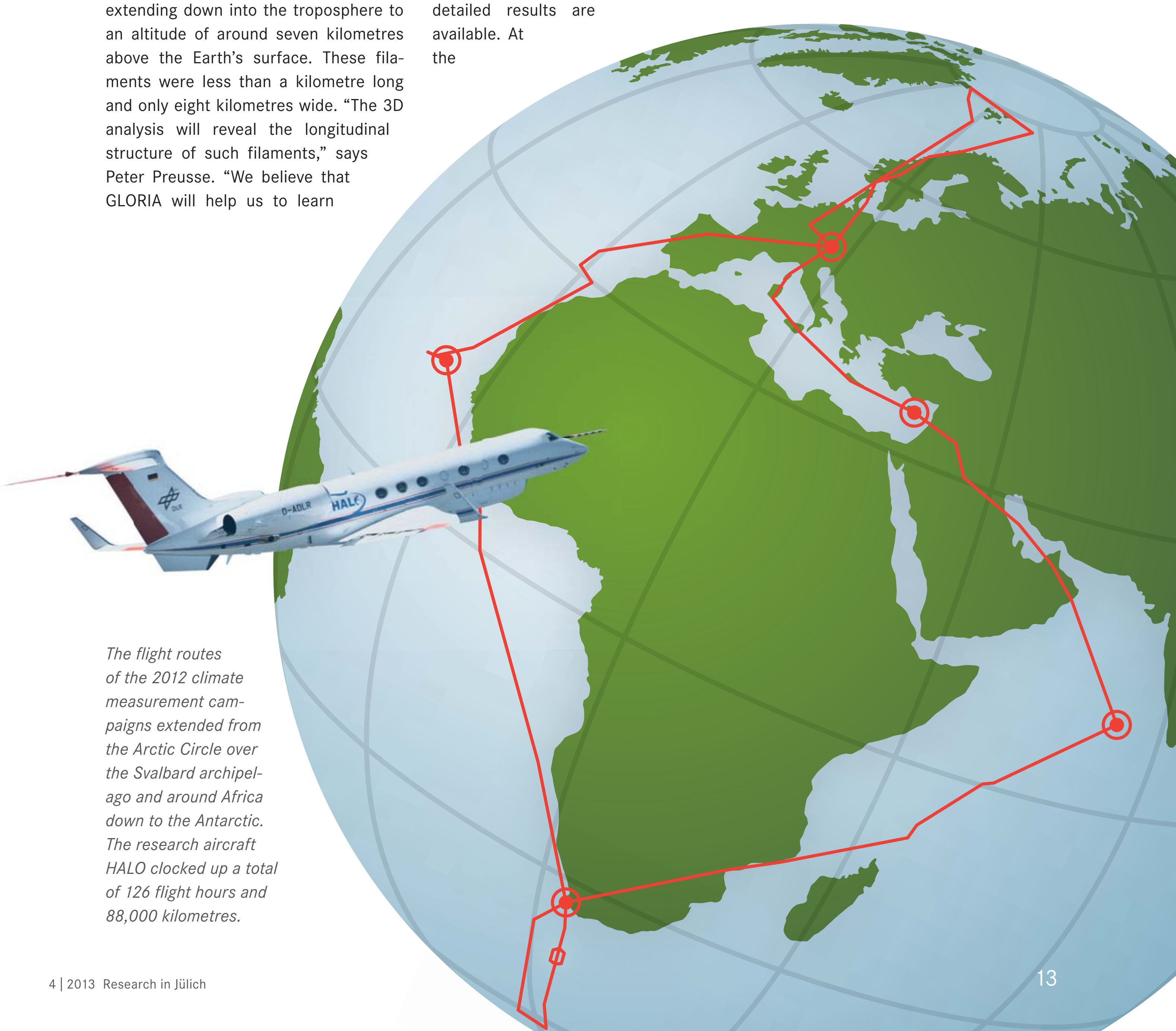
The Jülich researchers are particularly proud of their 3D data. "Thanks to outstanding flight planning and chemical weather forecasting, we were able to fly around two interesting air parcels in large hexagons. One of the air parcels was located off the Norwegian coast; the other at the edge of the high-altitude Antarctic wind that continuously circles the pole," says Preusse. In this region, the researcher tells us, there are areas with enormously different wind speeds. This causes tropospheric and stratospheric air to mix. "GLORIA then works a bit like a tomograph, producing 3D images of the air masses around which it flies," he adds.

A TREASURE TROVE OF DATA

The researchers are now analysing this treasure trove of data in meticulous detective work. Nitric acid and water vapour are to atmospheric researchers what fibres and DNA traces are to a criminologist. They serve as markers, allowing stratospheric and tropospheric air masses to be distinguished from each other. Nitric acid (HNO_3) is a natural trace gas formed in the stratosphere, where it is relatively stable. In the troposphere, in contrast, the acid is extremely rare – water vapour abounds here instead. It follows that extremely dry air masses with a high content of nitric acid originate in the stratosphere. Using GLORIA, the researchers identified many very fine filaments of stratospheric air extending down into the troposphere to an altitude of around seven kilometres above the Earth's surface. These filaments were less than a kilometre long and only eight kilometres wide. "The 3D analysis will reveal the longitudinal structure of such filaments," says Peter Preusse. "We believe that GLORIA will help us to learn more about the mass transport between the troposphere and the stratosphere and to define it more accurately," he adds.

In their analysis, the Jülich researchers are concentrating on how air masses move and mix. Their colleagues at Karlsruhe are analysing the chemical conditions in the boundary layer between the troposphere and the stratosphere. "For example, hydrogen cyanide, hydrocarbons, sulfur dioxide, and the trace gas peroxyacetyl nitrate – more widely known as PAN – are all on our list," says Dr. Michael Höpfner from the Institute for Meteorology and Climate Research at the Karlsruhe Institute of Technology. However, the researcher predicts that it will take another few months before detailed results are available. At the same time, the researchers are already planning GLORIA's next mission: in late 2015 and early 2016, travel to the polar regions on board HALO is on the agenda. Before this, however, things will become turbulent: in summer 2015, GLORIA will fly to the tropics on board the Geophysica, a Russian aircraft for stratospheric research – with a course set for the Indian Monsoon. ::

Brigitte Stahl-Busse



The flight routes of the 2012 climate measurement campaigns extended from the Arctic Circle over the Svalbard archipelago and around Africa down to the Antarctic. The research aircraft HALO clocked up a total of 126 flight hours and 88,000 kilometres.

Flying with Algae

It took millions of years for oil to form from algae and other plants and marine organisms. Microalgae in bioreactors are now set to speed up this process and produce the basis for fuel – and thus provide a sustainable way of powering aircraft. How this can be optimized technologically and economically is the key priority in the collaborative project AUFWIND coordinated by Jülich.

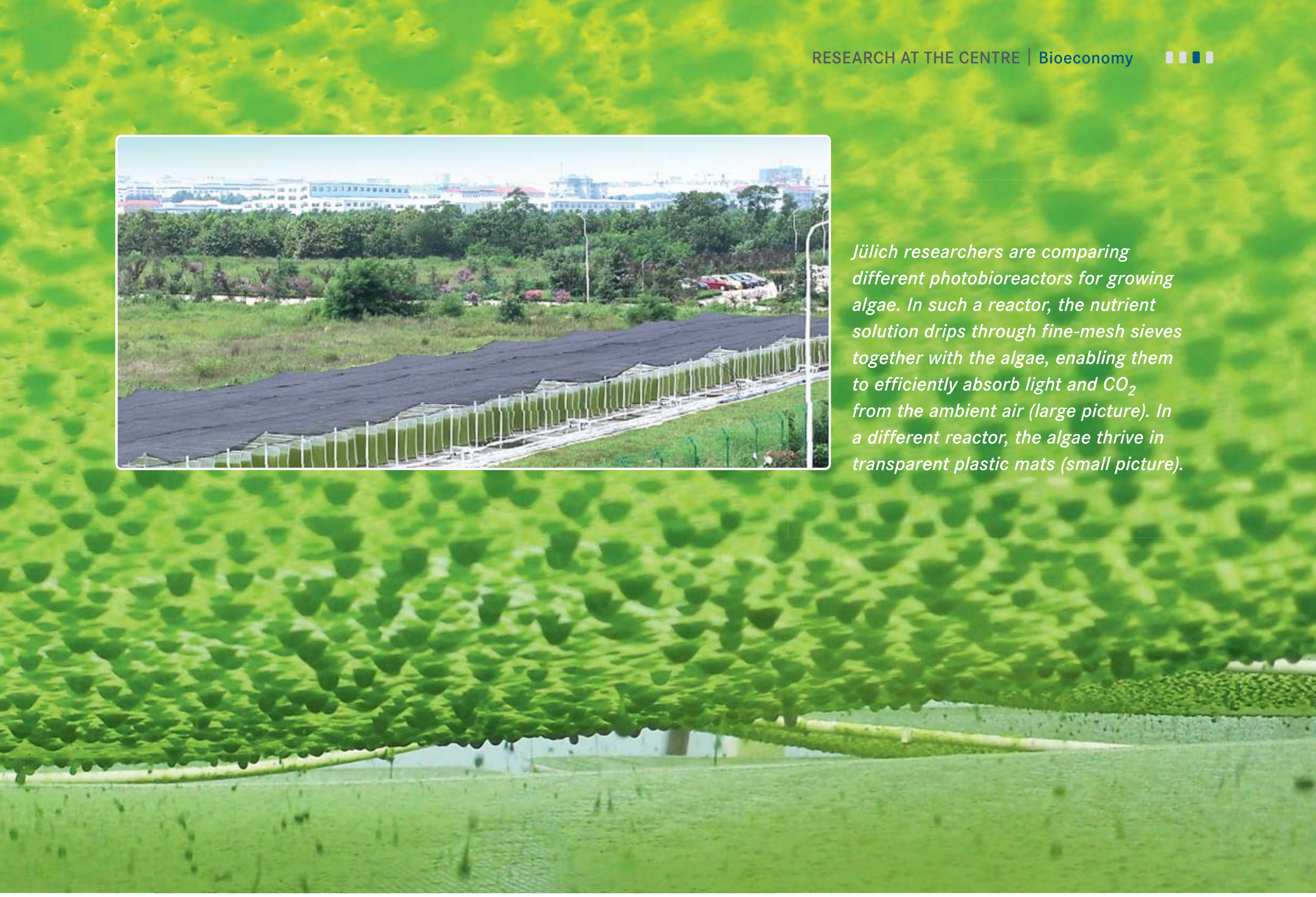
There is considerable ambivalence about fuels from biomass. Some people consider them an effective solution to energy and climate problems because biomass is essentially stored solar energy. During photosynthesis, plants produce organic material from sunlight and carbon dioxide. When fuels obtained from these plants are combusted, the amount of carbon dioxide released is equal to the amount consumed by the plants during the growth process. For the climate, it's theoretically a zero-sum game. In practice, however, the energy required for fertilizing, transporting, and processing the plants must also be taken into account.

Critics argue that when plants are cultivated for energy, the fields in which they grow can no longer be used for food crops. "Food versus fuel" is the resulting dilemma. Considering that 840 million people suffer from hunger and that the world's population continues to grow, the cultivation of maize for bioethanol production and rapeseed for biodiesel is

Dr. Andreas Müller is investigating the best conditions for microalgae growth – and not just on a laboratory scale.

attracting increased criticism. In the AUFWIND project, Jülich scientists and eleven partners from research and industry are exploring one option that may provide a way out of this dilemma: biomass from microalgae. Tiny algae containing up to 70 % fatty oils can be used to produce the aviation fuel kerosene. The objective is to make a sustainable source of energy available for aviation. The German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) has granted the project, which has a total volume of € 7.4 million, funding of € 5.75 million over a period of two and a half years.

"We want to produce biomass for fuel in a sustainable manner without using agricultural land," says Dr. Andreas Müller from Jülich's Institute of Bio- and Geosciences. The algae grow in transparent tubes or pipes, referred to as photobioreactors, which can be set up almost anywhere – on industrial wasteland or on other unused areas. Large quantities of algae can thus be grown in a comparatively small space. The tiny organisms multiply rapidly – their productivity is seven to ten times greater than that of land plants. In addition, the water containers in which they live can be mounted on top of each other, which keeps space requirements to a minimum compared to the cultivation of arable plants.



Jülich researchers are comparing different photobioreactors for growing algae. In such a reactor, the nutrient solution drips through fine-mesh sieves together with the algae, enabling them to efficiently absorb light and CO_2 from the ambient air (large picture). In a different reactor, the algae thrive in transparent plastic mats (small picture).

For the moment, however, the containers for algae are being set up on the premises of Forschungszentrum Jülich. Three different types are being installed. “Our task is to find out which bioreactors provide the best results,” says Andreas Müller. For this, the Jülich scientists are comparing photobioreactors from three commercial suppliers, each on 500 m^2. “There are already numerous publications from interested parties that describe the production of fuels from microalgae, but to date, there has been no independent comparison of different facilities from an ecological and economic point of view,” says Müller. “As a research centre, Forschungszentrum Jülich is predestined to assume the role of adjudicator because we are open to the system that ultimately emerges as the winner.”

This is not the only reason why Jülich is the ideal location for this kind of test. Here, there is sufficient space, the necessary infrastructure, and experience with the in-house cultivation of algae. In an earlier project, Jülich researchers and the electric utilities company RWE investigated how CO_2 emissions from a power plant can be used to cultivate algae.

KEROSENE AND MUCH MORE

Industry partners in the AUFWIND project include aeronautic company EADS and the international oil and gas company OMV. Andreas Müller explains why kerosene in particular is to be produced from algae: “In the aviation industry, there is no alternative to liquid fuels on the horizon. For cars, different drives are already being tested – for example, electric motors or fuel cells. However, weight and safety considerations rule these out for use in aircraft.” Furthermore, in international aviation, solutions that can utilize existing infrastructure are essential. If tankers at the airport were to pump kerosene produced from algae oil instead of from crude oil into planes, no huge modifications would be necessary.

However, we’re not quite at this stage yet. Although test flights with algae oil in the tank have proved successful, biokerosene from the bioreactor is still too expensive. But the green fuel could become competitive if crude oil prices continue to rise, or if it proves possible to obtain other attractive products apart from kerosene from algae. After all, the little green cells have lots to offer: they are packed with vitamins, pigments, amino acids, and sugar. “The extraction of food additives and high-quality products for the cosmetics and chemicals industries would be conceivable,” says Müller. The leftovers could then be used as animal feed or could be combusted in power plants. All in all, an environmentally friendly and versatile alternative to crude oil. ::

Dr. Wiebke Rögener

Making the Dream Catalyst a Reality

Without platinum, they don't work, but with it, they're too expensive: the noble metal is the catalyst and core component of fuel cells. Researchers from Berlin and Jülich are currently working on a variant that is just as efficient but requires less platinum. Electron microscopes with ultrahigh resolution are aiding their efforts.

Individual atoms light up as white spots on a grey background on the monitor in front of Jülich researcher Dr. Marc Heggen. They are platinum and nickel atoms, arranged in triangles that form an octahedron measuring almost 10 nanometres. Seen from above, it looks like the Great Pyramid of Giza.

Marc Heggen is sitting in front of one of the world's best ultrahigh-resolution electron microscopes at Jülich's Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons. On his monitor, he is looking at one of the most powerful catalysts ever developed for fuel cells.

For years, scientists have been competing with each other to produce the most effective catalyst for fuel cells. The reasons are simple. Fuel cells produce electrical energy from the energy carrier hydrogen when it reacts with oxygen. In this process, the only waste produced is water. In electric cars, for example, fuel cells could replace the battery. The advantages: fuel cells are lighter than batteries. They would also allow electric cars to be fuelled with hydrogen, which is easier and faster than recharging a battery.

However, the crux is that fuel cells require the expensive platinum as a catalyst. "It is the platinum in the electrodes that triggers the reaction between hydrogen and oxygen," says Heggen. Without platinum, the fuel cell wouldn't work, but when it's used, the fuel cell is too expensive to be competitive.

DECISIVE GEOMETRY

For some time now, scientists have therefore been working on developing catalysts that deliver the same perfor-

More expensive than gold: the high price of platinum prevents fuel cells from being used on a commercial scale.

mance with less platinum. One option is to mix platinum with baser metals such as nickel. Since catalysis takes place at the surface where the atoms dock on to the material, nanoparticles that are as small as possible are particularly useful, because they have a larger surface area at identical mass. Although they reduce the amount of platinum required, the small particles tend to clump together when used in fuel cells, which decreases the lifetime of the catalysts.

In 2007, the chemical physicist Stamenkovic had another exciting idea. He showed that an alloy of platinum and nickel with the crystallographic surface of an octahedron is theoretically 90 times more effective than conventional catalysts. Heggen explains: "Platinum-nickel octahedra measuring a few nanometres that remain stable during the reaction are the ultimate dream catalyst for fuel cells." The nanogeometry of the surface is decisive for increasing the performance of the catalyst.

Ever since the Serbian researcher described this ideal catalyst, scientists all over the world have been attempting to actually produce it. Heggen and his project partners at TU Berlin are also contenders in this race. The chemists in Berlin synthesize platinum-nickel nanoparticles and Heggen examines them with electron microscopes. He then provides "microfeedback", which helps his colleagues in Berlin to refine the nanoparticle catalysts.

A look at minute details: with the help of an electron microscope, Marc Heggen examines the atomic structure of potential dream catalysts for fuel cells.

A few months ago, the team achieved a breakthrough: "We produced a catalyst that is ten times more efficient than comparable platinum nanoparticles, and therefore one of the most powerful catalysts ever developed," says Heggen. However, a number of questions have yet to be answered: Do the particles have the correct octahedral shape? How exactly are the atoms arranged? And what happens to them when the catalyst is in operation?

SURPRISING PATTERN DISCOVERED

Answering such questions is an important step towards further optimizing the catalyst. Heggen therefore examines the nanoparticles at the Ernst Ruska-Centre using microscopes with an internationally unrivalled accuracy. By means of scanning electron microscopy and electron energy loss spectroscopy, he has taken extremely accurate "snapshots". They show each and every atom in the octahedron.

"We discovered a surprising pattern," says Heggen. "The atoms aren't as evenly distributed as we had assumed. Plenty of platinum accumulated at the edges of the octahedron, while nickel was distributed on the faces." This impairs both the activity and lifetime of the catalyst. "During operation, the nickel atoms dissolve, causing the initial formation of concave surfaces, until eventually, a platinum frame is all that's left. The faces of the octahedron are valuable for the reaction and when they disappear, the activity of the catalyst declines," says Heggen. "We now know how we can improve the catalyst further, and we already have a few ideas to prevent nickel from accumulating on the faces of the octahedron."

The physicist will soon receive new, optimized nanoparticles, which he will examine with an electron microscope. It is quite possible that one of them will turn out to be the dream catalyst that will help to power electric cars in the future. ::

Christoph Mann

Dr. Sebastian Bludau (left) and Hartmut Mohlberg worked on the virtual BigBrain model for several years.

Digital Jigsaw Puzzle

A team of Jülich researchers headed by Prof. Katrin Amunts caused a sensation with their internationally unique “BigBrain” model a few months ago. The virtual 3D model, which they developed together with Canadian colleagues, can zoom right in on the neurons in the human brain. But how is such a brain model created? Surprisingly, the process involves not only high tech, but also several manual steps and ideas on how to implement them.

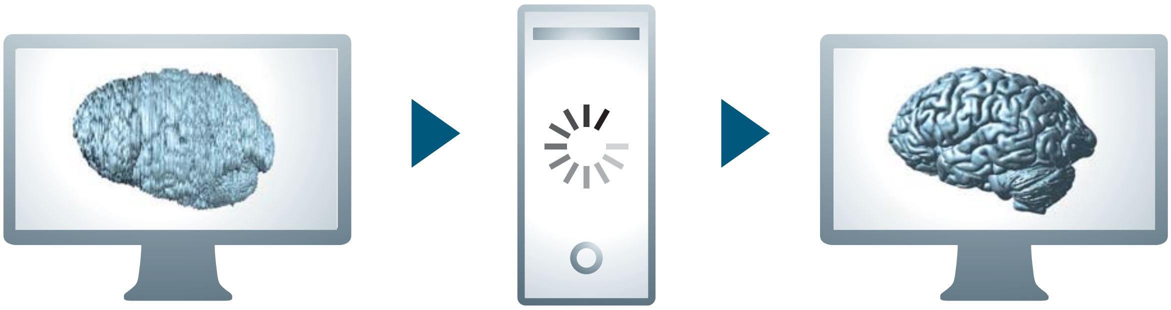
A repurposed hatband has been serving Ferdag Kocaer well for many years. The medical laboratory assistant specializes in producing brain slices at the Institute of Neuroscience and Medicine (INM-1). She works with the brains of deceased individuals that have been donated for research. These provide the basis of virtual brain models like BigBrain. After a multistage preparation procedure, Ferdag Kocaer cuts brains into more than 7,400 ultra-thin slices for further scientific use with a “microtome”.

It is important that each of the slices is cut very evenly and that they form a ribbon. Years ago, however, none of the commercial medical instrument manufacturers offered a microtome with an integrated conveyor belt. This required some creativity. A colleague from the C. and O. Vogt Institute of Brain Research in Düsseldorf had the brilliant idea of sewing a “conveyor belt” out of elastic hatband.

Cutting the brain into slices no thicker than 20 micrometres – much thinner than the diameter of a human hair – takes several days and requires dexterity, patience, stamina, and, above all, concentration. Problems are therefore inevitable: “The wafer-thin slices tend to roll up or tear, especially at the periph-

From real brain slices to the virtual BigBrain model

The ultrathin brain slices were scanned individually and the digital images roughly pieced together on computers (left screen). Researchers then postedited the digital images of damaged brain slices using supercomputers and special image processing software. They then combined all of the slices to form the virtual brain model known as BigBrain (right screen).



ery," says Ferdag Kocaer. With a fine brush, she flattens out the slices on her conveyor belt and tries to put any tissue that has become detached back into its original position. "On some days, I also quite literally have to take a deep breath," says the 37-year-old, laughing. She exhales on "difficult" tissue before cutting it to moisten it and thus prevent tearing.

As in all brain models, each of the 7,400 slices for BigBrain was then placed on a glass slide and stained. "The cell bodies are stained a dark-grey colour using a special technique. This makes them easy to discern in the next step," says Ferdag Kocaer. A flatbed scanner is used to produce digital images of the tissue slices with a resolution of 1,200 dpi that are then saved on Jülich's computers – this is the first step from real to virtual tissue.

ON-SCREEN REPAIRS

The scanned image on the computer corresponds to the real tissue – with all of the tears, detached tissue, and distortions that occurred during cutting. The BigBrain team in Jülich and Montreal then set about repairing these flaws on the computer in a very time-consuming process. "In order to be able to use the data, we took several mobile hard drives containing all of the data on the brain slices and flew across the Atlantic Ocean," grins Hartmut Mohlberg. Today, this is almost unimaginable. "All of our attempts to send the information to our colleagues via the Internet failed. The volume of data was simply too big, and discussing the details of projects face to face is incredibly important," says the physicist.

Hartmut Mohlberg estimates that about 30 % of the 7,400 brain slices had to be postedited in sessions lasting several hours. "In order to correct the most blatant errors, for example to reattach islands of tissue that had been completely torn off, we used a specialized image processing program," he says. Less severe tissue problems, such as fine tears, were detected by special software in a subsequent step and reconciled with neighbouring sections in a mathematical procedure. In total, repairing the digital images of the brain slices for BigBrain took around 260,000 computer hours.

Ferdag Kocaer cut the donated postmortem brain into more then 7,400 ultrathin slices.

The scientists working with Alan C. Evans at the McConnell Brain Imaging Center in Montreal are important cooperation partners for the researchers from Jülich. The Canadians developed a software to precisely "register" all 7,400 BigBrain slices after they had been repaired, allowing them to be correctly aligned with each other. Hartmut Mohlberg puts it in a nutshell: "Our Canadian colleagues are gifted at solving 3D jigsaw puzzles."

BIGBRAIN AS A TOOL

The brain model can be accessed free of charge by scientists around the globe. The data are stored on supercomputers and can be accessed at *http://bigbrain.cbrain.mcgill.ca*. Like many other brain researchers, Jülich neuroscientist Dr. Sebastian Bludau gets excited talking about BigBrain: "It's the first complete and realistic 3D brain model in the world, and it allows us to zoom in to dimensions of 20 micrometres. This makes it possible to discern not only the boundaries between distinctive areas, such as the visual cortex or the primary motor cortex, but also more complex brain areas with less marked microstructural differences." One example is Brodmann area 10 (BA10), which Sebastian Bludau localized precisely in the frontal pole. It is involved in processes such as planning future actions. ::

Ilse Trautwein

Technology with a Future?

For the first time, scientists have taken a close look at all of the different aspects related to the capture and storage of the greenhouse gas CO_2. Their conclusion is that the technology will have a hard time in Germany.

Carbon capture and storage (CCS) technology is designed to capture the climate-damaging carbon dioxide (CO_2) in the flue gases of coal power plants and store it underground. However, "CCS has a negative image and is not considered a recipe for success in Germany," says Dr. Wilhelm Kuckshinrichs from Forschungszentrum Jülich. He is the editor and one of the authors of a study that comprehensively evaluates CCS technology and its prospects.

Researchers reviewed publications that appeared over the last few years on CCS and interviewed experts as well as representative samples of the population. Engineers, economists, sociologists, and political scientists from Jülich, RWTH Aachen University, and Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences were all involved in the study.

Dr. Wilhelm Kuckshinrichs is the editor and one of the authors of a study on the public acceptance of CO_2 storage.

CO_2 STORAGE UNDESIRABLE

The result: in addition to social acceptance, the cost effectiveness and profitability of the technology are also factors of dispute. Yet these are the very factors that scientists consider most important for the technology to succeed.

"It is primarily underground storage that doesn't go down well with the general public, and politicians are reacting to this attitude," says Kuckshinrichs. He mentions the state of Schleswig-Holstein as an example: there had been plans to build a storage facility for carbon dioxide there by 2015. But when citizens protested vehemently, the state parliament abandoned the project. Many people consider underground carbon dioxide storage to be a risk beyond our control. They fear that gas may escape and lead to suffocation. Scientists see this differently: "The potential risk is relatively low," says Kuckshinrichs, "provided that all of the technical and geological requirements have been met and safety precautions taken." He adds that although risks can never be completely ruled out, "this also applies to many other technologies in use today".

That CCS didn't score high on profitability is simply due to the fact that capturing carbon dioxide is expensive. According to the study, the investment costs are up to 70% higher for power plants with carbon capture than for conventional power plants. Above all, the efficiency of power plants with carbon capture is lower, i.e. less electricity is generated from a certain amount of coal. Separation in particular, but also the transportation and storage of carbon dioxide consume energy – and this is taken from the electricity generated by the power plant. For example, separation decreases the efficiency of a power plant from 42% to 34%.

The higher costs would have to be offset by a power plant by means of emissions trading. At the moment, one tonne of carbon dioxide saved is worth about € 3. The researchers have established that in order for the introduction of CCS to pay off, the price of CO_2 would have to be about € 40-50 per tonne.

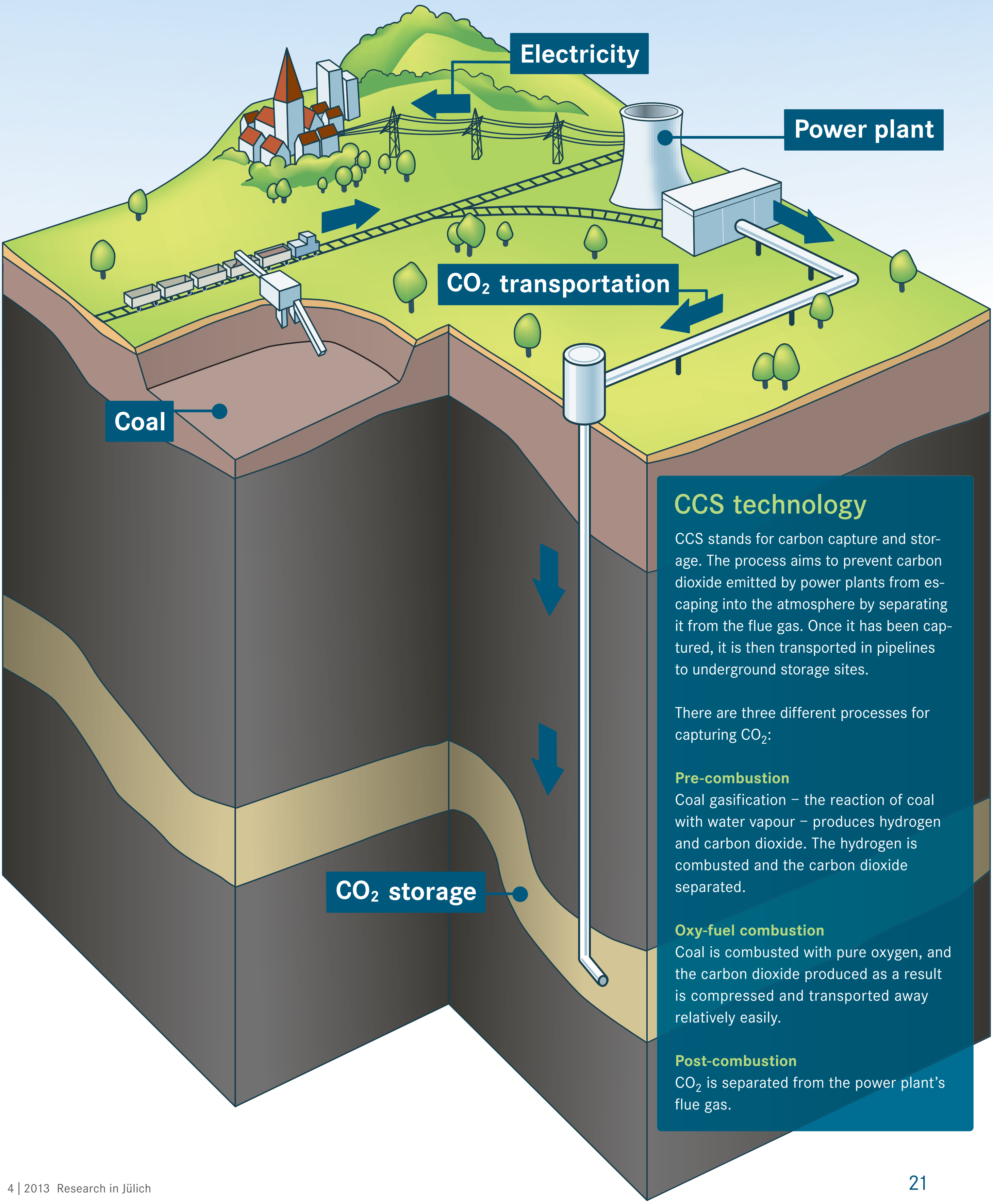
Kuckshinrichs is optimistic that technical developments will help to reduce efficiency losses in future. Membranes that Forschungszentrum Jülich is working on are one example. They will separate the greenhouse gas in an efficient and energy-saving manner. However, CCS will always reduce the efficiency of a power plant.

NO GENERAL REJECTION

Despite the difficulties, the scientists believe that CCS has a future – but not necessarily in Germany. Germany ratified a CCS bill in 2012, which allows up to four million tonnes of CO_2 to be stored underground every year. The law therefore facilitates further research into the technology. "However, we must not expect large-scale investment on this basis, particularly not in large demonstration plants," says Kuckshinrichs. The amount that may be stored is much too small for this. Yet demonstration plants are a prerequisite for developing the technology to market maturity.

Other countries, in contrast, could soon come to rely on the technology. "The global demand for coal power plants is growing steadily, particularly in countries such as China and India. Their expansion strategies can only meet the targets for reducing CO_2 if CCS is introduced," says Kuckshinrichs. And he adds: "If we cut back CCS activities in Germany, this doesn't necessarily mean that the rest of the world will follow suit." ::

Brigitte Osterath



CCS technology

CCS stands for carbon capture and storage. The process aims to prevent carbon dioxide emitted by power plants from escaping into the atmosphere by separating it from the flue gas. Once it has been captured, it is then transported in pipelines to underground storage sites.

There are three different processes for capturing CO_2:

Pre-combustion
Coal gasification – the reaction of coal with water vapour – produces hydrogen and carbon dioxide. The hydrogen is combusted and the carbon dioxide separated.

Oxy-fuel combustion
Coal is combusted with pure oxygen, and the carbon dioxide produced as a result is compressed and transported away relatively easily.

Post-combustion
CO_2 is separated from the power plant's flue gas.

20,000

visitors came to Forschungszentrum Jülich in glorious sunshine

Curiosity Galore!

The day finally arrived on the last Sunday in September: Forschungszentrum Jülich opened its gates to visitors. From 10:00 to 17:00, visitors of all ages had the opportunity to see everything first hand, ask questions, and perform experiments themselves. As many as 260 presentations, including 100 hands-on activities, provided information on supercomputers, particle accelerators, the atmosphere simulation chamber, and virtual brain models. In keeping with this year's motto – "sustainable campus" – 40 apple trees were planted on the day by visitors.

More than

300

tweets on highlights from Jülich research

More than

1,000

employees in action

310

Cartesian divers constructed by children to measure pressure in liquids

260
presentations on topics in science and research

100
hands-on activities

50
participating institutes and organizational units

300
kilometres travelled on Segways

More than
1,000
participants in the research rally

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